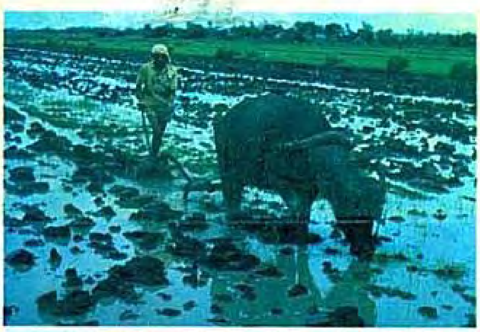




# WEED CONTROL IN RICE

International Rice Research Institute
International Weed Science Society

Proceedings of the Conference on

# WEED CONTROL IN RICE

31 August-4 September 1981

Jointly sponsored by the
International Rice Research Institute
and the
International Weed Science Society

**1983**
International Rice Research Institute
Los Baños, Laguna, Philippines
P.O. Box 933, Manila, Philippines

The International Rice Research Institute (IRRI) was established in 1962 by the Ford and Rockefeller Foundations with the help and approval of the Government of the Philippines. Today IRRI is one of 13 nonprofit international research and training centers supported by the Consultative Group for International Agricultural Research (CGIAR). The CGIAR is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). The CGIAR consists of 50 donor countries, international and regional organizations, and private foundations.

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The responsibility for this publication rests with the International Rice Research Institute.

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# CONTENTS

# PREFACE

The order of presentation of papers for the *Proceedings of the conference on weed control in rice* follows this general form: statement of the problem; factors affecting weed populations and methods of control; current weed control technology; weed, disease, insect interactions; special problems such as weed shift; perennial weeds and their control; wild rice and red rice; proposed and developing weed control technologies; and pesticides and the environment. The papers on current weed control technology describe farmers' typical weed control technology in Africa, mainland East Asia, insular East Asia, North America, Eastern Europe, Southern Europe, mainland Southeast Asia, and insular Southeast Asia. They may touch on, but are not intended to describe, the most advanced methods that can be employed.

To reduce the chances for errors and to make the individual papers more easily read, only the scientific names of weeds without the taxonomic authorities are included in the text. All weeds and weed synonyms mentioned in the text are grouped into an appendix that includes the taxonomic authorities. We departed from this practice in one paper, that by P. W. Michael, which is a taxonomic treatment of the genus *Echinochloa.*

Cultivated crops, diseases of crops and weeds, insects, and nematodes are referred to by their common names in the text, but they are listed along with their scientific names in separate appendices. Herbicides, insecticides, and fungicides are listed by their generic names only; their chemical names are supplied in an appendix.

# FOREWORD

The Conference on Weed Control in Rice, held at Los Baños, Philippines, 31 August to 4 September 1981, underscored the importance of the advance of weed science as a major factor in crop production. Through it, the gaps in our knowledge of weed control technology became apparent. And as a result of the Conference, we have a better idea of things that need to be done, how they should be done, and ways to organize to get them done as quickly and as efficiently as possible.

The Conference was held under the joint sponsorship of the International Rice Research Institute (IRRI) and the International Weed Science Society (IWSS). We at IRRI are particularly gratified at having been able to co-sponsor this Conference because it was the first single-topic symposium held by IWSS since it discontinued scheduling regular annual or biennial meetings in favor of holding single-topic symposia. We are pleased that IWSS has recognized weed control in rice to be of prime importance.

Over the years IRRI conferences have gained the reputation of being working conferences and this one was no exception. Workshops on research and collaboration opportunities and on training opportunities and needs developed realistic and implementable recommendations. The workshop moderators can take a great deal of credit for the success of the workshops: L. J. Matthews and L. C. Burrill on training and D. L. Plucknett, M. W. Schreiber, and Roy Smith, Jr. on research.

The Conference also enjoyed outstanding industrial support. Representatives of the chemical weed control industry, in a special panel discussion on new weed control technology, not only reviewed their newest developments but gave crop science specialists a glimpse of what the future may hold.

Throughout the Conference — in the papers presented and the discussions that followed — the need for maintaining an ecological balance between weeds and crops was stressed. Participants and observers alike were keenly aware that weeds — those plants that compete for light, water, and nutrients with our cultivated crops — are an inescapable, perhaps even a necessary part of the world's flora.

I would like to thank the members of the organizing committee for their efforts to make this Conference a success: co-chairmen Keith Moody of IRRI and Roy Smith, Jr. of USDA, and committee members Glenn Denning, S. K. De Datta, Edwin C. Price, and Benito S. Vergara, all of IRRI. This volume was edited by W. H. Smith with the assistance of Stephen J. Banta, Ms. Gloria Argosino, and Ms. Emy Cervantes.

M. S. Swaminathan
Director General

# WELCOME ADDRESS

On behalf of the International Weed Science Society (IWSS), I want to make several acknowledgements. First, to our host, The International Rice Research Institute (IRRI). We of IWSS deeply appreciate that cooperation. I also want to point out the important industry support that we have received. I particularly want to acknowledge each of the invited speakers. The efforts that they have taken to prepare their papers will produce a proceedings that we will all be proud to have our names associated with. Last, but not the least in acknowledgements, I would like to personally thank the Program Coordinator Keith Moody. who has done a yeoman's job in working with IWSS, and Roy Smith from Arkansas.

I know you did not come here to listen to me talk about IWSS, but I'd like to give you a little background on our programs and objectives. We have made a commitment not to hold annual or biannual meetings on a regular basis, but rather to concentrate our efforts on special symposiums such as this one. In this way, we can better disseminate information that is most needed in all parts of the world through up-todate proceedings. We are tentatively planning another symposium on technology transfer for weed science. Now, technology transfer in weed science means many things to many persons. To some it means weed scientists speaking to weed scientists, to others, weed scientists speaking to producers. But another aspect is equally important — weed scientists speaking to administrators. That is because administrators are the ones we must most influence to advance weed science.

Another IWSS objective, of course, is communication. One of the best methods of advancing our communication skill is through the development of a worldwide directory of weed scientists by their areas of interest. If we took the listing of this group, that would be the nucleus of all the major persons involved in weed science in rice. The directory is being prepared, but we need the cooperation of all national and regional societies to accomplish our goal. Another publication that we plan to issue is a compilation of weed science publications.

The second item in communication is the adequate distribution of the proceedings that will come from various symposia. This is extremely important. What we hope to accomplish is to get our information to the people who need it the most. We can do that by getting our publications — our proceedings — out rapidly after a conference and distributing them as widely as possible. We want to do that at prices that are affordable for everyone. If they are not, we will probably consider free distribution where we have to. That is why we need the support of as many people as possible.

I think IWSS will always make it a policy not to copyright any of its publications. Anybody, anywhere in the world, can reproduce local language editions of IWSS publications and we hope, credit the source.

In closing, I want to re-emphasize the need for the support of all individual members of IWSS. We need support to reach our mutual objective — to point out on a worldwide basis the importance of the advance of weed science as a major factor in crop production. Thank you very much.

M. M. Schreiber

# WELCOME ADDRESS

We welcome you to the International Rice Research Institute (IRRI) and thank you for coming to share your knowledge and your experience on the control of weeds in rice. Weeds are among the more important production constraints to increasing rice yields. Under certain rice production situations, direct-seeded rainfed rice for example, weeds are often the main constraint. This is hardly the group to preach to on the economic importance of weeds and their control in crop production. Rather, I will take this opportunity not only to welcome you to our Institute, but to tell you a little about IRRI. We encourage you to learn more about our programs and activities during the week.

IRRI was organized in 1960 to conduct research on the rice plant and on all phases of rice production. The Institute was established by the Ford Foundation and the Rockefeller Foundation, but now draws support from the Consultative Group on International Agricultural Research (CGIAR). A number of similar research institutes have been established since and supported by the CGIAR. Among them are the International Center for the Improvement of Wheat and Maize in Mexico; the International Crops Research Institute for the Semi-Arid Tropics in India; and the International Institute of Tropical Agriculture in Nigeria. In some ways, IRRI is fortunate in that its scientists are able to focus their research activities solely on rice; other institutes have two - even five - crops to work on. To attain its goals, IRRI has developed research and training programs on:

1. genetic evaluation and utilization,
2. control and management of pests,
3. irrigation water management,
4. soil and crop management,
5. environment and its influence,
6. constraints on rice yields,
7. consequences of rice technology,
8. cropping systems, and
9. machinery development.

Weed research falls under research program area no. 2. The work on weeds and their control is part of an Institute-wide interdisciplinary effort to attain IRRI's objectives.

The weed research program at IRRI includes:

1. Identification of weed problems in different rice cultures and different rice-based cropping systems;

2. Development of approaches to weed management, including chemical and nonchemical approaches; and

3. Studies on problem weeds such as *Scirpus* spp.

Our weed scientists carry out their activities here at the IRRI research center, in other countries with cooperating scientists in national programs, and in farmers' fields. Knowledge gained is shared through publications, training programs, seminars, and conferences. I am pleased that among our participants are some who were formerly associated with IRRI in our training programs.

This conference on *Weed Control in Rice* is cosponsored by IRRI and the International Weed Science Society (IWSS). The first discussion between IRRI and IWSS on organizing such a conference was in early May 1980 when Les Matthews visited us at IRRI. We are pleased the conference is now a reality. In this connection I would like to recognize, in addition to Les, Dr. Marvin M. Schreiber, IWSS president, 1980-81; Dr. Shouichi Matsunaka, IWSS president, 1981-82; and Dr. Larry Burrill, IWSS secretary-treasurer. The organizing committee of the conference is chaired jointly by Dr. Keith Moody of IRRI and Dr. Roy J. Smith, Jr., IWSS.

I am certain that as the week progresses a great deal of information and a lot of experiences will be shared — I am also certain that as this sharing of information and experiences happens, gaps in weed control technology will become apparent. We are counting on the outcome of the workshops and panel discussions to really call attention to what needs to be done, how those things that need to be done should be done, and how we should organize to get the work done effectively and efficiently in the shortest time possible. We are counting on you.

Once again, on behalf of my colleagues at IRRI, I welcome all of you. We wish your stay with us to be professionally and personally rewarding. We will certainly try to make it so. Do let us know if there is anything we can do to ensure that you remember your visit to IRRI as pleasant and fruitful.

Marcos R. Vega
Deputy Director General

# EVOLUTION OF RICE WEED CONTROL PRACTICES AND RESEARCH: WORLD PERSPECTIVE

S. Matsunaka

Two facets of the evolution of rice weed control are discussed: 1) the contribution of the $C_3$ and $C_4$ classification in higher plants to the understanding of rice-weed competition, and 2) the contributions of biochemistry and genetics to understanding the selectivity mechanism of the rice herbicide propanil. The relation of this fundamental work to chemical weed control is developed through a discussion of the ability of the enzyme rice aryl acylamidase I to hydrolyze or detoxify propanil. The selectivity of propanil among rice species was clarified by a survey of the distribution of the enzyme in *Oryza* genus, which yielded information on the genetic systematics of the genus as well. Herbicide-insecticide interaction is treated in detail.

A description of the evolution of rice weed control should begin with an overview of the history of rice cultivation. Cultivated rice seems to have originated in South and Southeast Asia and in Africa, *Oryza sativa* between northern India and northern Vietnam, and *Oryza glaberrima* in the Niger River basin. Whatever its origin, cultivated rice most certainly developed in areas where abundant water was available.

Even in ancient times it was recognized that rice grown under submergence

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competed better with weeds than dryland rice in which weed problems were more severe. The selection of submerged rice culture may be said to have been the first step in traditional weed control. The second weed control step was probably the transplanting of rice seedlings.

In direct-seeded rice culture the rice plants compete with weeds from the time they emerge. And if paddy preparation has been inadequate, weeds will compete vigorously with newly emerged rice plants. Transplanted seedlings have a greater competitive advantage over weeds that emerge after transplanting. In the tropics, especially where weeds grow rapidly, older seedlings or rapid-growing cultivars were used to give the rice plants an advantage in the age-old competition between crops and weeds.

As early as 1697, Antei Miyazaki wrote: “After transplanting of rice seedlings, the farmers’ duty is weeding . . . ”

Under the physiocracy that prevailed in Japan, farmers considered it a moral obligation to keep their paddy fields weed-free. Weeding was done by hand, by trampling, and with simple hand tools such as an iron claw, simple knives, or hoes. In 1892 a Japanese farmer developed a rotary weeder. In Asia, rotary and basket-shaped weeders, hand-operated or animal-drawn, are common mechanical weeding devices.

Before the introduction of chemical weed control, mechanical weeding was supplemented by seedbed preparation, crop rotation, land leveling, levee construction, seed selection, and water management.

Inorganic herbicides such as copper sulfate or calcium cyanamide were used for rice weed control before World War II. But the genuine use of herbicides in rice began in 1948 in the U.S. and in 1950 in Japan. Since then, the development of new herbicides suitable for rice has been remarkable. Weed control measures in major rice-producing countries are shown in Table 1.

Direct seeding and mechanical transplanting require less labor than hand transplanting, but they require improved weeding practices. It took the development of selective herbicides such as propanil for these methods to be used successfully. Selective herbicides are especially important in direct-seeded rice. Because the shorter seedlings used in mechanical transplanting are less competitive with weeds than taller seedlings used in hand transplanting, they also benefit from selective herbicides.

For high production, shorter cultivars are recommended. The heavy fertilization that accompanies the cultivation of short cultivars increases the severity of weed competition and necessitates more careful weed management.

Environmental problems arising from the use of herbicides have caused a re-examination of biological weed control in rice culture. Daniel et al (1973) have used fungal control of *Aeschynomene virginica.* In Japan there is limited use of tadpole shrimp (*Triopus longicaudatus* Le Conte and *T. granarius* Lucas) to control weeds in flooded paddy fields (Matsunaka 1976). At the International Rice Research Institute the cover effect of *Azolla* spp. is being evaluated as a means of weed control in rice.

I will present two examples of the close relation between weeding practice and fundamental research to illustrate the evolution of rice weed control measures.

**Table 1. Weed control measures in rice. by country.[a]**

| Area | Country | Main culture[b] | Control measure[c] and mevalence[d] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Asia and Pacific | Australia | D | C | C | | | | VC | C | | |
| | China[e] | T | | C | C | U | C | U | Tr | | |
| | Fiji | D | | C | | | U | U | Tr | | U |
| | Indonesia | T | | C | VC | | C | | Tr | | |
| | Japan | T | | C | U | | C | | VC | Tr | |
| | Korea | T | | C | U | C | C | U | C | | |
| | Malaysia | T | | C | VC | | C | | Tr | | |
| | Philippines | T | | C | VC | U | C | | U | | |
| | Vietnam | T | | C | VC | | C | | | | |
| | Sri Lanka | Dw | | C | | | C | | | | C |
| | Taiwan, China | T | | C | C | C | C | | C | | |
| | Thailand | T | | C | C | | C | U | Tr | | |
| North and South America | Brazil | D | | C | C | | C | U | U | | |
| | Colombia | T,D | | C | C | | U | | U | | |
| | Cuba | D | | | C | | | U | U | | |
| | Peru | T | | C | C | | C | | U | | |
| | USA | D | C | C | | VC | | VC | VC | Tr | U |
| Europe | Italy | Dw | | | | | U | VC | VC | | |
| | Portugal | Dw,T | | C | | | C | | VC | | |
| | Spain | Dw,T | | C | | | C | | VC | | |
| Africa | Egypt | T | | C | | | | VC | | | |
| | Madagascar | T | | U | C | | | | | | |
| | Nigeria | D | | U | U | | | U | | | |
| Others | USSR | Dd | | C | C | | | U | C | | |

[a]From Noda (1977). [b]T = transplanted, D = direct-seeded, Dw = direct water-seeded, Dd = direct dry-seeded. [c]1 = preventive means, 2 = soil preparation, 3 = manual weeding, 4 = mechanical weeding, 5 = water management, 6 = crop rotation, 7 = chemical control, 8 = biological control, 9 = miscellaneous. [d]VC = very common, C = common, U = uncommon, Tr = under trial. [e]Includes all provinces except Taiwan.

PHOTOSYNTHETIC PATHWAYS OF PLANTS AND WEED CONTROL IN RICE

**Classification of $C_3$, $C_4$, and CAM plants**

A major step in our understanding of crop photosynthesis in the last 20 years has been the characterization of $C_3$, $C_4$ plants, and those exhibiting Crassulasean acid metabolism (CAM). Their main differences are summarized in Table 2. In general, $C_4$ plants have higher photosynthetic activity, are fond of higher temperature and higher solar radiation, and have lower water requirements than $C_3$ plants. Of 10 major crop plants, only maize is a $C_4$ plant (Harlan 1976). Of 10 major weeds proposed by Holm (1969), 8 are $C_4$ plants (Table 3). In general $C_4$ plants as weeds provide a troublesome existence for $C_3$ plants as crops.

**Water requirement**

Because of their histological and biochemical properties, $C_4$ plants utilize water more efficiently than $C_3$ plants. Shantz and Piemeisel (1927) determined water requirements of 29 species of $C_3$ plants and 10 species of $C_4$ plants (g water required/g dry weight produced). The water requirements of $C_3$ plants were higher than those of $C_4$ plants in all cases. The average water requirement of $C_3$ plants was 628 g water/g dry weight; for $C_4$ plants the average was 300 g water/g dry weight.

Hasegawa and Okuda (1974) surveyed the geographical distribution of $C_3$ and $C_4$ crop plants. They found that $C_4$ plants predominated (more than 50% of the crops) in areas where average temperatures were more than 17° or 18°C and precipitation varied from 200 to 1,500 mm/ year. $C_3$ plants predominated (more than 80% of the crops) in areas where the precipitation range was the same, but average temperatures were lower than 19° or 20°C or, if average temperatures exceeded 19° or 20°C, precipitation was less than 200 or more than 1,500 mm/year.

**Soil moisture regime**

Arai et a1 (1955) examined the growth of weeds and their competition in relation to submerged, water-saturated, and usual dryland conditions. Tanaka (1976) rearranged their results on the basis of the $C_3$ and $C_4$ classification (Table 4). The total dry weight of weeds per unit area was significantly retarded by submergence. The $C_4$ species accounted for more than 90% of the total dry weight in water-saturated and dryland plots, but for only 10% in submerged plots.

Nishida and Kasahara (1975) prepared an inclined soil surface in a concrete tank so the soil moisture regime was on a continuum from submerged to dryland conditions, and surveyed the distribution of emerged weeds. $C_3$ plants were dominant in the submerged condition while $C_4$ plants were dominant in the dryland condition.

These results explain why submergence protects rice plants from severe competition with $C_4$ weeds. On the other hand, dryland rice or rainfed wetland rice with limited precipitation faces severe competition with $C_4$ weeds. Many herbicide evaluation experiments on dryland rice show that in nonweeded plots the yield loss from weeds is 40 to 100%. Vega et a1 (1969a,b) evaluated herbicides from wetland and dryland rice. Their data for hand-weeded and nonweeded plots are cited in Table 5. The average grain yield of wetland rice was more than twice that of dryland one. The

**Table 2. Characteristics of $C_3$, $C_4$, and CAM plants.**[a]

| Criterion | Characteristics | | |
|---|---|---|---|
| | $C_3$ plants | $C_4$ plants | CAM plants |
| Leaf structure | Chloroplast-rich mesophyll cells | Developed bundle sheath cells with chloroplasts | Mesophyll with chloroplasts and big vacuoles |
| Maximum growth rate (mg dry wt/ $dm^2$ per day) | 0.5-2.0 | 4-5 | 0.015-0.018 |
| Maximum photosynthetic rate (mg $CO_2/dm^2$ leaf per hour) | 15-40 | 40-80 | 1-4 |
| Optimum temperature for photosynthesis (°C) | 15-25 | 30-45 | -35[b] |
| Light saturation (lux) | 20,000-50,000 | over 100,000 | low |
| $CO_2$ compensation point (ppm) | 30-70 | 0-10 | 0-5 (in dark) |
| Photorespiration | high | very low | low |
| Warburg effect | yes | no | yes |
| Water requirement (g water/g dry wt) | 400-950 | 250-350 | 50-55 |
| $CO_2$ fixed:ATP:NADPH | 1:3:2 | 1:5:2 | |
| Sodium requirement | no | yes | |

[a]From Matsunaka and Saka (1977). CAM = Crassulasean acid metabolism. [b]Lower temperature distributed over wide range.

**Table 3. The 10 major crop plants and the 10 worst weeds.**[a]

| Crop plants | | | Weeds | |
|---|---|---|---|---|
| Wheat | *Triticum* spp. | o | *Cyperus rotundus* | • |
| Rice | *Oryza sativa* and *O. glaberrima* | o | *Cynodon dactylon* | • |
| Maize | *Zea mays* | • | *Echinochloa crus-galli* | • |
| Potato | *Solanum tuberosum* | o | *Echinochloa colona* | • |
| Barley | *Hordeum vulgare* | o | *Eleusine indica* | • |
| Sweet potato | *Ipomoea batatas* | o | *Sorghum halepense* | • |
| Cassava | *Manihot esculenta* | o | *Eichhornia crassipes* | o |
| Grapes | *Vitis* spp. and *Muscadinia* spp | o | *Imperata cylindrica* | • |
| Soybean | *Glycine max* | o | *Lantana camara* | ? |
| Oats | *Avena sativa* | o | *Panicum maximum* | • |

[a]Crops from Harlan (1976) and weeds from Holm (1969). o = $C_3$ plants, • = $C_4$ plants.

**Table 4. Distribution of summer weeds with different photosynthetic pathways as affected by 3 soil moisture regimes**[a]

| Photosynthetic pathway | Weed | Total weed dry wt (g/90 cm²) | | |
|---|---|---|---|---|
| | | Submerged | Water saturated | Dryland |
| $C_3$ type | *Rotala indica* var. *uliginosa* | 3.55 | 0.05 | 0 |
| | *Elatine orientalis* | 1.55 | 0 | 0 |
| | *Dopatrium junceum* | 1.50 | +[b] | 0 |
| | *Monochoria vaginalis* | 0.70 | 0 | 0 |
| | *Eleocharis acicularis* | 0.60 | + | 0 |
| | *Cyperus difformis* | 0.35 | 0 | 0 |
| | *Ericaulon sieboldianum* | 0.20 | 0.15 | 0 |
| | *Lindernia pyxidaria* | 0.20 | + | 0 |
| | *Polygonum bluemei* | 0 | 1.20 | 2.20 |
| | *Poa acroleuca* | 0 | 0.25 | 0.05 |
| | *Acalypha australis* | 0 | 0.05 | 0.50 |
| | *Chenopodium album* | 0 | + | 1.10 |
| | Subtotal (g) | 8.65 | 1.70 | 3.85 |
| | (%) | (89) | (6) | (7) |
| $C_4$ type | *Echinochloa crus-galli* var. *oryzicola* | 0.70 | 7.95 | 5.75 |
| | *Cyperus microiria* | 0.25 | 3.90 | 4.85 |
| | *Fimbristylis littoralis* | 0.10 | 1.10 | 1.55 |
| | *Amaranthus blitum* | 0 | 0.10 | 0.50 |
| | *Echinochloa crus-galli* var. *platocola* | 0 | 3.20 | 5.55 |
| | *Setaria viridis* | 0 | 9.25 | 10.10 |
| | *Digitaria ciliaris* | 0 | 3.60 | 25.35 |
| | *Portulaca oleracea* | 0 | + | 0.35 |
| | Subtotal (g) | 1.05 | 29.10 | 54.0 |
| | (%) | (11) | (94) | (93) |
| | Total ($C_3$ + $C_4$ types) | 9.70 | 30.80 | 57.85 |
| | (%) | (100) | (100) | (100) |

[a]From Tanaka (1976). Submerged: 6 cm standing water depth; water saturated: 80-90% of maximum moisture capacity; dryland: 40-60% of maximum moisture capacity. [b]+ = weed found, but dry weight accumulation too low to measure.

**Table 5. Yield losses due to weeds in wetland and dryland rice.**[a]

| Wetland rice | | | Dryland rice | | |
|---|---|---|---|---|---|
| Grain yield (kg/ha) | | Yield loss (%) | Grain yield (kg/ha) | | Yield loss (%) |
| Hand weeded | Non-weeded | | Hand weeded | Non-weeded | |
| 4006 | 2697 | 33 | 3028 | 355 | 88 |
| 2155 | 911 | 58 | 2111 | 321 | 85 |
| 4583 | 4362 | 5 | 2733 | 301 | 89 |
| 6114 | 2450 | 60 | 1020 | 210 | 79 |
| 4336 | 2876 | 34 | 1351 | 278 | 79 |
| 6181 | 5115 | 17 | | | |
| 6795 | 2107 | 44 | | | |
| 3891 | 3212 | 34 | | | |
| 4508[b] | 2960[b] | 36[b] | 2049[b] | 293[b] | 84[b] |

[a] From Vega et al (1969a,b). [b] Average.

yield loss from weeds averaged 84% in dryland rice and 36% in wetland rice. The main weed species in dryland rice were almost all $C_4$ plants. Weed problems are more severe in dryland rice cultivation, mainly because rice is a $C_3$ plant.

## HERBICIDES, BIOCHEMISTRY, AND GENETICS

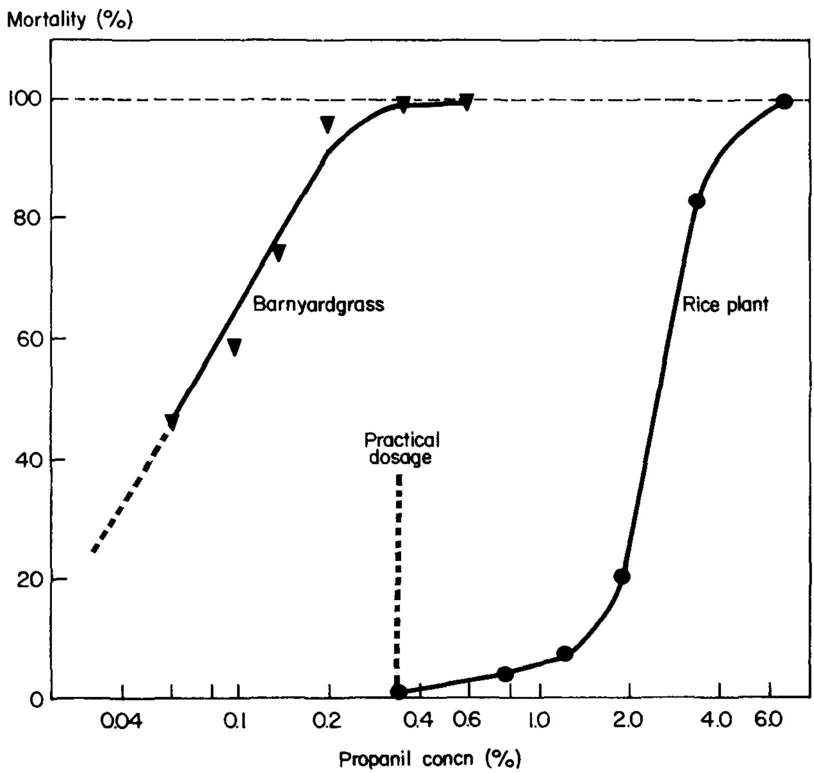
Propanil is a typical herbicide that has high inhibitory activity on the Hill reaction of photosynthesis. The concentration of half inhibition of the reaction is between $2\text{-}5 \times 10^{-6}$ M, which is comparable to that of diuron and simazine. Although propanil mainly inhibits photosynthesis, it has another more drastic and acute phytotoxic activity whose mechanism has not been clarified. Weeds on which propanil has been sprayed will show symptoms more rapidly than would be expected from the inhibition of photosynthesis alone.

Propanil is especially valuable in rice culture because of its high selectivity. Rice plants are 40 times more tolerant of propanil than *Echinochloa crus-galli* (Fig. 1). For this reason it can be used for weeding in direct-seeded or broadcast rice where rice and weeds are growing at the same stage. The use of propanil by commercial rice growers in the U. S. has steadily increased since 1961. Smith (1969) reported that rice yields in the U. S. have increased by about 1.0 t/ha since the advent of propanil.

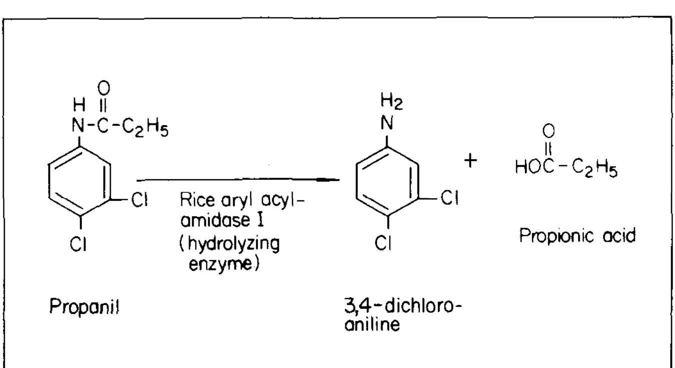
The tolerance of rice plants for propanil can be explained by the existence of an enzyme isolated by McRae et al (1964) and Adachi et al (1966), and named rice aryl acylamidase I by Akatsuka (1979). A hydrolyzing enzyme, it hydrolyzes propanil to 3,4-dichloroaniline and propionic acid (Fig. 2).

The most purified enzyme exhibits the following properties: optimum pH, 7.0; optimum temperature, 50°C; Michaelis constant Km, $3.5 \times 10^{-4}$ M; molecular weight, about 200,000 (in the presence of Triton X-100) (Akatsuka 1979). It is a particulated or bound enzyme difficult to solubilize. Although propanil is not the best substrate for rice aryl acylamidase I, still it has high affinity for the enzyme and is a suitable substrate. Another rice herbicide, pentanochlor has a low affinity for the enzyme, but the enzyme still acts and contributes to the selectivity of the herbicide.

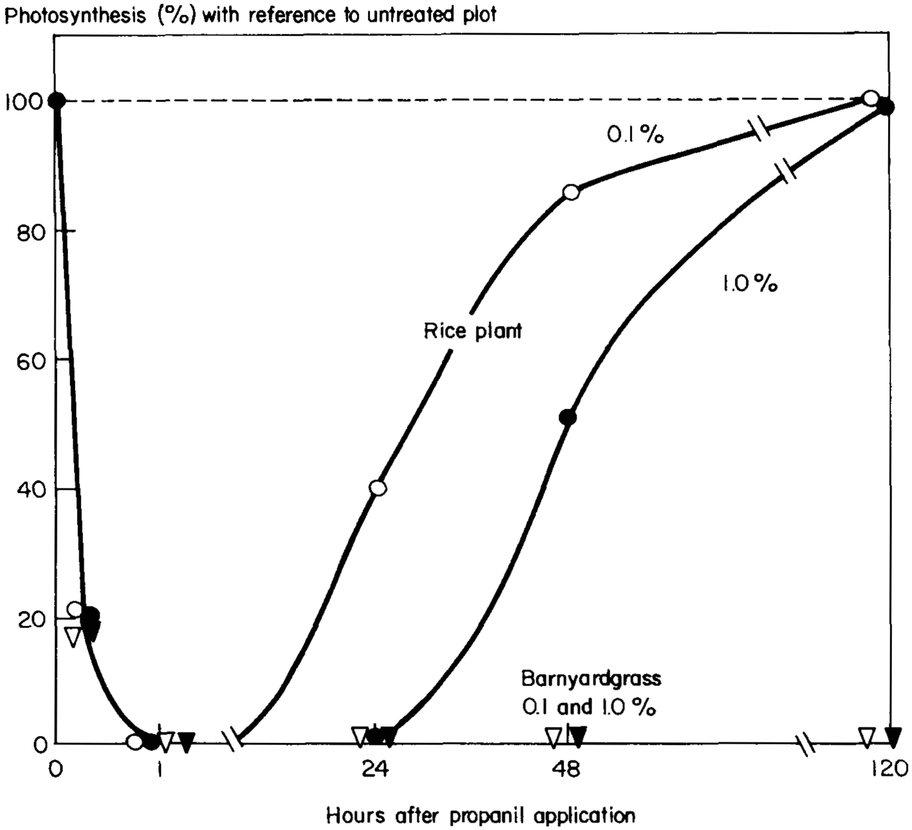
Plants other than rice have little or no aryl acylamidase I activity. *E. crus-gulli* has properties similar to rice, not only in outward appearance but in its adaptability to the submergence. It lacks rice aryl acylamidase I activity, however, and is very susceptible to propanil.




**1.** Selectivity of propanil in rice plants and barnyardgrass (from Matsunaka 1965).




**2.** Hydrolysis of propanil by rice aryl acylamidase I.




**3.** Inhibition of photosynthesis and recovery in rice plants and barnyardgrass treated with propanil (from Nakamura et al 1968).

From the standpoint of inhibiting the Hill reaction, propionanilide is the best of the acylanilides having 3,4-dichlorophenyl structure. For rice culture propanil has the optimum structure of activity and selectivity just described.

The hydrolyzed product 3,4-dichloroaniline is nontoxic to higher plants. Thus, in those plants its enzyme action or hydrolyzing process may be considered a detoxification process. Photosynthetic activity was inhibited in rice and barnyardgrass *E. crus-galli* immediately after they were treated with propanil; the rice plants recovered, barnyardgrass did not (Fig. 3). Two or three days were required for rice to recover completely from the effects of propanil under the usual application rates. Proper timing of the application of propanil to rice is important because the plants will suffer some permanent injury if extended rainfall follows herbicide application.

## Propanil-insecticide interaction

There is one severe problem in the practical application of propanil. Some rice leaf injury occurs when some insecticides are sprayed simultaneously with or just before or after propanil. The reason is that these insecticides inhibit rice aryl acylamidase I enzyme.

It is well-known that organophosphorus insecticides having P = S structure, after metabolizing to the P = O structure, act as strong inhibitors of acetylcholine esterase of insect pests. The inhibitory activity against rice aryl acylamidase I of insecticides with P = S and P = O structures is very nearly the same as with acetylcholine esterase; that is, P = O structures (oxon types of parathion and fenitrothion) were considerably more active than the corresponding P = S compounds, parathion or fenitrothion alone (Matsunaka 1968). Carbaryl and other carbamate group insecticides that inhibit acetylcholine esterase also show the synergistic action with propanil in rice plants by inhibiting the propanil-detoxifying enzyme.

Other insecticides such as BHC or DDT have no inhibitory activity on acetylcholine esterase. Neither can they inhibit rice aryl acylamidase I. They do not injure rice when they are applied at the same time as propanil. We may assume that rice aryl acylamidase I and acetylcholine esterase may resemble each other in structure and properties. Pentanochlor also shows synergistic phytotoxicity to rice plants when it is applied with these organophosphorus or carbamate insecticides.

Some soil microorganisms can hydrolyze amide compounds such as propanil or pentanochlor. These processes can be inhibited by organophosphorus and carbamate insecticides. Combining propanil or pentanochlor (Shirakawa 1970) with carbaryl may result in long residual activity in the soil.

**Genetics of rice aryl acylamidase I production**

This herbicide is contributing to the fundamental research on genetic systematics of the genus *Oryza.* I found a mutant of rice which lacks the aryl acylamidase I enzyme, and consequently is very susceptible to propanil. It was screened by the application of propanil emulsion on about 700 lines of artificial mutants created from cultivar Norin No. 8 by Kawai and others in the National Institute of Agriculture Science in Hiratsuka. The mutant was designated as S, susceptible, and the original Norin No. 8 as R resistant. I then crossed S and R, and R and S. The $F_1$ had the enzyme activity and was resistant. $F_2$ plants showed an R-to-S ratio of 3:1. The backcross experiment with S and $F_2$ segregated on a 1:1 as shown in Table 6 (Matsunaka 1974).

Biosynthesis of the aryl acylamidase I in normal rice plants is performed by a single dominant gene. Therefore the tolerance of rice plants to propanil is a fundamental property and the selectivity is very stable. The S mutant is also very susceptible to pentanochlor.

**Distribution of rice aryl acylamidase I in genus *Oryza***

Our recent work on propanil clarified the distribution of aryl acylamidase I in the *Oryza* genus. Of the 21 *Oryza* spp. only two are widely cultivated, *O. sativa* and *O. glaberrima.* Other *Oryza* spp. are assumed to be weeds of cultivated rice plants (Parker and Dean 1976). Some of them are tolerant of propanil.

I surveyed the distribution of aryl acylamidase I in the genus *Oryza* to gain fundamental information on how to control rice weeds and to learn some of the genetic systematics of the genus *Oryza* and the origin of cultivated ones. Seeds of wild rices were collected by Oka's group at the National Institute of Genetics.

Rice species which can hydrolyze propanil are as follows (letters in parentheses

**Table 6. $x^2$ analysis of the segregation ratio in $F_2$-plants after crossing of original rice plant (R) and propanil-susceptible mutant.**

| | Plants (no.) after application of propanil | | |
|---|---|---|---|
| | Survived | Dead | Total |
| Observed (O) | 899 | 304 | 1203 |
| Calculated (C) | 902.2 | 300.8 | 1203 |
| O-C | -3.2 | 3.2 | |

$x^2 = \frac{(O - C)^2}{C} = 0.0454$ P = 0.090 - 0.80

show the genome of the species): *O. sativa* (AA), *O. sativa* f. *spontanea* (AA), *O. glaberrima* ($A^gA^g$), *O. barthii* ($A^gA^g$), *O. punctata* (BBCC), *O. minuta* (BBCC), *O. eichingeri* (CC or BBCC), *O. officinalis* (CC), *O. latifolia* (CCDD), *O. alta* (CCDD), and *O. grandiglumis* (CCDD). Of the *Oryzae* section species only *O. australiensis* (EE) failed to show enzyme activity. Two species belonging to the *Ridleyanae* section, *O. brachyantha* (FF) and *Leersia perrieri,* also lacked the enzyme. Two other *Ridleyanae* species, *O. ridleyi* and *Leersia tisseranti,* showed a low activity of the enzyme. *Rhynchoryza subulata,* once called *Oryza subulata,* also showed the enzyme activity.

We may tentatively conclude that rice species having genomes related to A, B, C, and D have the propanil-hydrolyzing enzyme (aryl acylamidase I), and should be tolerant of the herbicide. Those species having genomes E and F lacked the enzyme and may be susceptible to propanil. Four species belonging to the *Ridleyanae* section showed very low or no enzyme activity. *R. subulata* occupies a special position and has the enzyme activity.

## CONCLUSION

I have described only two facets of the evolution of rice weed control: the contribution of the $C_3$, $C_4$ classification of higher plants to understand the competition of rice ($C_3$ plant) with weeds ($C_4$ plants), especially in submerged or dryland conditions; and the contribution of biochemistry and genetics in understanding the safe utilization or selectivity mechanism of the rice herbicide propanil. This fundamental work may lead to many practical weed control developments in rice. For instance, rice aryl acylamidase I may be utilized to hydrolyze a special N-C structure in new pesticides and make them nontoxic to rice.

The knowledge will contribute to plant biochemistry, plant genetics, and other fields. For example, the ability of rice aryl acylamidase I to hydrolyze the amide suggests that it has a relation with nitrogen metabolism. I found that the S mutant has a lower tolerance for higher nitrogen fertility than the original Norin No. 8. Comparisons of these two rice plants will give us new information on nitrogen metabolism and help to clarify the physiology of aryl acylamidase I in normal rice plants. The enzyme was carried in the rice plant well before propanil was developed as a means of weed control.

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## DISCUSSION

VEGA: Under what situations are tadpole shrimps effective?

*MATSUNAKA:* The application of tadpole shrimp is limited because hatching occurs at temperatures lower than 30°C. In Japan, conditions are suitable for hatching. In tropical zones, they cannot hatch in the field. If they are to be used in the tropics, hatching must be done in artificial ponds before release in the field. I do not think that this is practical. I do not think that their weeding activity is sufficient. Therefore a combination of a herbicide with the tadpole shrimp is needed.

WIRJAHARDJA (comment): It is interesting to note that species belonging to the *Ridleyanae* cannot hydrolyze propanil while those belonging to the *Oryzae* section can. The *Ridleyanae,* which do not have apicules, have a hydrophytic to terrestrial habitat while the *Oryzae,* which have apicules, have a hygrophytic to hydrophytic habitat. *Oryza australiensis,* which has no apicules, should be grouped in the *Ridleyanae,* which have no hydrolyzing power, and not the *Oyzae.*

MATTHEWS: Is there any adverse reaction between propanil and the thiocarbamate herbicides?

*MATSUNAKA:* No problem. In the case of thiocarbamate herbicides only carbamate herbicides create problems. Organophosphorus fungicides have some adverse effect on propanil application.

DE DATTA: What direction should we take in weed control research in dryland and rainfed wetland rice? Should we use more potent herbicides or do we need to shift the weeds around by various methods?

*MATSUNAKA:* I am not so familiar with dryland rice cultivation, but I hope that new herbicides will appear that would be suitable in this condition.

VONGSAROJ: In Thailand we have a number of *Echinochloa* species, *hispidula, oryzicola,* and *frumentacea.* Are they all susceptible to propanil?

*MATSUNKA:* I have done no experiments with these species. However, I suppose that all of them are susceptible. Apparent tolerance of *Echinochloa* can be observed after the 3-leaf stage. After the 3-4 leaf stage, the sprayed parts will be killed, but the bigger seedlings contain lots of stored carbohydrates and they can regrow. This gives the impression that they are tolerant of propanil. They do not have any aryl acylamidase I.

BAKER: What is the possibility of developing a safener to protect against the herbicide-insecticide interaction?

*MATSUNAKA:* I think that the use of safeners will be difficult for the farmers. Sometimes farmers have problems in applying the herbicide at the correct rate. More problems will arise when they have to apply a safener. Other problems are the toxicity of the safener itself and economics. Herbicides by themselves are expensive. There will be an additional economic stress placed on the farmers if they have to use a safener.

# WEEDS OF MAJOR ECONOMIC IMPORTANCE IN RICE AND YIELD LOSSES DUE TO WEED COMPETITION

R. J. Smith, Jr.

The purpose of this paper is to 1) identify the weeds that are economically important in rice production, 2) discuss principles that influence weed communities in rice cultures, 3) establish an estimate of losses caused by weeds in rice, and 4) characterize the components of weed interference with rice. The topics are developed from a world view.

Rice, a major world crop, was produced in about 82 countries during 1977-1979; average annual world production during the 3-year period was about 372 million tons grown on 143 million ha (USDA 1980). Numerous weed species infest transplanted and direct-seeded rice. They alter the health, food supply, and economy of many people in rice-producing countries of the world.

Losses due to weeds have been estimated in several rice-producing countries. In India, losses have been estimated at 10% of the crop (De Datta 1980). In the Philippines, losses were estimated at 11% for the dry season and 13% for the wet. Yield and quality losses were estimated at 15% in the U. S. (Smith et al 1977) and

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10% for the world (De Datta 1980).

In addition to yield and quality losses, there are losses due to the cost of herbicides, cultural and mechanical practices, and hand weeding to prevent even greater losses (Smith et al 1977). Such losses are estimated at about 5% worldwide. Thus, for the world the total estimated direct losses from weeds and expenditures for their control in rice are 15% annually. If the 1977-79 average annual world production value is used to determine worldwide losses from weeds, then the rice losses caused by weeds are about 56 million tons annually, valued at $12 billion (based on 1977-79 average export prices at Bangkok, Thailand, for 5% broken white rice) (USDA Econ. and Stat. Ser. 1981).

## ECONOMICALLY IMPORTANT WEEDS OF RICE

Weed species that cause problems in rice vary with soil, temperature, latitude, altitude, rice culture, seeding method, water management, fertility level, and weed control technology (Smith and Moody 1979). About 350 species in more than 150 genera and 60 plant families have been reported as weeds of rice (Akobundu and Fagade 1978, Barrett and Seaman 1980, De Datta 1977, Holm et al 1977, Horng and Leu 1977, Matsunaka 1970, Noda 1977a, Pancho et al 1969, Ronoprawiro et al 1971, Singh et al 1974, Smithet al 1977, Suvatabandhu 1950, Swain 1973, WARDA 1979). Species of Poaceae are the most common, with more than 80 reported as weeds of rice. Species of Cyperaceae rank next in abundance with more than 50 reported as weeds of rice. Other families with 10 or more species reported as weeds of rice include Alismataceae, Asteraceae, Fabaceae, Lythraceae, and Scrophulariaceae.

*Echinochloa crus-galli* is the most troublesome weed of rice in the world (Holm et al 1977). *E. colona* is second in importance. *E. colona* tends to grow along the equator, but *E. crus-galli* has a greater range from north to south. Other rice field weeds of world importance are *Cyperus difformis, C. rotundus, C. iria, Eleusine indica, Fimbristylis littoralis, Ischaemum rugosum, Monochoria vaginalis,* and *Sphenochlea zeylanica.* Table 1 gives the economically important weeds of rice of different cultures and estimates of interference in rice production.

## FACTORS THAT INFLUENCE WEEDS IN RICE

Many ecological and crop production principles influence the presence and abundance of species or groups of weeds in rice fields. Important factors include seeding method and soil moisture regime, crop rotation, air and soil temperatures, land preparation, fertilization, rice cultivar, weed control technology, and the interactions of those factors.

### Seeding method and soil moisture regime

Rice is transplanted by setting plants that have been grown in nurseries into wet paddy fields (Smith and Moody 1979). Rice may also be direct-seeded by drilling or broadcasting seeds into moist soil or by broadcasting dry or sprouted seed on the floodwater. Transplanted and direct-seeded rice are grown under different moisture

**Table 1. Selected weeds of economic importance in rice.[a]**

| Taxon | Type[b] | Rice culture[c] | Interference level[d] |
|---|---|---|---|
| *Aeschynomene virginica* | A | DP | b |
| *Ageratum conyzoides* | A | DU | b |
| *Alisma triviale* | P | DP | b |
| *Alternanthera philoxeroides* | P | DP,TP | b |
| *A. sessilis* | P | TP | b |
| *Amaranthus spinosus* | A | DU | b |
| *Ammannia auriculata* | A | DP | b |
| *A. coccinea* | A | DP,TP | b |
| *Bacopa* spp. | A | DP,TP | b |
| *Brachiarb* spp. | A | DP,DU | b |
| *Caperonia castanaefolia* | A | DP | b |
| *Commelina* spp. | A | DP,DU | a |
| *Cynodon dactylon* | P | DU | c |
| *Cyperus difformis* | A | DP,TP | a |
| *C. esculentus* | P | DP | b |
| *C. imbricatus* | P | TP | c |
| *C. iria* | A | DP,DU,TP | a |
| *C. rotundus* | P | DU | a |
| *C. serotinus* | P | TP | b |
| *Damasonium australe* | A | DP | c |
| *Digitaria ciliaris* | A | DU | c |
| *D. sanguinalis* | A | DU | c |
| *Diplachne fusca* | P | DP | c |
| *Dopatrium junceum* | A | TP | c |
| *Echinochloa colona* | A | DP,DU | a |
| *E. crus-galli* | A | DP,DU,TP | a |
| *Echinodorus cordifolius* | A | DP,TP | c |
| *Eclipta prostrata* | A | DP,TP | c |
| *Eichhornia crassipes* | P | DW | c |
| *Eleocharis acicularis* | P | TP | b |
| *E. kuroguwai* | P | TP | b |
| *E. obtusa* | A | DP | b |
| *Eleusine indica* | A | DU | b |
| *Fimbristylis littoralis* | A,P | DP | b |
| *Heteranthera limosa* | A | DP | b |
| *Imperata cylindrica* | P | DU | b |
| *Ipomoea* spp. | A | DP,DU | b |
| *I. aquatica* | A,P | DW | b |
| *Ischaemum rugosum* | A | DW | a |
| *Leersia hexandra* | P | DP,DU,TP | a |
| *Leptochloa chinensis* | A | DP,DW,TP | a |
| *L. fascicularis* | A | DP | a |
| *L. panicoides* | A | DP | a |
| *Lindernia* spp. | A | DP,TP | b |
| *Ludwigia adscendens* | P | DP,TP | c |
| *L. decurrens* | A | DP,TP | c |
| *Marsilea minuta* | P | TP | b |
| *Melochia concatenata* | A | DW | c |
| *Mimosa invisa* | P | DU | c |
| *Monochoria vaginalis* | A,P | DP,TP | a |
| *Najas* spp. | A | DP | c |
| *Nymphaea stellata* | P | DW | c |
| *Oryza longistaminata* | P | DW | b |
| *O. rufipogon* | P | DP,TP | b |
| *O. sativa* L. *(red rice)* | A | DP,DU | a |
| *Panicum* spp. | A,P | DP,DU,DW,TP | a |
| *Paspalum paspalodes* | P | DP,TP | a |

Continued on next page

**Table 1** continued

| Taxon | Type[b] | Rice culture[c] | Interference level[d] |
|---|---|---|---|
| *Pennisetum* spp. | A,P | DU | c |
| *Polygonum* spp. | A,P | DP,TP | b |
| *Portulaca oleracea* | A | DU | c |
| *Potamogeton* spp. | P | DP,TP | b |
| *Rhynchospora corniculata* | P | DP | c |
| *Rotala indica* | A | TP | c |
| *Rottboellia exaltata* | A | DU | b |
| *Sagittaria* spp. | P | DP,TP | b |
| *Salvinia molesta* | A,P | DP,DW,TP | b |
| *Scirpus hotarui* | P | TP | b |
| *S. maritimus* | P | TP | b |
| *Sesbania exaltata* | A | DP | b |
| *Setaria glauca* | A | DP,DU | c |
| *Sphenoclea zeylanica* | A | DP,TP | b |
| *Spirodela polyrhiza* | P | TP | b |
| *Typha* spp. | P | DP,TP | c |
| *Zannichellia palustris* | P | DP | c |

[a]Adapted from Akobundu and Fagade (1978), Barrett and Seaman (1980), Carson (1978), De Datta (1977,1979,1980), Holm et a1 (1977), Horng and Leu (1977), Matsunaka (1970), Noda (1977a), Pancho et a1 (1969), Ronoprawio et a1 (1971), Singh et a1 (1974) Smith et a1 (1977), Suvatabandhu (1950), Swain (1973), and WARDA (1979). [b]A = annual, P = perennial. [c]DP = direct-seeded paddy rice (dry- or water-seeded, irrigated or rainfed); DU = direct-seeded upland rice (rainfed); DW = deepwater or floating rice; TP = transplanted paddy rice (irrigated or rainfed). [d] a = weed causes major yield or quality losses and is economically troublesome worldwide, b = weed causes moderate yield or quality losses and is economically troublesome in certain rice cultures in rice-producing countries of the world, c = weed causes slight yield or quality losses and is economically troublesome in isolated, rice-producing areas of the world.

regimes: controlled irrigation, deep flooding, or rainfed (De Datta 1980, Smith and Moody 1979). Special weed problems are associated with each seeding method and moisture regime.

Direct seeding of rice in floodwater reduced problems with annual grasses in the southern USA, but enhanced problems with aquatic weeds (Smith et a1 1977). Seeding presprouted rice with aerial equipment on a well-prepared and smoothed-in-the-water seedbed reduced *E. crus-galli,* but increased problems with aquatic weeds, such as blue-green algae and species of *Ammannia, Bacopa,* and *Heteranthera.*

In Australia, rice is direct-seeded by drilling into dry soil or by broadcasting sprouted seed in flooded fields (Swain 1973). In dry-seeded rice E. crus-galli and *Diplachne fusca* were the dominant species, while *C. difformis* and *Damasonium australe* were the principal species in water-seeded rice.

Special weed problems are associated with deepwater and floating rice (De Datta 1980). In Thailand where deepwater rice is grown in large areas, principal weeds associated with this culture are *Echinochloa stagnina, E. picta, Ischaemum rugosum, Leptochloa chinensis, L. panicea, Pentapetes phoenicia,* and *Melochia concatenata.* These weeds are usually not a problem in conventionally managed transplanted rice. In India, troublesome weeds in dryland rice such as *Leersia hexandra, Hymenachne acutigluma, Hygroryza aristata, Scirpus articulatus,* and *Oryza* spp.

(wild rice) were controlled by deepwater culture. *Eichhornia crassipes* and *Nymphaea stellata,* however, became problem weeds in deepwater culture.

Moisture regimes influenced weeds present (De Datta 1980). In the Philippines, *Scirpus maritimus* was the principal weed in conventionally irrigated paddy rice. However, *Paspalum paspalodes* became prevalent where floodwater was not maintained in the rice fields. In dryland rice, *C. rotundus* and *Imperata cylindrica* were the dominant species.

**Crop rotation**

The Occurrence of a particular weed species in rice was often associated with crop rotation. In a 10-year experiment in the U. S., cropping systems included either soybean or rice grown continuously, or a rotation of soybean and rice in a 2-year cycle (Smith and Frans 1969). All plots had low weed infestations in 1960 when the experiment began. In plots planted continuously to rice, the infestations of *E. crus-galli, Oryza sativa* (red rice), and *C. iria* increased with time, but plots in the rice - soybean rotation contained few of those weeds during the tenth year.

When transplanted rice was grown continuously in the Philippines, *S. maritimus* infestations were at constantly high levels in a 3-year period, but *C. rotundus* was not present (Jereza and De Datta 1977). When upland crops were rotated with rice, *S. maritimus* infestations were reduced, but *C. rotundus* infestations increased. *S. maritimus* reduced rice yields less in the rotated system than in continuous cropping.

Rotation of wetland rice with an upland crop such as soybean reduced infestations of water-tolerant weeds in the rice crop (Matsubayashi et al 1966). Dryland weeds in the upland crop were reduced. Introduction of soybean into a rice - wheat rotation reduced water-tolerant weeds in the rice crop up to 76%. In another experiment in the first year after an upland crop, rice plots contained 61% fewer water-tolerant weeds than plots planted to rice continuously. In a third experiment, soybean grown after rice contained 83% fewer dryland weeds than soybean grown after an upland crop.

**Air and soil temperatures**

Weed species require different temperatures for germination and emergence. Noda (1977b) reported that annual weed species in rice fields in Japan can be separated into five groups based on minimum air and water temperatures. Species of *Ahma, Aneilema,* and *Callitriche* emerged in paddy rice at minimum air temperature of 8° C and water temperature of 13° C. Species of *Echinochloa, Eleocharis, Ludwigia,* and *Rotala* emerged at 9° to 10° C and 14° to 15° C; species of *Lindernia* and *Sagittaria* emerged at 11° to 12° C and 16° to 17° C; *C. difformis* emerged at 13° to 14° C and 18° C; and *M. vaginalis* emerged at 15° to 16° C and 19° C. Noda concluded that weed species germinate over a long period in northern Japan where temperature in the spring rises slowly. In southern Japan where temperatures at transplanting are at or above threshold temperatures for *M. vaginalis,* all of the above weed species germinate and emerge immediately after transplanting.

Temperature also affected the growth rate of *E. crus-galli.* Noda (1977b) reported that this weed took a longer period to reach a specific stage of growth in northern Japan.

## Land preparation

Land preparation before transplanting or direct-seeding rice influenced the presence of weeds. In the Philippines, tillage practices during the dry season increased problems with annual grasses such as *E. colona* in transplanted rice grown during the wet season, but decreased the prevalence of *C. rotundus* and *Cynodon dactylon* (Moody 1979). In the Philippines, puddling the soil instead of dry tilling in preparation for seeding dryland or rainfed wetland rice reduced by 96% the weight of broadleaf, grass, and sedge weeds4 weeks after direct seeding or transplanting (Moody 1979).

In the U. S., repeated tilling of the soil at 1- to 3-week intervals beforedry-seeding rice reduced *E. crus-galli* and other annual grass infestations, but did not control blue-green algae, species of *Heteranthera, Ammannia,* and the annual species *Eleocharis* or *Cyperus* (Smith et al 1977).

## Fertilization

Fertilization affects weed growth in rice fields. In Taiwan, *E. crus-galli* and *C. difformis* reduced yields of rice that received high rates of nitrogen more than did *M. vaginalis* or *Spirodela polyrhiza,* but the converse was true of rice that received low nitrogen levels (Chang 1970a).

Phosphorus applied to rice at preplanting stimulated the growth of many weeds, including annual grasses such as *E. crus-galli* and aquatic weeds such as blue-green algae, and species of *Ammannia, Bacopa,* and *Heteranthera* (Smith et al 1977). In fields severely infested with annual grass and aquatic weeds, application of phosphorus to another crop in the rotation prevented the stimulation of weed growth that would be expected after direct application to the rice crop.

## Rice cultivars

The cultivar affected the type of weeds that grew in rice fields. Weeds that grew in association with BR3 — a short, erect cultivar — were sedges, such as *F. littoralis, C. difformis,* and *C. iria. E. crus-galli* rather than sedges, however, was associated with the traditional tall, drooping Dharial.

The replacement of the traditional, tall rice cultivars with modem short-statured ones has increased problems with annual grass weeds in tropical Asia (De Datta 1980). Broadleaf and sedge weeds, which were prevalent in rice fields planted to the traditional cultivars, were reduced by rapidly growing grass weeds that infested modem rice cultivars.

## Weed control technology

In countries where herbicides have been used to control annual weeds for many years, perennial weeds have increased. De Datta (1977) reported that in Korea, where the same or similar herbicides have been used continually for several years for controlling annual weeds in rice, infestations of perennials including *Cyperus serotinus, S. polyrhiza, Potamogeton franchetii, Eleocharis acicularis, E. kuroguwai, Sagittaria pygmaea,* and *Scirpus hotarui* have increased significantly. In Taiwan, *Marsilea minuta* has become more prevalent. Populations of *E. crus-galli* have increased in Japan. In tropical Asia, *S. maritimus* has increased in recent years in wetland rice fields. In the Philippines, *P. paspalodes* has increased in rice fields with minimum tillage.

In an experiment in Japan, paddy rice plots treated for 5 successive years with the same herbicides exhibited changes in weed ecology (Sakamoto et al 1979). At the beginning of the experiment all plots contained *C. difformis, Rotala indica,* and *S. hotauri.* Use of some herbicide treatments caused a shift to mostly *C. serotinus* and *S. pygmaea* in the fifth year.

## LOSSES DUE TO WEED COMPETITION IN RICE

Losses in rice caused by species or groups of weeds are presented in Table 2. They are based on weed competition and herbicide comparison experiments.

Weeds interfere with rice production and processing in the following ways (Chisaka 1977, De Datta 1980, Matsunaka 1970, Moody 1979, Noda 1977a, Shaw 1964, Smith et al 1977). They:

- reduce rice yields and quality;
- intensify problems with insects, diseases, and other pests by serving as hosts;
- reduce harvesting and processing efficiency;
- reduce efficiency of irrigation systems by restricting the flow of water in reservoirs, canals, and ditches;
- cause consumption of energy for their control;
- may be poisonous and injure animals and humans; and
- reduce the value and productivity of land.

## COMPONENTS OF WEED INTERFERENCE

The most common and severe effect of weed interference is yield loss by weed competition in rice fields. Losses are influenced by:

- competitive efficiency of weeds and rice,
- species or group of weed,
- weed density,
- duration of weed-crop competition,
- planting method,
- cultivar,
- fertility level,
- water management,
- row spacing of the rice crop,
- allelopathy, and
- interactions among the preceding factors.

### Competitive efficiency of plants

Black et al (1969) divided crop and weed plants into efficient and nonefficient groups based on biochemical characteristics, with emphasis on factors affecting photosynthesis.

Efficient plants, which are more competitive than nonefficient ones, have:

- increased uptake of carbon dioxide as light intensity increases to nearly full sunlight and as temperature increases up to 30-40° C,

**Table 2. Interference of selected species or groups of weeds in rice.[a]**

| Taxon or group | Country | Rice culture | Loss | | Reference |
|---|---|---|---|---|---|
| | | | Type[c] | %[d] | |
| *Aeschynomene virginica* | USA | DP | Q | 4 | USDA-Stales-EPA (1979) |
| *A. virginia* | USA | DP | Y | 4-19 | Smith (1968) |
| *Ammania* spp. | USA | DP | Q | 2 | USDA-States-EPA (1979) |
| *Cyperus difformis* | Taiwan | TP | Y | 49-90 | Chang (1970a) |
| *C. difformis* | Australia | DP | Y | 33-44 | Swain (1973) |
| *C. iria* and *Echinochloa colona* | Egypt | TP | Y | 36 | Tag El-Din et al (1979) |
| *C. rotundus* | Philippines | DU | Y | 29-51 | De Datta (1979) |
| *Echinochloa* spp. | Australia | DP | Y | 76-100 | Kleinig & Noble (1968) |
| *Echinochloa* spp. | Australia | DP | Y | 54-89 | Swain (1973) |
| *Echinochloa* spp. | Hungary | DP | Y | 60-63 | Szilvassy (1979) |
| *E. colona* | Philippines | DP | Y | 2-76 | Mercado & Talatala (1977) |
| *E. crus-galli* | Japan | TP | Y | 5-7s | Noda et al (1968) |
| *E. crus-galli* | Taiwan | TP | Y | 71-92 | Chang (1970a) |
| *E. crus-galli* | USA | DP | Y | 25-95 | Smith (1968) |
| *Eleocharis kuroguwai* and *Cyperus serotinus* | Korea | TP | Y | 59 | De Datta (1977) |
| Grasses | Philippines | DP | Y | 86 | De Datta (1979) |
| Grasses | Japan | TP | Y | 27-89 | Matsunaka (1976) |
| Grarses | Philippims | TP | Y | 75 | De Datta (1979) |
| Grasses, sedges, and broadleaf weeds | Philippines | TP | Y | 67 | De Datta (1979) |
| Grasses, sedges, and broadleaf weeds | Philippines | DP | Y | 100 | De Datta (1979) |
| *Heteranthera limosa* | USA | DP | Y | 6-27 | Smith (1968) |
| *Ipomoea* spp. | USA | DP | Q | 4 | USDA-States-EPA (1979) |
| *Leptochloa panicoides* | USA | DP | Y | 35 | Smith (1975) |
| *Marsilea minuta* | Taiwan | TP | Y | 45-87 | Chang (1970a) |
| *Monochoria vaginalis* | Taiwan | TP | Y | 31-86 | Chang (1970a) |
| *Scirpus maritimus* | Philippines | TP | Y | 18-25 | De Datta (1977) |
| *S. maritimus* | Philippines | TP | Y | 48 | De Datta (1979) |
| Sedges and broadleaf weeds | Philippines | DP | Y | 24 | De Datta (1979) |
| *Sesbania exaltata* | USA | DP | Q | 4 | USDA-States-EPA (1979) |
| *S. exaltata* | USA | DP | Y | 10-40 | Smith (1968) |
| *Spirodela polyrhiza* | Taiwan | TP | Y | 3-27 | Chang (1970a) |

[a]Losses based on weed competition and herbicide comparison experiments conducted by weed scientists. [b]DP = direct-seeded paddy rice (dry- or water-seeded, irrigated or rainfed), DU = direct-seeded dryland rice (rainfed), TP = transplanted paddy rice (irrigated or rainfed). [c]Y = yield loss, Q = quality loss. [d]Single or range values.

- photosynthesis uninhibited by oxygen at atmospheric levels (21%),
- no detectable photorespiration,
- $C_4$ carbon dioxide fixation, and
- low photosynthetic carbon dioxide compensation concentration of 5 ppm or less.

Nonefficient plants have

- increased uptake of carbon dioxide as light increases up to about one-tenth to one-third of full sunlight and as temperature increases to 10-20° C,
- photosynthesis inhibited by oxygen at levels well below atmospheric concentration,
- photorespiration,
- Calvin cycle of carbon dioxide fixation, and
- high photosynthetic carbon dioxide compensation concentration in the range of 30-70 ppm.

By those definitions, rice is a nonefficient plant. Many rice weeds, including *C. rotundus, Digitaria sanguinalis, E. crus-galli, P. paspalodes, Portulaca oleracea,* and *Setaria glauca,* are classed as efficient plants.

## Weed species or group

Species or types of weeds vary in the losses they inflict. Weed competition experiments in the U. S. indicated that all-season competition from *E. crus-galli* reduced rice grain yields more than that from broadleaf and aquatic weeds such as *Aeschynomene virginica, Sesbania exaltata,* or *Heteranthera limosa* (Table 3) (USDA-States-EPA 1979).

In direct-seeded rice in the Philippines, sedges and broadleaf weeds reduced grain yields 24%, grass weeds 86%, and combinations of them 100% (De Datta 1979). In transplanted rice, the grain yield reductions were 0, 75, and 67%.

## Weed density

The density of weeds in drill-seeded rice affects rice yields — the thinner the rice stand, the greater the yield loss. In the U. S., season-long competition from E. crus-galli reduced grain yields 25-79% in an optimum stand of rice (Table 4). In the same experiment, season-long competition from *E. crus-galli* at a density of 11 plants/$m^2$ reduced grain yields inversely to rice stands (Table 5).

**Table 3. Yield loss in direct-seeded paddy rice due to competition with different weed species.**[a]

| Weed | Yield loss (%) with a given period of competition | | | |
|---|---|---|---|---|
| | 4 wk | 8 wk | 12 wk | Season-long |
| *Sesbania exaltata* | 2 | 6 | 9 | 19 |
| *Aeschynomene virginica* | 2 | 8 | 8 | 17 |
| *Heteranthera limosa* | 15 | 27 | – | 21 |
| *Echinochloa crus-galli* | 8 | 35 | 43 | 70 |
| *Leptochloa panicoides* | – | – | – | 35 |

[a]Data adapted from Smith (1968, 1975).

**Table 4. Yield loss in drill-seeded rice due to season-long competition from *Echinochloa crus-galli.*** [a]

| Weed density (plants/$m^2$) | Yield loss (%) |
|---|---|
| 11 | 25 |
| 54 | 49 |
| 269 | 79 |

[a] Adapted from Smith (1968).

**Table 5. Yield loss due to season-long competition from *Echinochloa crus-galli* in 3 drill-seeded rice stands.** [a]

| Rice stand (plants/$m^2$) | Yield loss (%) |
|---|---|
| 32 | 57 |
| 108 | 40 |
| 334 | 25 |

[a] Adapted from Smith (1968). Weed density was 11 plants/$m^2$.

Densities of two broadleaf leguminous weeds affected drill-seeded rice yields less than *E. crus-galli.* Season-long competition from *S. exaltata* at densities of 1-11 plants/$m^2$ reduced grain yields of drill-seeded rice an average of 10-40% in a 3-year experiment in the U. S. (Table 6). In a similar experiment *A. virginica* at the same densities reduced drill-seeded rice yields 4-19%.

In Japan, a negative quadratic relation was found between competition from *E. crus-galli* and transplanted rice yield (Matsunaka 1970). Increased densities of *E. crus-galli* at dry weights of 250-1,500 g/$m^2$ reduced rough rice yields 20-85% (Table 7). This research indicated that rice yields were not reduced proportionally with each density increase of *E. crus-galli.* But at densities normally encountered in the field, a linear relationship existed between weed density and yield loss.

At moderate levels of nitrogen (140 kg/ha), grain yields of Early Caloro in Australia, decreased from about 5.6 to 0.1 t/ha as the density of *Echinochloa* spp. increased from 50 to 348 plants/$m^2$ (Kleinig and Noble 1968).

Weed species at different densities vary in their competitiveness with rice (Chang 1970a). *E. crus-galli* at densities of 100 and 200 plants/$m^2$ reduced rice yields 86 and 91%; *M. vaginalis* at the same densities reduced yields 58 and 60%; and *S. polyrhiza* at both densities reduced yields only 7%.

**Duration of weed-rice competition**

In numerous field experiments with different rice cultures, yields decreased with increasing lengths of weed-rice competition.

In the U. S., *E. crus-galli* reduced drill-seeded rice yields of standard cultivars 9-79% when competition lasted for about 20 days to season-long (Table 8). *S. exaltata* and *A. virginica* reduced rice yields 2-19% and 2-17%, respectively, when competition lasted for 4 weeks to season-long (Table 9).

In the Philippines IR8 rice yields were reduced by 11-40% when the crop was hand weeded once between 21 and 63 days after transplanting (DT) (Table 10); these treatments were compared with 2 hand weedings 21 and 42 DT. All hand-weeding treatments, however, increased yields 2 to 3 times compared with an unweeded treatment.

**Table 6. Yield losses due to season-long competition from *Sesbania exaltata* and *Aeschynomene virginica* in an optimum stand of drill-seeded rice.[a]**

| Weed density (plants/$m^2$) | Yield losses (%) | |
|---|---|---|
| | *S. exaltata* | *A. virginica* |
| 1 | 10 | 4 |
| 3 | 15 | 7 |
| 5 | 27 | 11 |
| 11 | 40 | 19 |

[a]Adapted from Smith (1968).

**Table 7. Yield loss in transplanted rice due to competition from *Echinochloa ausealli*.[a]**

| Dry wt of weed (g/$m^2$) | Yield loss (%) |
|---|---|
| 250 | 20 |
| 500 | 40 |
| 750 | 57 |
| 1000 | 68 |
| 1250 | 80 |
| 1500 | 85 |

[a]Adapted from Matsunaka (1970).

**Table 8. Yield loss in drill-seeded rice as influenced by duration of competition from *Echinochloa crus-galli*.[a]**

| Duration of competition (days) | Yield loss (%) |
|---|---|
| 20 | 9 |
| 40 | 20 |
| 50 | 35 |
| 65 | 43 |
| Season-long | 79 |

[a]Adapted from Smith (1968).

**Table 9. Yield losses in drill-seeded rice as influenced by duration of competition from *Sesbania exaltata* and *Aeschynomene virginica*.[a]**

| Duration of competition (weeks) | Yield losses (%) | |
|---|---|---|
| | *S. exaltata* | *A. virginica* |
| 4 | 2 | 2 |
| 8 | 6 | 8 |
| 12 | 9 | 8 |
| Season-long | 19 | 17 |

[a]Adapted from Smith (1968).

**Table 10. Yield loss in transplanted rice from weeds controlled at various times.** [a]

| Time hand weeded [b] (DT) | Yield loss (%) |
|---|---|
| 21 | 11 |
| 49 | 19 |
| 56 | 23 |
| 63 | 40 |

[a] Adapted from De Datta (1979). [b] DT = days after transplanting.

In Japan, *E. crus-galli* was most competitive with rice at the maximum tillering or the early ripening stage (Noda 1973). Competition during maximum tillering reduced the number of panicles, while competition during early ripening reduced grain weight and quality.

Weeds that were established later than the rice crop were less competitive. In pot-culture experiments in Taiwan, *E. crus-galli, M. vaginalis,* and *C. difformis* were established in Chianung 242 (a japonica rice cultivar) 15 to 60 DT (Table 11). Grain yields were reduced 85-18% when weeds were established 15-60 DT and permitted to compete with the crop until maturity.

## Planting method

In Japan weed competition is greater in machne-transplanted rice than in hand-transplanted rice because machine-transplanting requires 1) the use of smaller seedlings, and 2) a longer interval between puddling and transplanting to allow the soil to become firm (Noda 1977a). Weed competition for about 9 weeks after puddling the soil reduced grain yields 59% in hand-transplanted rice and 80% in machine-transplanted rice compared with the hand-weeded check (Matsunaka 1976). Competition for only 5 to 6 weeks reduced yields by 27% in hand-transplanted rice and 85% in machine-transplanted rice compared with the hand-weeded treatment.

Weed competition was greater in direct-seeded than in transplanted rice. In India all-season competition reduced grain yields 11% in transplanted rice, 20% in direct-wet-seeded rice, and 46% in directdry-seeded rice (De Datta 1979).

In dryland rice grown in the Philippines, weed populations and yield losses were similar for drill- and broadcast-seeded rice (De Datta 1979). Annual and perennial weed infestations reduced yields of drill- or broadcast-seeded rice about 80%.

## Rice cultivar

Short-statured, early-maturing, erect rice cultivars were less competitive with weeds than tall, late-maturing, drooping cultivars. In the Philippines, medium-height IR442-2-58 competed better with weeds than semidwarf IR20 (De Datta 1974).

In the U. S., season-long competition of *E. crus-galli* reduced grain yields of Starbonnet and Bluebelle cultivars 40% and 64% (Smith 1974). Competitiveness was thought to be associated with maturity; Starbonnet matures in about 145 days, Bluebelle in 125.

In Peru rice types that grew rapidly (tall and high plant weight) during early growth stages were more competitive with weeds such as *Cyperus esculentus, E.*

Table 11. Yield loss from weeds established at various times after transplanting.[a]

| Time of weed establishment [b] (DT) | Yield loss (%) |
|---|---|
| 15 | 85 |
| 30 | 72 |
| 45 | 42 |
| 60 | 18 |

[a] Adapted from Chang (1970b). [b] DT = days after transplanting.

*colona, Eclipta prostrata,* and *Leptochloa uninervia* than slow-growing types (Kawano et a1 1974). Rice types with high vegetative vigor, rapid leaf area expansion, and vigorous nitrogenabsorption had a competitive advantage over less vegetatively vigorous types. Types that matured quickly also were less competitive with weeds than those with a long growth duration. This research suggests that the evolution of rice cultivars has been accompanied by improved crop production technology and the subsequent loss of competitiveness of the crop.

**Fertility level**

Weed growth and subsequent competition with rice were usually stimulated by preplant application of phosphorus and nitrogen. Knowledge of the relation between fertility and weed-rice competition can help the farmer manipulate fertilizers to favor the crop and suppress weed growth.

In Australia, *Echinochloa* spp. at high densities of 50 to 200 plants/ $m^2$ caused crop failure in direct-seeded rice when 56 kg P/ ha and 280 kg N/ ha were applied (Kleinig and Noble 1968). In the U. S., nitrogen stimulated the growth of *E. crus-galli* and aquatic weeds such as *H. limosa* and *Ammannia auriculata* when it was applied before seeding, or during the vegetative growth stage after weed emergence—weed competition increased and grain yields were reduced (Smith et al 1977). Nitrogen applied after *E. crus-galli* headed benefited rice more than earlier applications.

In Taiwan, weed species varied in their competitiveness with transplanted Chianung 242 rice grown at high fertility (160 kg N/ ha, 80 kg P/ ha, and 80 kg K/ ha) and low fertility (80 kg N/ ha, 40 kg P/ ha, and 40 kg K/ ha) (Chang 1970a). *E. crus-galli* reduced rice yields 89% and 84% at high and low fertility levels; *C. difformis* reduced yields 78% and 53% at the high and low levels. Conversely, *M. vaginalis* reduced yields 33% and 45% at high and low fertility levels; *S. polyrhiza* reduced yields 10% and 18% at the high and low levels.

**Water management**

In the U. S., flooding rice to a depth of 10 to 20 cm early in the season reduced infestations of *E. crus-galli.* But flooding frequenlty etiolated and weakened the rice (Smith et a1 1977). Water controlled grass plants in the 1 -to 4-leaf stages better than it controlled larger plants; deep water usually failed to control grass plants that were in the tillering or advanced stages of growth. High water temperatures of 35° C or above facilitated control of *E. crus-galli,* presumably because of the low oxygen content of warm water, but the rice was frequently injured as well. Early flooding for control of *E. crus-galli* increased problems with aquatic weeds such as blue-green algae, species of *Ammannia* and *Heteranthera,* and annual species of *Cyperus* and *Eleocharis* (Smith et al 1977). Timely draining reduced growth of those aquatics.

In the Philippines, IR36 yielded 3.3 t/ha when water depth was held at 2.5 cm, and 4 t/ha at a water depth of 7.5 cm in plots that received no weed control treatments (De Datta 1979). The yield difference was attributed to fewer weeds in the deepwater treatment.

**Row spacing**

When IR28 or IR30 cultivars were transplanted in narrow rows, weed competition was reduced. In the Philipines, yield losses from weeds averaged 52% for rice transplanted on 25- × 25-cm spacing, 29% for rice on 20- × 20-cm spacing, and 19% for rice on 15- × 15-cm spacing (Estorninos and Moody 1976). Weed weight increased from 2.2 t/ha at the narrowest spacing to 3.2 and 3.6 t/ha at the 20- × 20-cm and 25- × 25-cm spacings. Light penetration into the crop canopy increased as row spacing increased, stimulating weed growth and subsequently depressing rice yields.

**Allelopathic substances**

Plant-plant interactions involve the direct competitiveness of weeds and rice, and the action of chemical compounds added to the environment by an allelopathic agent (Buchanan 1977). Aqueous extracts of plant parts, exudates from living roots, and leachates and volatile compounds from aboveground parts of living and decaying plants demonstrate allelopathic properties. Although considerable research has been done on allelopathic responses in plant communities, most has been directed at explaining observed phenomena of allelopathy. Little research has been directed toward the use of allelopathy as a practical approach to weed control; however, it has been found that some genotypes of crops such as cucumber (Putnam and Duke 1974) and tall fescue (Peters and Mohammed Zam 1981) exhibited allelopathy.

It has been hypothesized that many presently cultivated crop species may have possessed allelopathic substances when growing in their wild habitat. The trait could have been lost through domestication with intensive breeding and selection for specific characters. If we assume that 1) allelopathic traits existed in wild types of rices, 2) these traits can be transferred to presently used or equally good cultivars, and 3) weed control technology can be integrated with allelopathy, then allelopathy may be considered a valuable component of weed control in rice. Allelopathic control is desirable because it would be inexpensive, nonpolluting, and would require no labels or paraphernalia for use.

Allelopathy is an interesting phenomenon, but its use in rice holds no promise of an effective approach to weed control. Although root extracts of *E. crassipes* have inhibited root growth of rice (Kasasian 1971), few plant species are known to exhibit allelopathic properties.

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## DISCUSSION

SUNDARU: You showed us that grasses, especially *E. crus-galli.* cause a high percentage of yield losses in rice. In certain areas, where labor is scarce, we could not get 100% clean weeding. Have you any experience with experiments on economic threshold of those weeds.

*SMITH:* Economic thresholds for weeds in different rice cultivars vary with weed species, fertility level, water management, environment, economic, and social factors. For example, research in the US indicated that *E. crus-galli* densities as low as 2 or 3 plants/m$^2$ reduced rice yields sufficiently to justify the use of herbicides. Likewise, *Sesbania exaltata* densities less than 1 plant/m$^2$ caused sufficient yield losses to warrant herbicide treatment. Economic thresholds for these two weeds vary with the value of the crop and the cost of control inputs.

BURRILL: (1) Were most of the yield data you showed under uncontrolled situations? (2) I feel that data that indicate losses from weeds after the farmer has used his weed control practices are more important.

*SMITH:* (1) Yes, most of them were from all-season competition. (2) This is an important aspect. However, the farmer may have different levels of weed control in different fields, depending on the specific conditions that exist when he is applying the weed control practice.

MATTHEWS: What differences occur in weed losses in crop rotations conducted under weed-free and weedy levels?

*SMITH:* Crop rotations alone do not control weeds well enough to prevent weeds from causing yield losses in rice. An integrated system of weed control inputs, including cultural, mechanical, and herbicide practices is required to prevent weeds from increasing to economic threshold levels. Cropping systems must be combined with efficient use of mechanical and herbicide practices to keep weed losses to a minimum. The best weed control technology, however, will not prevent weed losses when rice is grown continually on the same land.

OBIEN: What can be done to regain yield losses due to delays in weeding?

*SMITH:* There are some management practices that we can manipulate to counteract the early loss. We can compensate somewhat by making adjustments in seeding (or transplanting) rates and fertilizer levels applied at later dates. Also, you can compensate by using increased nitrogen levels and timely applications of nitrogen.

BAKER: Could you identify the yield components influenced by weed competition and which of these were important in the ability of varieties to recover from competition?

*SMITH:* Important yield components influenced by weed competition were the number of panicles/unit area and the number of filled grains/panicle. Competition from *E. crus-galli* reduced the number of panicles/$m^2$ and the number of rice grains/ panicle. Longer maturing rice varieties recovered better than shorter maturing cultivars from early- to mid-season competition of *E. crus-galli.*

SEAMAN: You made an excellent case for further research on allelopathic traits of rice for possible advantages in competition with weeds. Yet you indicated that you found no reports of rice allelopathy. Did you find any negative reports that rice allelopathy exists? In other words, has this subject been studied adequately?

*SMITH:* In relation to allelopathy in rice, I found no positive or negative reports in reviewing the literature. My assessment of allelopathy in rice is that we must conduct additional research to determine if it is a viable approach for controlling weeds in rice.

# WEED CONTROL PRACTICES AS A COMPONENT OF RICE PRODUCTION SYSTEMS

R. Barker and Y. Hayami

This paper briefly traces the historical evolution of weed control practices in Asia and examines alternative techniques for weed control, then focuses on the use of human labor in weed control. Weed control has been an important factor in the spread of wetland rice culture throughout Asia, allowing yields in wetland areas to reach levels double those in drylands. Weed control in Asian wetland rice culture involves two basic steps—puddling and flooding of rice fields and subsequent extermination of weeds by hand labor, use of mechanical devices, or use of herbicides. Hand labor will continue to be the dominant method of weed control in most of South and Southeast Asia in the forseeable future. The amount of labor used in weeding has generally increased. The continuing pressure of population on the land coupled with the introduction of modem inputs is resulting in changes in labor contractual relationships in many areas. Frequently, hired laborers undertake the task of weeding at no charge (e. g. the *gama* system in the Philippines) so as to obtain the right to participate and share in the harvest.

Weed control is often ignored in discussions of modem rice technology. Historically, however, the development of cultural practices to control weeds allowed an increase

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in rice productivity that permitted that crop to replace more traditional ones such as taro, yam, and millet as the staple throughout most of Asia. Weed control remains one of the major input costs in rice production. We will discuss first the evolution of weed control in rice culture and alternative weed control techniques in relation to their economic significance in different rice production systems. Then we will focus on the use of human labor, which today is still the main input for weed control in Asia. Labor inputs have changed dramatically in many Asian countries in the past several years, depending on the resource and technology base. The contractual relationships under which hired labor is employed have also changed; these in turn have influenced the choice of weed control technology.

## EVOLUTION OF WEED CONTROL PRACTICES

Scholars still debate whether rice was first domesticated as a wetland or a dryland crop (Spencer 1963). However, there seems to be agreement that it originated between 4000 to 3000 BC in the upland regions of tropical Asia extending from the Ganges plains below the foothills of the Himalayas, across upper Burma and Northern Thailand to North Vietnam and South China (Chang 1976b). In South and Southeast Asia, rice spread slowly in the upland terraces and slopes. It did not become an important lowland crop of the region until the coming of the Europeans.

In China by contrast, rice developed initially as a lowland crop. Rice was first planted in the low plain areas of Hunan and the central Shensi basin between 3000 and 2500 BC (Chang 1976a). As rice spread south and east, a lowland culture developed. Substantial gains in production and productivity resulted.

The basic elements of Chinese rice culture were practices that facilitated the control of weeds. By the third and second centuries BC irrigation was widely practiced, and some large-scale irrigation systems were operated (Chang 1976b). Rice had become a staple in the middle and lower Yangtze River Valley. The water buffalo, indigenous to Southeast Asia, was in common use, and the iron plow and hoe had been introduced as primary cultivation implements.

During the early Christian era rice cultivation in China extended south, and manuring and transplanting were adopted (Chang 1976b). A revolution in farming between the 8th and 12th centuries led to a mastery of lowland rice cultivation techniques. Introduction of the spike-tooth harrow and roller compactor greatly facilitated weed control and transplanting.

The cultural practices perfected in China — and still commonly practiced in Asia today — gradually spread over the next several hundred years to Southeast Asia as more of the lowlands were cultivated.

A similar technology of lowland cultivation developed in the Indian subcontinent, although the origin and dissemination of various cultural practices are not as well documented as those of China. In Burma and Indonesia, which were exposed to Chinese and Indian cultures, it is easy to identify implements of Indian and Chinese origin. Lowland rice culture gradually dominated upland culture because techniques such as slash and bum practiced in the uplands were not effective in controlling weeds in the humid tropics. Well before the use of modern inputs, lowland rice yields were double those of upland rice.

## ALTERNATIVE TECHNIQUES OF WEED CONTROL

Weed control in Asian lowland rice culture still involves two basic steps:

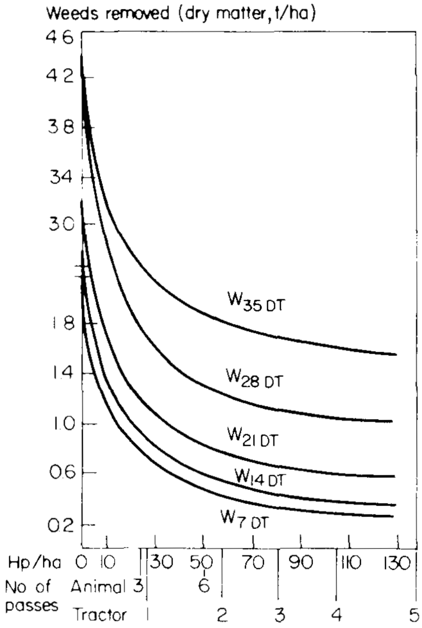
- puddling and flooding of the rice fields, and
- subsequent control of weeds by hand labor, mechanical devices, or herbicides.

The two functions are intimately related (Fig. 1). The more thorough the land preparation, the fewer the weeds. Farmers typically expend 20 to 30 hp/ha (1 pass with the tiller or 3 passes with the water buffalo) to harrow 1 ha. That seems rational in that the return for additional horsepower/hectare is significantly lower.

The degree of subsequent weeding required depends heavily on water control. Alternate flooding and drying encourage weed growth. If fields can be kept flooded, weed populations can be kept to a minimum. The consensus of farmers in three villages in Central Luzon, Philippines, is that using tractors for tillage frequently reduces the weed problem, but does not usually result in higher yields (Table 1).

An informal survey of rice scientists in 1974-75 showed that hand weeding was common throughout Asia, but that rotary and chemical weed control were common only in selected sites (Table 2). A 1971-72 survey of rice production in relatively progressive Asian villages suggested that even in these villages, where more than 80% of the farmers adopted modern cultivars, fertilizer, and insecticides, only a relatively small percentage used rotary weeders or herbicides (Table 3).

In South and Southeast Asia herbicide use is generally limited to phenoxy compounds that cost about US$10/ ha (De Datta and Barker 1977). Herbicides for




**1.** Relation between weeds removed at weeding time and horsepower/ hectare for harrowing (av of 2 varieties: IR8 and H4). IRRI, 1967 dry season. W = weeds removed at weeding time, DT = days after transplanting.

**Table 1. Farmers' evaluation of the effect of mechanized land preparation on weed population and yield. Nueva Ecija Province. Philippines 1973.[a]**

| Barrio and mechanical device for weeding | Farms (no.) | Farmers reporting (%) after tractor adoption | |
|---|---|---|---|
| | | Fewer weeds | Higher yields |
| Balwarte (irrigated) | | | |
| Tractor rented | 39 | 68 | 21 |
| Tiller rented | 11 | 80 | 10 |
| Tiller owned | 21 | 68 | na[b] |
| Pulo (irrigated) | | | |
| Tractor rented | 20 | 65 | 10 |
| Kapalangan (rainfed) | | | |
| Tractor rented | 18 | 56 | 11 |

[a]Source: De Datta and Barker 1977. [b]Not available.

**Table 2. Method of weed control in transplanted rice and wage rate for weeding in selected Asian countries, 1974-75.[a]**

| Country | Prevalence[b] of weeding method | | | | Daily wage for hand weeding (US$) | Av farm size[c] (ha) |
|---|---|---|---|---|---|---|
| | Hand | Rotary | Chemical | No weeding | | |
| Bangladesh | VC | C | – | U | 0.80 | 1.3 |
| Indonesia | VC | VC | – | U | 0.40 | 1.1 |
| India | VC | U | U | U | 0.40 | 2.5 |
| Philippines | VC | U | C | C | 0.80 | 3.6 |
| Sri Lanka | VC | – | C | U | 0.80 | 1.6 |
| Taiwan, China | VC | VC | VC | – | 3.75 | 1.3 |
| Thailand | VC | U | U | C | 0.80 | 3.5 |
| Vietnam | VC | – | U | C | 1.50 | 1.3 |

[a]Source: De Datta and Barker 1977. [b]VC = very common, C = common, U = uncommon.
[c]Based on government and FAO statistics.

**Table 3. Weed control practices related to farm size in selected Asian villages, 1971-72.[a]**

| Weed control practice | Weed control practices (%) in farms measuring | | |
|---|---|---|---|
| | <1 ha | 1-3 ha | >3 ha |
| Herbicides | 6 | 20 | 29 |
| Rotary weeding | 3 | 20 | 37 |
| Hand weeding | 82 | 83 | 87 |

[a]Based on survey of 32 villages in South and Southeast Asia (IRRI 1975).

tropical rice production are normally used in combination with hand labor, partly because chemical control methods alone frequently are not effective against all species. The sparing use of herbicides has an ecological as well as an employment advantage. Dependence on herbicides as the sole source of weed control encourages the spread of resistant perennial weeds. We anticipate a more widespread use of herbicides only with a change in the basic factor costs — a significant rise in wages or a significant decline in herbicide costs.

We conclude that rotary weeders and herbicides are not an essential element in modern rice technology. High yields can be achieved with the traditional practice of hand weeding. Rotary weeding or herbicides will be more popular when labor is scarce and wages are high, i. e. in places such as Taiwan (Table 2) where herbicides are used on more than 90% of the total paddy area, or on large farms (Table 3).

Perhaps 20% of the world's rice area is devoted to dryland, deepwater, and floating rice. Typically seeds are broadcast onto dry soils. Yields seldom exceed 1.5 t/ha. Drought and lack of weed control are the major limitations to yield. Hand weeding is difficult and time-consuming. Herbicides are not widely used (De Datta and Barker 1977). More adequate weed control is not likely to be practiced in most of these areas unless cultivars that provide not only higher but stable yield potential can be developed.

## LABOR TRENDS IN WEED CONTROL

As suggested, we should expect the amount of labor employed in weed control to vary among countries and over time within a country. As wage rates rise relative to other input costs, we would expect a decline in labor use for weed control. Advances in alternative weed control technologies may accelerate the decline or advances in yield-increasing technology may encourage more intensive use of labor for weed control.

Table 4 presents some trends in labor use for land preparation and weeding in Japan, Taiwan, Indonesia, and the Philippines. Irrigated rice was predominant during the period studied.

Before the turn of the century land preparation and weeding in Japan and Indonesia required more than 100 labor days/ha; by the end of World War II labor had been reduced by more than one-third. In Japan, the decline has continued steadily to less than 20 labor days/ha. The reduction has been marked by the introduction of tractor power for land preparation, and the transition from hand weeding to rotary weeders to herbicides as the primary source of weed control. Taiwan has followed a pattern similar to Japan in the postwar period.

Labor inputs for weed control were low in prewar Taiwan before the introduction of ponlai cultivars and in the Philippines before the introduction of modern cultivars. The introduction of new seed-fertilizer technology seems to have increased the demand for weeding labor. But in the Philippine site, a sharp rise in weeding labor input after 1962 was offset by a decline in labor input for land preparation as a result of the adoption of power tillers.

Labor days devoted to weeding in the 1970s reflect the differences in labor supply and wage rates among the four sites. Despite the changes in technology over the period, the labor devoted to weed control has remained at about one-third to one-half of total labor input. The only exception is Japan where the labor input for land preparation and weeding fell to less than a quarter of the total in 1964.

Land preparation and weeding costs as a percentage of total costs in 1972 for both

**Table 4. Labor trends in weed control in four Asian sites**

| Year | Labor days/ha | | | | | Land preparation and weeding (%) |
|---|---|---|---|---|---|---|
| | Land preparation | Weeding | Other preharvest tasks | Harvesting | Total | |
| | | | *Shonai Plain, Japan*[a] | | | |
| 1888 | 50 | 62 | 75 | 113 | 300 | 37 |
| 1915-23 | 53 | 50 | 62 | 85 | 250 | 41 |
| 1952 | 28 | 46 | 83 | 71 | 228 | 32 |
| 1964 | 12 | 30 | 74 | 63 | 179 | 23 |
| 1976 | 7 | 11 | 41 | 23 | 82 | 22 |
| | | | *Central Taiwan, China*[b] | | | |
| 1926-27 | 17 | 20 | 35 | 24 | 96 | 39 |
| 1961 | 37 | 29 | 42 | 30 | 138 | 48 |
| 1967 | 11 | 27 | 51 | 21 | 110 | 35 |
| 1972 | 10 | 19 | 39 | 16 | 84 | 35 |
| | | | Java, Indonesia[c] | | | |
| 1875-78 | 72 | 58 | 40 | 66 | 236 | 55 |
| 1924-30 | 33 | 28 | 54 | 75 | 190 | 32 |
| 1968-69 | 35 | 43 | 41 | 40 | 159 | 49 |
| 1977-80 | 23 | 42 | 36 | 43 | 144 | 45 |
| | | | *Laguna, Philippines*[d] | | | |
| 1965 | 19 | 11 | 20 | 36 | 86 | 35 |
| 1978 | 9 | 27 | 22 | 28 | 86 | 42 |

[a]From Ishikawa 1980. [b]From Tsai 1976. [c]From Collier et al 1981. [d]From Smith and Gascon 1979.

mechanized and nonmechanized farms in Central Taiwan are given in Table 5. Those two operations accounted for close to one-third of total costs (somewhat higher for nonmechanized than mechanized farms).

At current wage rates in South and Southeast Asia, labor input for weeding will continue to be high for some time to come.

## INSTITUTIONAL WEEDING ARRANGEMENTS

New technology and the labor market condition are two major determinants of labor input for weeding.

Increased fertilizer application and the use of young seedlings associated with the adoption of modern semidwarf cultivars increase the weed problem. The weed population grows in response to the high fertilizer application. It is difficult to control weeds by flooding fields because of the danger of drowning the short seedlings.

Thus the new technology increases the demand for weeding labor. In an economy where labor is scarce and the wage rate is high, however, the increased need for weed control induces the development of labor-saving technologies such as herbicides — examples are Japan since the 1950s and Taiwan since the 1960s. In contrast, in most areas of South and Southeast Asia where abundant labor supply has depressed farm

**Table 5. Percent of total input costs used in direct and indirect weeding for mechanized and nonmechanized farms, Central Taiwan, China, 1972.** [a]

| Farms (no.) | Farm size (ha) | Input cost (%) | | | |
|---|---|---|---|---|---|
| | | Land preparation | Weeding | Other preharvest tasks | Harvest |
| | | *Mechanized rice farms* | | | |
| 72 | <1 | 15 | 12 | 32 | 41 |
| 58 | 1-2 | 18 | 14 | 33 | 35 |
| | | *Nonmechanized rice farms* | | | |
| 14 | <1 | 16 | 21 | 34 | 29 |
| 12 | 1-2 | 18 | 16 | 29 | 37 |

[a] Source: Tsai 1976.

wage rates, labor input for weeding has increased sharply in response to the introduction of new technology; Laguna, Philippines, is an example.

Before the introduction of new cultivars and fertilizers, weed control in wetland rice in Southeast Asia was based mainly on the indirect method of puddling and flooding the fields before transplanting. Weeding at the plant-growth stage was not practiced intensively. Only a modest amount of weeding labor, if any, was met by family labor. With the new rice technology, it became necessary to apply a large amount of labor — above the family labor capacity — to complete weeding.

New institutional arrangements are required for hiring labor for weeding. This process of institutional change in response to technological change is illustrated by a new contractual arrangement for weeding in Laguna, Philippines.

The labor contract for harvesting once took the traditional form of community activity called *hunusan.* In the hunusan system all villagers may participate in harvesting (and threshing). They then share in a portion (typically one-sixth) of what they harvested. This system is common in Southeast Asia and reflects the traditional community principle of work and income sharing.

With the growing demand for weeding labor, the hunusan system has been replaced by the *gama* system. This is an output-sharing contract similar to hunusan, except that only the workers who weeded the field without pay may harvest the crop. The free weeding labor establishes the right of workers to participate in harvesting and receive one-sixth of the produce. In one village surveyed, the gama system began about 20 years ago and rapidly replaced the hunusan system within 10 years of the introduction of modern cultivars in the late 1960s.

The village that adopted the gama system was typical of irrigated rice areas in the Philippines. It was characterized by a rapid population growth combining a high natural reproduction rate with net immigration from depressed dryland areas (Kikuchi and Hayami 1980). Although the increase in the number of households paralleled the population growth, the number of landless-worker households increased much faster than farmer households. Landless-worker households increased from 30% in 1966 to 50% in 1976. The rapid growth in their number reflects the strong population pressure to cultivate the limited land area. As more and more landless workers have competed for employment, their wage rate has been held down despite significant progress in rice technology and yield increases.

When labor was scarce and rice yields were low, the traditional one-sixth share for harvesters would have been close to a market wage rate that could approximate the marginal product of harvest labor. The one-sixth of harvest should have become substantially larger than the prevailing wage rate, but as the yield level increased the increase in labor supply prevented the wage rate from rising.

It was in such a situation that the gama system was introduced as an institutional innovation to reduce the gap between the marginal labor productivity and the harvesters' share. We made an imputation of labor inputs applied to rice production under the gama system by using market wage rates; imputed wage costs were compared with the actual shares of gama harvesters (Table 6).

A major question is why gama was chosen to reduce the wage rate for harvesters. The wage rate can be reduced by reducing the share rate under the hunusan system or by hiring daily wage workers. The gama system has several advantages. First, an incentive for employees to do more conscientious weeding is built into the system in the form of output sharing. Second, the availability of labor for harvest is guaranteed to the farmer by contract. The landless laborers are more certain of finding employment in the narrow labor market. The most critical consideration in the choice of the gama system is that it is more congruent with the traditional hunusan system of mutual help and income sharing.

Farmers using gama in Laguna increased from 33% in 1970 to 85% in 1975 (Barker and Cordova 1978). Gama has been practiced in other areas of the Philip-

**Table 6. Imputed value of harvesters' share and the imputed cost of gama labor in a village in laguna, Philippines.[a]**

| | Imputed value | |
|---|---|---|
| | Based on employers' data | Based on employees' data |
| Gama labor days[b] (no./ha) | | |
| Weeding | 20.9 | 18.3 |
| Harvesting-threshing | 33.6 | 33.6 |
| Imputed cost of gama labor[c] (US$/ha) | | |
| Weeding | 22.30 | 19.52 |
| Harvesting-threshing | 49.28 | 49.28 |
| (1) Total | 71.58 | 68.80 |
| Actual share of harvesters | | |
| In kind[d] (kg/ha) | 67.20 | 73.20 |
| (2) Imputed value[e] (US$/ha) | 67.20 | 73.20 |
| (2) - (1) | -4.38 | 4.40 |

[a]Source: Kikuchi and Hayami (1980). [b]Includes labor of family members who worked as gama laborers. [c]Imputation using market wage rates (daily wage = $1.06 for weeding; $1.46 for harvesting). [d]One-sixth of output/ha. [e]Imputation using market prices (1 kg = $0.13).

pines (Kikuchi and Hayami 1980, Ledesma 1980) and a similar system operates in Indonesia (Kikuchi et al 1980).

The gama system illustrates how growing population pressure and the introduction of new rice technology have resulted in a new contractual arrangement for hiring labor for weeding in a form consistent with the institutional environments or rural communities in Asia.

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## DISCUSSION

HUEY: In the data given for the Philippines in Table 4, when you add the labor in land preparation and weeding, there is little difference in the total amount. (1) Was this simply a seasonal variation? (2) Why were only two years compared?

*BARKER:* (1) No, this is not just a seasonal variation. (2) There are additional data for 1970 and 1975. They simply confirm that there has been a downward trend in labor used for land preparation in Laguna due to the introduction of the power tiller and at the same time an upward trend in labor for weeding.

DE DATTA: In Table 4, why did harvesting labor in Java decrease from 66 man days/ ha in 1975 to 43 man days in 1977? I would have expected an increase.

*BARKER:* I'm not exactly certain. However, there was a trend away from the ani-ani knife to the sickle. This would in part explain those figures.

MOODY: Has the introduction of the gama system resulted in poorer weed control — weeders doing many fields poorly in contrast to doing a few fields well?

*BARKER:* Because the gama worker receives a share of the harvest, he is normally eager to do a good job of weeding. If he does a poor job, the farm operator can replace him next season. Recently, however, as off-farm job opportunities have increased in Laguna, gama workers have paid less attention to their plots. With the rise in wage rates, there now seems to be a trend developing to eliminate the gama system and substitute herbicides for hand weeding in this region.

VEGA: I understand that none of the gama workers use herbicides. Is that correct?

*BARKER:* Recently, farmers have complained that gama workers are not doing as intensive weeding as they like. Therefore, some farmers have started to use herbicides in addition to gama labor.

GREENLAND (1) In relation to the large differences in labor inputs in Table 4, one of the factors related to this is the difference in the average farm size. If comparisons are made on an equal basis, are the large differences still there or do they start to disappear? (2) The average farm size in the Philippines was given in Table 2 as 3.6 ha. That seems to be rather large.

*BARKER:* (1)I don't know how much of this would disappear. Under conditions of larger farm size, you might even justify a lower intensity not only of labor input but other things as well and a lower yield. This is one of the things that is difficult to explain to people who think only in terms of yield. You are better off being a Thai farmer with 2 ti ha and 5 ha than a Java farmer with 4–5 t/ha and 0.5 ha. The lack of intensity in the Philippines is due to the general lack of land pressure relative to these other areas. (2) This is rather large. It should be more like 2.5 ha.

SOONG: Who pays for the herbicides, the land owner or the worker who will get one-sixth of the harvest?

*BARKER:* The farm operator.

DE DATTA: (I) How extensive is the gama system in the Philippines? (2) You haven't said anything about intensity of weed control as affected by the price of rice. If the price of rice is high enough, the intensity will go up irrespective of the farm size.

*BARKER:* (1) The gama system is not widespread in the Philippines. It is common in Laguna province, but in Central Luzon it is seldom used. The reason for this is the difference in the land tenure system. (2) This is characteristic of what you see in a place like Japan where the price of rice is three times the world market price. You can afford to do anything. Not only is the level of mechanization high, but the level of herbicide use as well.

# EFFECTS OF HYDROLOGY, SOIL MOISTURE REGIME, AND FERTILITY MANAGEMENT ON WEED POPULATIONS AND THEIR CONTROL IN RICE

V. M. Bhan

The degree of crop-weed competition vanes with the type of rice culture, planting method, and cultural practices. Competition is severe in direct sown rice where weed dry matter exceeds that of the crop. In transplanted rice, weed emergence and growth generally remain less than that of the crop, although competition continues up to 60 days after transplanting. The water requirement of direct sown rice is met by frequent rains and seedbeds generally retain moisture near field capacity, a condition that favors weed growth. Weed emergence and growth reduce with increased submergence up to 15 cm. Deepwater and floating rice face weed competition early in the season until increased water level kills most weeds. Herbicide efficiency increases with moisture. Butachlor, fluchloralin, nitrofen, thiobencarb, and oxadiazon effectively control weeds in transplanted rice. Herbicides used under high fertility levels reduce the dry matter accumulation of weeds.

Weeds with direct-seeded rice in dry seedbeds cause grain yield losses of 10-70% depending on weed density and species. Maximum weed competition is during the early stages of crop growth. Direct-seeded rice is grown in dryland and flood-prone areas in northeast India, Bangladesh, Burma, Sri Lanka, and Indonesia. The water

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requirement is met by the frequent rains the crop receives during the growing season. Generally the soil moisture is maintained at field capacity to saturation. When there is a lack of natural precipitation the moisture content may go below field capacity. With excess rainfall, especially in flood-prone areas, the land may remain flooded and wetland to deepwater conditions develop late in the season. Major weeds germinate with the germinating crop seedlings and grow along with them. The results are severe crop-weed competition during the early stages of crop growth and reduced grain yield. Weed flora observed with various types of rice cultivation are given in Table 1.

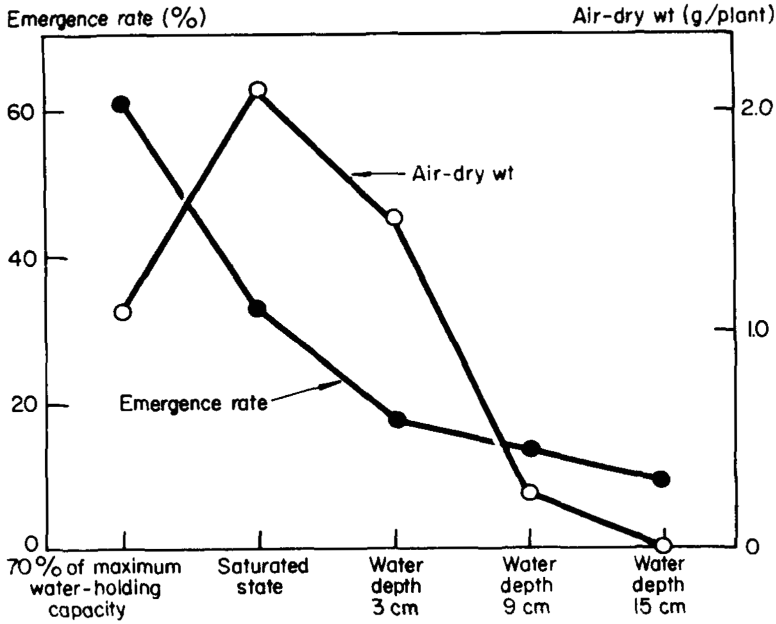
In areas where rainfall is high or where sufficient water is available, rice is grown in puddled soil. The moisture content ranges from saturation to various degrees of submergence. Rice is either direct-seeded or transplanted. Annual grasses, broadleaf weeds, and sedges compete severely with the crop, reducing grain yield from 10 to 50% depending on weed species and population. *Echinochloa crus-galli,* a hygrophytic weed, emerges and grows best at soil moisture of 80% of the water-holding capacity. Emergence and growth become increasingly poor with increased depth of submergence (Arai et a1 1954); when water depth reaches 10-15 cm, *E. crus-galli* stops growing and most of the plants die (Fig. 1).

Weed control is most critical and difficult in rice grown from pregerminated seed broadcast in puddled fields (De Datta 1980). The practice is followed in Sri Lanka, northeast India, and parts of Bangladesh and the Philippines. Mechanical and hand weeding cannot be done in broadcast rice because of possible damage to rice plants and the difficulty of differentiating grassy weeds from rice at early growth stages.

Deepwater and floating rice are sown in dry seedbeds and later flooded. The rice generally grows for 4 to 6 weeks under nonflooded conditions. That causes severe

**Table 1. Major weeds of different rice cultures.**

| Rice culture | Major weeds |
|---|---|
| Drilled rice | *Ammannia coccinea, Celosia argentea, Commelina benghalensis, Cyanotis axillaris, Cynodon dactylon, Cyperus diffusus, C. iria, C. rotundus, Digitaria sanguinalis, Echinochloa colona, E. crus-galli, Eclipta prostrata, Eleusine indica, Ischaemum rugosum, Panicum repens, Paspalum paspalodes, Phyllanthus niruri, Physalis minima, Portulaca oleracea* (Pantnagar, Hissar IRRI, Cuba) |
| Transplanted rice | *Ammannia multiflora, Brachiaria ramosa, Commelina benghalensis, Corchorus aestuans, Cyperus compressus, C. difformis, C. iria, C. rotundus, Digitaria spp., Echinochloa colona, E. crus-galli, Eclipta prostrata, Eragrostis japonica, Fimbristylis littoralis, Ipomoea triloba, Jussiaea spp., Lindernia anagallis, L. crustacea, Monochoria vaginalis, Oryza sativa (red rice), Panicum spp., Paspalum paspalodes, Phyllanthus niruri, Sesbania exaltata* (Pantnagar, Hissar Ludhiana, IRRI, Cuba) |
| Deepwater and floating rice | *Aeschynomene aspera, Echinochloa stagnina, E. picta, Eichhornia crassipes, Ischaemum rugosum, Leptochloa chinensis, L. panicea, Melochia corchorifolia, Nymphea stillata, Pentapetes phoenicia* |
| Perennial weeds | *Cyperus rotundus, Imperata cylindrica, Paspalum paspalodes, Scuirpus maritimus* |




**1.** Relation between water depth and emergence and growth of *Echinochloa crus-galli,*

competition from weeds that emerge with crop seedlings. About 11% of the world's rice areas is grown to deepwater rice and 4% to floating rice (De Datta 1980). Thailand, Bangladesh, and small areas of northeast India grow these rices. The weed spectrum consists of annual grasses and broadleaf weeds (Table 1).

## HYDROLOGY OF DIFFERENT RICE CULTURES

The hydrology of rice cultures vanes widely. It is extremely difficult to get hydrology data on weeds; however, I will attempt to give a general behavior pattern of hydrology of rice and weeds.

Direct-seeded rice under dryland conditions is planted in a dry seedbed as any other dryland crop. The crop and weed seeds germinate and grow together, with water requirements being supplied by frequent rains during the growing season. Seedbeds generally do not retain moisture that is more than field capacity to saturation. This environment seems ideal for weed germination and growth. Suzuki et a1 (1975) report highest weed populations at soil moisture content of 90% and lowest populations below 70% moisture content. *Digitaria ciliaris* and *E. crus-galli* were predominant weeds. Optimum temperature and sufficient aeration are the chief factors that encourage the germination and growth of weeds.

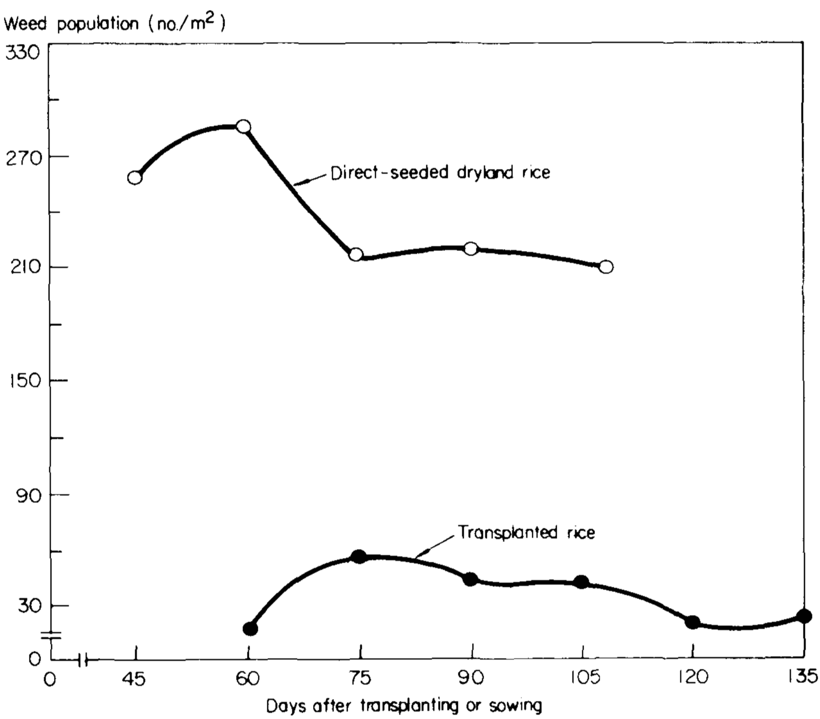
Where rainfall exceeds 50 cm or where irrigation is available, rice is cultivated in puddled fields. Such areas often have a high water table that reduces the downward movement of water. Generally, fields are kept submerged, and farmers maintain soil moisture regimes from saturation to submergence up to 10 cm deep. The exposure of the soil surface to air, especially immediately after transplanting, induces weed germination and growth. In eastern India and in the coastal belt of peninsular India, rainfall exceeds 100 cm and rice is grown at various water depths. In many East and Southeast Asian countries rice is grown on terraces from which excess water is drained and higher rice yields are obtained.

Poor drainage affects rice and weed growth adversely. Smith and Fox (1973) observed that flooding controlled *Oryza sativa, E. crus-galli, Brachiaria platyphylla,*

**Table 2. Effect of submergence on the dry matter production of total weed species.**

| Water management regime | Dry matter[a] ($g/m^2$) | |
|---|---|---|
| | Pantnagar | Kaul |
| Field capacity, 5 cm submergence | 251 | – |
| Saturation to 5 cm submergence | 206 | 119 |
| 5-10 cm submergence | 167 | 83 |
| 10-15 cm submergence | – | 44 |

[a]Dash = no data.



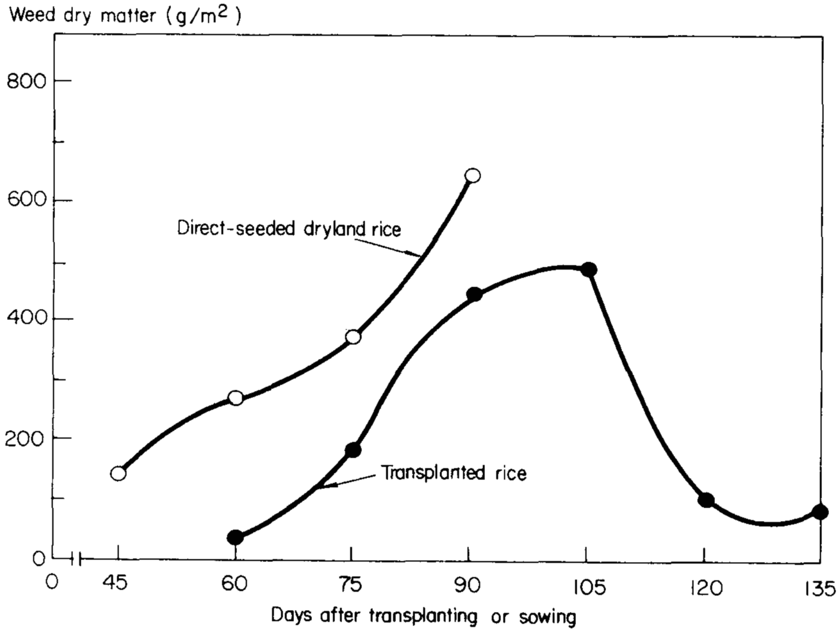

**2.** Weed populations in direct-seeded and transplanted rice at successive stages of crop growth.

*Aeschynomene virginica,* and *Sesbania exaltata,* and also reduced the emergence and growth of dry sown rice. The reduced oxygen level near the upper layer of submerged soil accounts for the poor germination of annual weeds.

Deepwater and floating rices are sown in dry seedbeds and grown from 4 to 6 weeks with little water. When heavy rainfall begins, low-lying areas are flooded and rice plants and weeds grow as the water level rises. Where flooding is frequent, aquatic weeds establish themselves and multiply. If flooding is delayed, weeds become severe and total crop failure may result.

## INFLUENCE OF WATER REGIME ON WEED GROWTH AND CONTROL

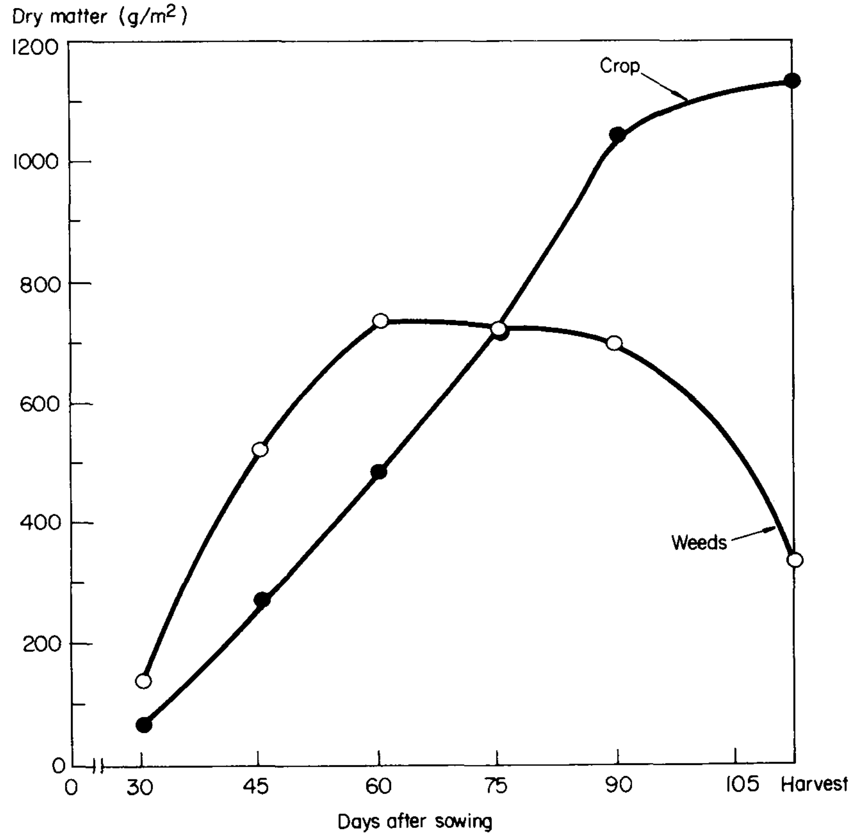
Appropriate water management is singularly important for controlling weeds in different rice cultures. Total weed populations were higher in dryland than in irrigated fields (Suzuki et al 1975). Yamamoto and Ohaba (1976) reported that optimum soil moisture values for the emergence of 12 weed species ranged from 70 to 85% of the maximum water-holding capacity. The effect of submergence depth (0 to 15 cm) on weed occurrence in transplanted rice was measured by Park et al (1973). The major broadleaf weed *Rotala indica* increased in number and weight with water depths up to 9 cm. *E. crus-galli* numbers and weight decreased sharply as the depth increased from 0 to 5 cm. The decrease was more gradual as depth increased from 5 to 15 cm. Chauhan (1978) and Singh (1980) also reported significant decreases in the growth of weeds as submergence level increased up to 15 cm (Table 2).



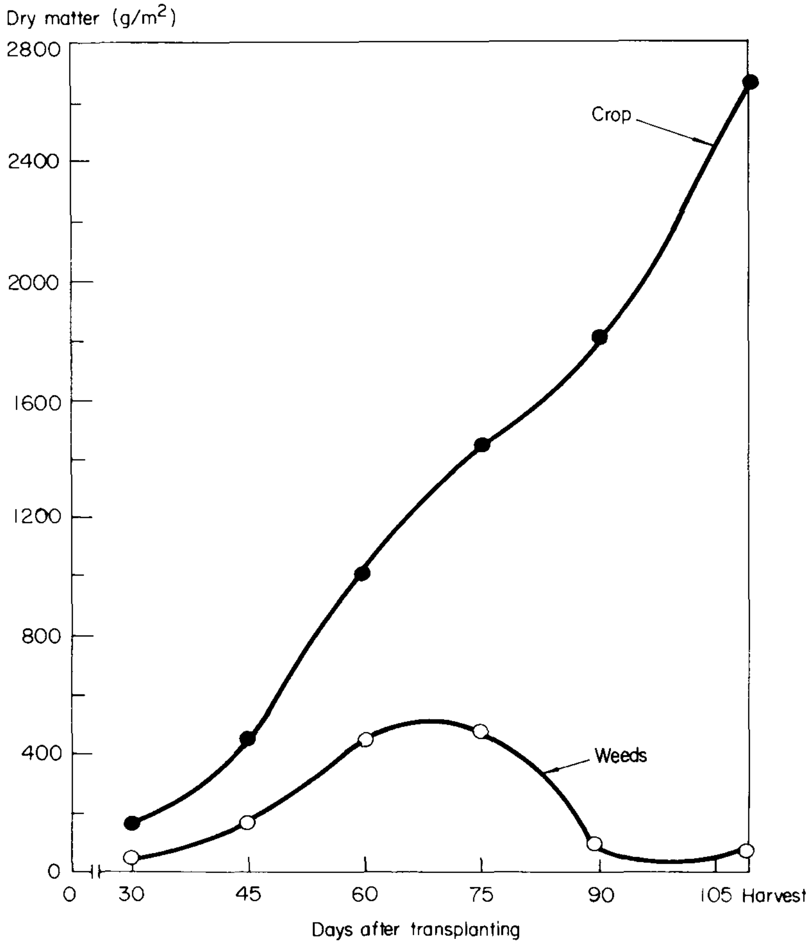

**3.** Dry matter production of total weed species in direct-seeded and transplanted rice at successive stages of crop growth.

Population and dry matter of weeds per unit area were markedly higher in direct-seeded rice than in transplanted rice (Fig. 2 and 3). Competition was severe in direct-seeded rice where weed dry matter remained higher than that of the crop for up to 60 days (Fig. 4). In transplanted rice (Fig. 5) weed growth generally remained less than that of the crop although competition continued up to 60 days after transplanting (DT).

Weed control in direct-seeded rice has not been achieved. Periodical manual weedings done at the right time may reduce weed competition. Herbicides have been found effective but, because of their risks, are unacceptable to farmers. Schiller and Indhaphun (1979) reported excellent control of grass weeds with preemergence application of butachlor at 2.1 kg/ha. The efficiency of the herbicide was dependent on soil moisture conditions. Its effect was markedly reduced under dry conditions. It was not effective when applied postemergence to weeds beyond the 2- to 3-leaf stage. Reddi and Hukkeri (1979) observed remarkable reductions in weed infestation when fields were puddled twice at 15-day intervals. Puddling enhanced crop growth yield and water use efficiency in direct-seeded irrigated rice.




**4.** Dry matter production of crop and weeds in direct-seeded dryland rice. Hissar, India, 1980.




**5.** Dry matter production of crop and weeds in transplanted rice. Pantnagar, India, 1978.

Annual weeds in transplanted rice have been controlled in northwest India by butachlor, fluchloralin, nitrofen, thiobencarb, and oxadiazon (Katyal and Bhan 1981). Effects of herbicides on grain yield of rice in farmers' fields are given in Table 3. Butachlor at 1 kg/ha + 2,4-D butyl ester at 0.5 kg/ha applied 4 DT provided broad-spectrum weed control regardless of water depth (Jana 1974). Akobundu (1978) observed best control of *Cyperus* spp. with cyperquat applied postemergence at 3 kg/ha. Ahmad et al (1975) reported increased herbicidal efficiency with continuous flooding 5 cm deep for the first 10 days after treatment in Pakistan. They obtained maximum rice yield using TCE-styrene at 0.75 kg/ha + 2,4-D IPE at 0.5 kg/ha applied 10 DT. Bentazon was effective when applied on foliage and to floodwater. Its activity against *Cyperus serotinus* and *Sagittaria pygmaea* was very low in dry soil, but increased with moisture content to a maximum with slight flooding (Mine et al 1974).

At the International Rice Research Institute, effective control of weeds in rice was achieved using butachlor, thiobencarb, propanil, 2,4-D, and propanil + fenoprop at all water regimes, but 2,4-D mixed with either amiprofos-methyl or thiobencarb applied 6 days after seeding gave better weed control when soil was wet during early growth stages. Rotary weeding gave poor control (IRRI 1972, 1977, 1978).

## INFLUENCE OF FERTILITY MANAGEMENT

Yield reductions due to weeds result mainly from competition for nutrients, especially during the early growth stages (Pande and Bhan 1966, Smith 1968, Shetty and Gill 1974). Guh (1974) observed that annual broadleaf weeds such as *Monochoria vaginalis* are dominant in highly fertile soil; perennial weeds such *Eleocharis kuroguwai* are dominant on low fertility soils. Legume weeds dominated plots fertilized with nonnitrogenous manures (Ueda et al 1977). In plots fertilized with nonphosphorus manures, only weeds such as *Lapsana apogonoides, Scirpus juncoides,* and *Fimbristylis littoralis* grew.

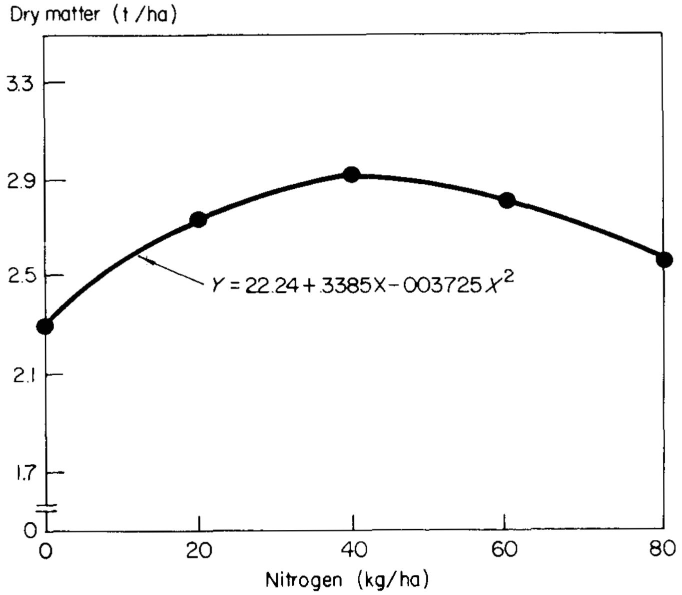
Weed infestation affects the nitrogen response of modem rice cultivars. Nitrogen responses of IR20 were greater with weed control than without it (De Datta and Malabuyoc 1976). In a study of the effect of fertilization on the growth of upland weeds, Noguchi and Nakayama (1978) observed that the relative growth rate of all weeds exceeded that of rice for the first 70 days on fertilized plots. Lack of fertilizer delayed heading and flowering, especially of *Amaranthus lividus.* Pande and Bhan (1966) found a quadratic relation between the increase of weed dry matter and the increase of nitrogen fertilizer level up to 50 kg N/ ha (Fig. 6). Increased nitrogen level suppressed weed emergence, but increased dry matter accumulation (Kakati and Mani 1977).

Butachlor and propanil reduced weed dry matter accumulation from 170 $g/m^2$

**Table 3. Effect of herbicides on grain yield of rice in transplanted paddy in farmers' fields.[a]**

| Treatment | Formulation[b] | Active ingredient (kg/ha) | Yield[c] (t/ha) | | | |
|---|---|---|---|---|---|---|
| | | | Kurukshetra | Karnal | Ambala | Hissar |
| Oxadiazon | EC | 0.60 | – | – | – | 6.4 |
| Butachlor | EC | 1.50 | 2.8 | – | – | 7.7 |
| Pendimethalin | EC | 1.50 | – | 2.3 | 3.5 | 8.5 |
| Butachlor | G | 1.50 | – | 2.5 | 3.4 | 8.1 |
| Thiobencarb | G | 2.00 | – | 2.3 | – | 6.7 |
| Pendimethalin | G | 1.50 | – | 2.2 | 3.5 | 7.8 |
| Thiobencarb | EC | 2.00 | 2.9 | 2.3 | 3.6 | 7.3 |
| Fluchloralin | G | 0.75 | 2.7 | 2.0 | 3.3 | 7.7 |
| Oxadiazon | 12 L | 0.60 | 2.4 | 2.2 | 3.5 | 5.8 |
| Farmers' weed control method | | | 3.0 | 1.7 | 3.0 | 5.5 |
| Oxyfluorfen | G | 0.20 | 3.0 | – | 3.4 | – |

[a]At Hissar, Jaya cultivar was grown; at other sites, local scented cultivars. [b]EC = emulsifiable concentrate, G = granule, 12 L = shaker bottle application. [c]Dash = no data.




**6.** Effect of various levels of nitrogen on dry matter production of weeds in dryland rice.

(weedy control) to 19 g/m$^2$ in direct-seeded rice. In transplanted rice, weed dry matter accumulation was reduced from 23.8 g/m$^2$ (weedy control) to 4.6 g/m$^2$. In a study of the relative efficiency of herbicides under graded nitrogen levels in rice, Narayanaswamy and Sankaran (1977) observed a linear response to nitrogen at application rates of 0, 60, 120, and 180 kg N/ha. Pendirnethalin gave 75% control of weeds and the highest grain yields of 5.7 t/ha in summer and 5.0 t/ha in kharif.

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# EFFECTS OF STAND ESTABLISHMENT TECHNIQUES ON WEED POPULATION IN RICE

P. A. Sarkar and K. Moody

The effects of stand establishment techniques on weed populations in different types of rice culture as well as time, method, and depth of land preparation are discussed. The use of the stale-seedbed technique and blind cultivation and the problems associated with them are evaluated. Reduced tillage systems are dealt with in detail. The effects of the cultivar grown, seedling age, and plant spacing on weed growth and yield losses due to weeds are also discussed.

Land preparation is an extremely important weed control practice that is frequently overlooked. Throughout the tropics, farmers often plant fields that have been hurriedly and poorly prepared. The method of land preparation and the equipment used vary depending on the system of rice culture, but the overall objectives are the same. The first and primary reason for land preparation is to provide weed-free conditions at planting, and the second is to provide favorable conditions for the growth and development of the crop.

Barker (1970) reported that the number of weeds in transplanted rice declined as the number of preplanting harrowings increased. More weeds were found in land prepared with one pass of a harrow pulled by a hand tractor than with two passes; more weeds were present after three passes of an animal-drawn harrow than after six passes (Fig. 1).

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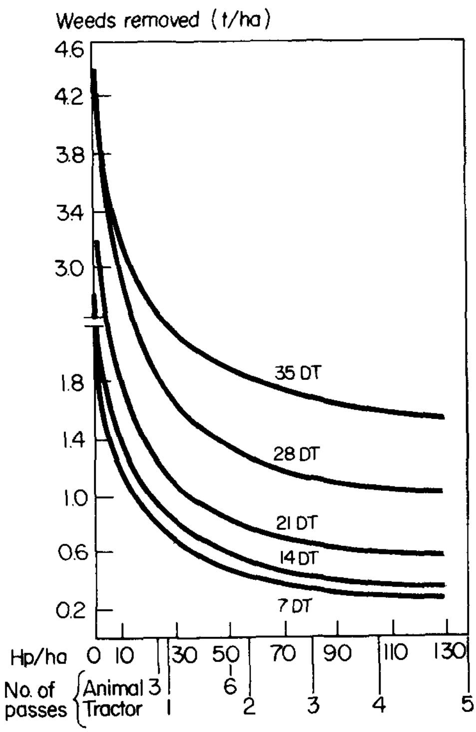
The time between operations and the number of operations can be reduced substantially with postplanting weed control. However, the degree of weed control will be less and the time spent weeding will be longer as the degree of land preparation decreases and the interval between successive tillage operations is decreased (Moody 1977c). At IRRI (1977), weed weights were lowest when the time interval between land preparation operations was 3 days compared to the shortest time possible.

Others have reported that the number of harrowings (IRRI 1977, Kim 1979) and the time between plowing and harrowing (IRRI 1979) did not affect the number or weight of weeds growing in the subsequent crop. Kim (1979) stated that for reducing weed weight, the time of the final harrowing was more critical than the number of harrowings.

In dryland rice, Vargas (1978) reported that weed growth decreased as the number of rototillings following plowing increased from one to two. Additional research (IRRI 1978) failed to substantiate these findings. There were no significant differences in weed populations, weed biomasses, the time required for weeding, or the grain yield between land preparation methods.

For dry-seeded wetland rice and for wet-seeded rice, weed growth did not decrease as the number of rototillings or harrowings increased from one to three (Vargas 1978).




**1.** Relationship between weeds removed at weeding time and horsepower per hectare for harrowing (av of 2 cultivars: IR8 and H4). IRRI, 1967 dry season. Adapted from Barker (1970). DT = days after transplanting.

## TIME OF LAND PREPARATION

There may be advantages to plowing immediately after the rice crop is harvested rather than at the beginning of the next rainy season. Plowing after the previous rice crops is only possible if the vegetative cycle of the rice crop is shorter than the rainy season or if sufficient residual moisture remains so that the soil is still moist when plowed (Moody 1979b). Moody (1980) stated that land preparation during the dry season was of only limited usage in reducing weed problems in the following rice crop.

Partohardjono and Harahap (1979) reported that in Indonesia tillage is done in the dry season to control weeds. In areas where drought-tolerant crops are grown during the dry season, weed infestations are reduced.

Moody (1980) reported that there were four to six times as many grasses, primarily *Echinochloa colona,* in land that had previously been maintained as a weed-free fallow than in land that had been maintained as a weedy fallow. Where there was less *E. colona,* yields in the unweeded check plot were higher and herbicide performance was superior. In another trial, land preparation during the dry season led to a significant reduction in the number of *Cyperus rotundus* but had no effect on the grass population (Moody 1980).

Castin and Moody (1981) reported that more time was required for hand weeding in plots that were harrowed weekly in the dry season than in those that were maintained as a weedy fallow. A change in the weed flora was also observed (Table 1). As the degree of land preparation increased, the degree of weed control achieved with herbicides also increased.

Curfs (1976) observed that, although there was a marked change in the weed flora between (a) plots that had been plowed at the end of the wet season and (b) those that were left undisturbed during the dry season and not plowed until the following wet season, the amount of weeds was not reduced.

Janiya and Moody (1979) reported that there was a significant reduction in weed weight 45 days after emergence but not at harvest as a result of land preparation

**Table 1. Relative dry weight of weed species in the unweeded plots 40 days after emergence as affected by method of land preparation. IRRI, 1980 wet season.[a]**

| Weed species | Relative dry wt[b] | | |
|---|---|---|---|
| | None | 1 plowing + 1 rototilling | 1 plowing + 1 rototilling + weekly harrowing |
| *Ipomoea triloba* | 27.7 | 25.4 | 53.5 |
| *Paspalum paspalodes* | 26.7 | 14.6 | 5.6 |
| *Ipomoea aquatica* | 20.3 | 0.0 | 0.0 |
| *Echinochloa glabrescens* | 16.3 | 12.9 | 17.9 |
| *E. colona* | 2.1 | 31.3 | 1.1 |
| Others | 6.9 | 15.8 | 21.9 |
| Total weed wt (g/m$^2$) | 112.6 | 181.6 | 139.8 |

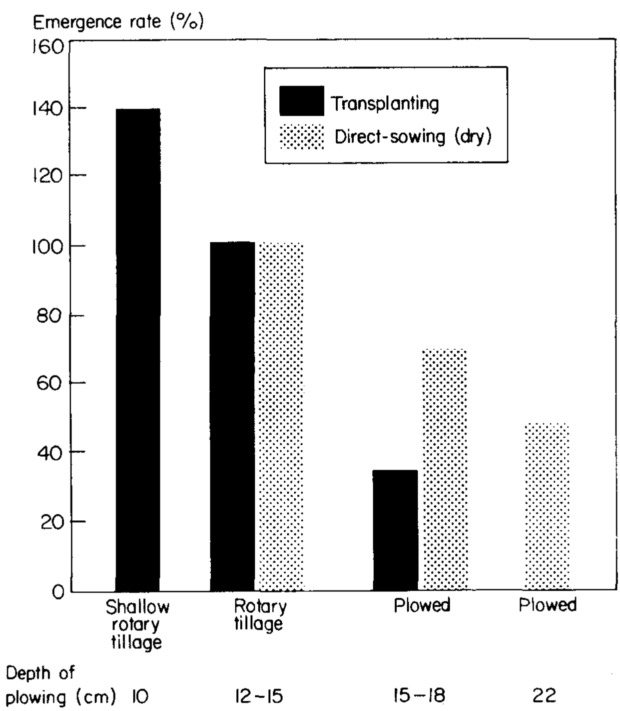
[a]From Castin and Moody (1981). [b]Av of 3 replications.

during the dry season compared to land preparation at the start of the rainy season. *Celosia argentea* was the dominant weed when the land was prepared during the dry season, while *Rottboellia exaltata* and *Digitaria* sp. dominated when land preparation was done at the start of the rains. Superior weed control was achieved with herbicides when the land was prepared during the dry season.

Castin and Moody (1980) reported that time of land preparation had no effect on total weed weight. However, *C. rotundus* increased in importance when land preparation was started closer to the start of the rainy season, while *Digitaria* sp. and *Eleusine indica* decreased in importance. Weed control with herbicides was better when the land was prepared earlier.

## DEPTH OF PLOWING

Arai and Matsunaka (1968) reported that the emergence of *Echinochloa crus-galli* in transplanted rice was reduced greatly when the field was plowed to a depth of 15-18 cm compared to a shallow rotary tillage of 10 cm or a rotary tillage of 12-15 cm (Fig. 2). Kim et a1 (1975) reported a decline in the total number of weeds (both annuals and perennials) as the plowing depth increased. In Japan, plowing to a depth of 15 cm in December resulted in better control of *Sagittaria pygmaea, Cyperus monti,* and *Eleocharis kuroguwai* than rotary tillage to a depth of 10 cm or zero tillage (Kusanagi 1977).




**2.** Effect of tillage on the emergence of *Echinochloa crus-galli* seedlings (from Arai and Matsunaka 1968).

Curfs (1976) reported that weed growth 3 and 6 weeks after planting dryland rice was least after deep plowing and greatest following zero tillage. Seguy (1970 as cited in Curfs 1976) observed that deep plowing resulted in the most efficient weed control.

## PUDDLING

Although time, degree, and method of tillage can affect weed growth to a certain extent, the most important effect comes from puddling and good water control. Puddling results in fewer weed species (Ahmed and Moody 1978), fewer weeds (Table 2) (Curfs 1976, Moody 1977a), and a higher proportion of broadleaf weeds in the weed flora (Moody 1977a, b) than under dryland conditions.

## STALE SEEDBED

It may be possible to reduce weeds in dry-seeded rice by using the stale-seedbed technique. After land preparation, weeds which emerge following rain or irrigation are destroyed by chemical, mechanical, or manual methods. Chemical methods have the advantage of not bringing more weed seeds to the soil surface where conditions are more favorable for germination. If mechanical or manual methods are used to destroy the weeds, the soil disturbance should be as shallow as possible.

Germination of most of the germinable weed seeds is essential to the success of the stale-seedbed technique (Moody 1980). The herbicides should be applied or cultivation should be done when most of the weed seeds in the surface soil have germinated and have reached the two- to five-leaf stage.

In a trial conducted in Pangasinan Province, Philippines, use of the stale-seedbed technique reduced the weight of *E. colona* by 78%. Superior weed control with butachlor was obtained and less time was required to hand weed the stale-seedbed plots (Moody 1980).

At IRRI, Castin and Moody (1981) reported significantly lower weed weight and a change in the weed flora from using the stale-seedbed technique compared to conventional and zero tillage. *Paspalum* sp. and *Ipomoea triloba* decreased in importance, whereas *Commelina diffusa, C. rotundus,* and *Ludwigia octovalvis* increased in importance. Weed control with herbicides and yields were superior in the stale-seedbed plots (Table 3).

**Table 2. Effect of different methods of land preparation on weeds growing in association with rice 4 weeks after planting.**[a]

| Method of land preparation | Type of rice culture | Composition of the weed flora (%) | | | Weed wt (kg/ha) |
|---|---|---|---|---|---|
| | | Broadleaf weeds | Grasses | Sedges | |
| Puddled | Wet-seeded | 57 | 35 | 8 | 72 |
| Puddled | Transplanted | 83 | 7 | 10 | 106 |
| Dry | Dryland | 39 | 56 | 5 | 1519 |
| Dry | Dry-seeded wetland | 33 | 64 | 3 | 1582 |

[a] From Moody (1977a).

**Table 3. Grain yield of dry-seeded wetland IR50 as affected by land preparation methods and weed control treatments. IRRI, 1980 wet season.[a]**

| Land preparation method | Grain yield[b] (t/ha) | | | | |
|---|---|---|---|---|---|
| | Unweeded | Butachlor fb 2,4-D | Thiobencarb fb 2,4-D | Pendimethalin fb 2,4-D | 2 hand weedings (14 & 35 WE)[c] |
| Zero tillage | 0 a | 0 b | 0 b | 0.8 b | 3.5 a |
| 1 plowing fb 1 harrowing | 0 a | 0 b | 0 b | 1.1 b | 2.0 b |
| 2 plowings fb 2 harrowings | 0 a | 0.5 b | 0.8 b | 0.9 b | 3.2 ab |
| Stale-seedbed (harrow) | 0 a | 1.9 a | 2.7 a | 2.9 a | 2.9 ab |
| Stale-seedbed (paraquat) | 0.5 a | 2.5 a | 3.5 a | 2.6 a | 2.1 ab |

[a]From Castin and Moody (1981). [b]In a column, means followed by a common letter are not significantly different at the 5% level. fb = followed by. [c]WE = weeks after emergence.

## REDUCED TILLAGE SYSTEMS

Minimum and zero-tillage techniques have resulted in considerable savings in time, labor, water, power, and capital without loss in rice yields under widely varying ecological conditions (Mittra and Pieris 1968, Novero 1968, Elias 1969, Seth et al 1971, Croon 1978). In other instances, especially where perennial weeds were present, weed growth was greater and yields were lower with reduced tillage than with conventional tillage (De Datta et al 1979). Thus, reduced tillage techniques may be limited to areas where perennial weeds are not present (Moody and De Datta 1980).

In Malaysia, Seth et al (1971) observed that the incidence of weeds in the crop was generally less following minimum tillage than after conventional tillage. In the absence of perennial weeds, a similar trend was noted with zero tillage. However, where perennial grasses were present, continued use of zero tillage resulted in rapid regeneration and an increased incidence of these weeds.

Mittra and Pieris (1968) noted that where perennial grasses were present a sequential treatment of dalapon followed by paraquat was superior for weed control than paraquat alone in the absence of cultivation, but when one cultivation was carried out after spraying, control given by paraquat alone was as good as that given by dalapon followed by paraquat. However, De Datta et al (1979) showed that a preplanting treatment of dalapon followed by paraquat failed to give satisfactory perennial weed control, and yields were significantly lower than those from the conventionally tilled plots.

Elias (1969) noted that after several seasons of minimum tillage, no major problems had arisen. However, De Datta et al (1979) reported that after two crops without tillage, perennial weeds became dominant because of ineffective control by the dalapon-paraquat preplanting treatment. For the third crop, the plots were thoroughly tilled prior to planting. Before planting the fourth crop, *Paspalum puspalodes* and other weeds were virtually absent (Table 4). In the fifth and succeeding crops, as tillage was reduced from conventional to zero, weed weight increased and the perennials became more dominant in the weed flora. Due to the inability of the minimum- and zero-tillage techniques to control perennial weeds, the minimum- and zero-tillage plots were thoroughly cultivated prior to the eighth and eleventh crops. The virtual absence of weeds in these crops was mainly due to the recultivation which completely controlled the perennial weeds (Moody and De Datta 1980).

Beyond two successive crops, yields decreased progressively as the level of tillage was reduced. In areas heavily infested with *P. paspalodes,* minimum tillage may not be feasible for more than two successive crops, and zero tillage for more than one crop, if satisfactory grain yields are to be maintained on a continuous basis (Bernasor and De Datta 1981).

In the absence of perennial grasses, land preparation may also be replaced by chemicals in wet-seeded rice (Moomaw et al 1968).

In Taiwan, Chiu and Lin (1977) reported that zero tillage could be substituted for the traditional tillage operations in both transplanted and wet-seeded rice. However, the yield with zero tillage was only 60-80% and the net profit only 50-70% of that obtained with traditional tillage operations. They concluded that, given the present circumstances, zero tillage cannot be recommended as a substitute for traditional land preparation methods.

In a reduced tillage experiment conducted over three seasons, Cheong (1978) recorded the highest weed weights in the zero tillage plots where chemicals were applied for preplant weed control. The lowest weed weights were recorded where the preplant weeding operation consisted of a herbicide application combined with two

**Table 4. Average weed dry weights at tillering (30 days after planting) and grain yield with conventional, minimum, and zero tillage in 4 consecutive rice crops.** [a]

| | Weed dry wt ($g/m^2$) | | | Yield (t/ha) |
|---|---|---|---|---|
| | Annuals | *Scirpus matimus* | *Paspalum paspalodes* | |
| | | *First crop* | | |
| Conventional tillage | 13 a | 10 a | 2 a | 5.0 a |
| Minimum tillage | 5 a | 9 a | 45 b | 4.6 b |
| Zero tillage | 18 a | 16 a | 125 c | 3.6 c |
| | | *Second crop* | | |
| Conventional tillage | 2 a | 19 a | 0 a | 2.7 a |
| Minimum tillage | 11 b | 16 a | 2 a | 2.5 a |
| Zero tillage | 0 a | 40 b | 60 b | 0.7 b |
| | | *Third crop* | | |
| Conventional tillage | 6 a | 16 a | 1 a | 3.1 a |
| Minimum tillage | 2 a | 21 a | 2 a | 3.0 a |
| Zero tillage | 3 a | 21 a | 7 b | 3.2 a |
| | | *Fourth crop* | | |
| Conventional tillage | 1 a | 6 a | 1 a | 3.4 a |
| Minimum tillage | 0 a | 1 a | 1 a | 3.7 a |
| Zero tillage | 3 a | 4 a | 1 a | 3.5 a |

[a] From De Datta et al(1979). In a column within each crop, means followed by a common letter are not significantly different at the 5% level.

rototillings. A single rototilling reduced the weed weight considerably compared to the zero-tillage plots that had chemical applied. A general decline in yield was observed over the three seasons, with the greatest yield reduction being observed in the zero-tillage plots.

Failures to establish and control weeds successfully in dryland rice grown under zero tillage in Nigeria and the Philippines have been reported by Moody and Mukhopadhyay (1980). Lacsina (1980) reported that rice crops in reduced-tillage plots that were treated with a herbicide failed to produce any grain because of heavy weed infestation, whereas conventionally tilled plots that were hand weeded twice yielded between 1.0 and 2.4 t/ ha.

In contrast, Wijewardene (1980) reported successful establishment of dryland rice with zero tillage in Nigeria.

## BLIND CULTIVATION

Cultivation after rice is planted but before the seedlings have emerged is sometimes practiced in dry-seeded rice to break up the soil crust to create conditions favorable for rice emergence and stand establishment and to kill young weed seedlings. This practice is commonly done with a spike-tooth harrow or other implements with fingerlike tines that lightly penetrate the soil.

Shallow cultivation is usually best. Deep cultivation is no better than shallow cultivation and sometimes not as good. Deep cultivation turns up weed seeds that have been dormant at greater depths and thus creates favorable conditions for them to germinate, grow, and compete with the crop. Greater destruction of germinated rice seeds also occurs with deeper cultivation.

## CULTIVAR GROWN

Ghosh and Sarkar (1975) reported a higher light transmission ratio for the dwarf cultivar Ratna than for tall Saket-1, resulting in twice the weight of weeds growing in association with the short cultivar at panicle emergence. Sarkar and Ghosh (1977) reported that light transmission ratios at 60 days after transplanting was 23% for tall (> 120 cm), 36% for medium (100-120 cm), and 47% for dwarf (< 100 cm) cultivars. Corresponding values for weed weight were 19, 20, and 23 g/m$^2$, respectively.

Moody and De Datta (1977) reported a highly significant negative correlation between yield reduction caused by weeds and plant height — the taller the rice plants, the lower the yield reduction. As a result, yield losses due to weeds are greater in the modern cultivars, and more time is spent in removing weeds than in the traditional cultivars. The modem cultivars also exhibit a greater response to weeding (Moody 1979a).

The selection of shorter rice cultivars has led to reduced ability to compete with weeds (Moody 1979a). Moody (1979a) concluded that because of a strong negative correlation between competitive ability and rice yield, the chances of success in exploiting cultivar differences to improve weed control would be slight.

Kim et a1 (1977a, b) reported that the yield reduction percentage in Tongil — a short, high-tillering cultivar — and Milyang 22 — a tall, moderate-tillering cultivar

— depended upon the weed species with which the rice was competing. Competition from *Aneilema japonica* (Kim et al 1977a), *C. serotinus,* and *Potamogeton distinctus* (Kim et al 1977b) resulted in greater yield reduction in Tongil than in Milyang 22, while *Ludwigia prostrata* (Kim et al 1977a) and *E. kuroguwai* (Kim et al 1977b) caused greater yield reduction in Milyang 22 than in Tongil. The yield losses caused by *Monochoria vaginalis* were about the same for both cultivars (Kim et al 1977a).

The weed flora growing in association with different rice cultivars may also change. Radanachaless and Mercado (1980) reported that mote weeds grew in association with IR36 than with IR38. Both are modern cultivars, but IR38 has a longer growth duration than IR36. *M. vaginalis* was the major weed growing in association with IR38, while *Scirpus supinus* was the most important weed in IR36.

## SEEDLING AGE

In tropical Asia, farmers have usually transplanted tall, older seedlings of traditional cultivars. Superior weed competition may be the reason for this. Kim (1979) reported that older seedlings were more competitive against weeds than younger seedlings. The weight of weeds of a community consisting primarily of *Echinochloa crus-galli* ssp. *hispidula, Scirpus maritimus, C. difformis,* and *M. vaginalis* needed to reduce grain yield by 50% for each seedling age was 100 g/m$^2$ for the 10- and 20day-old seedlings, 130 g for the 30-day-old seedlings, and 160 g for the 40day-old seedlings. In the weeded plots, however, grain yield decreased with increase in seedling age.

## PLANT SPACING

Various workers (Estorninos and Moody 1976, Manuel et al 1979, Kim and Moody 1980) have shown that, as the planting distance between hills of transplanted rice is reduced, the crop becomes more competitive against weeds, and yield losses due to weeds are reduced. Roa et al (1977) reported that, in addition to reducing weed weight and weed competition, closer plant spacing resulted in more options from which a farmer could select a suitable weed control practice. The number of weed control treatments to ensure that the yield was not significantly less than that from the weed-free check decreased from 7 at 15- × 15-cm spacing to 3 when plant spacing was 25 × 25 cm. However, Kim and Moody (1980) concluded that even though the highest net benefits were obtained when rice was transplanted at a 10- × 10-cm spacing, a farmer would probably plant at a wider spacing (20 × 20 cm) and weed chemically or by hand because of the greater benefit-cost ratio at the wider plant spacing.

Seeding rates used in wet-seeded rice are generally high to help control weeds. In the Philippines, rates of 150 kg/ha are not uncommon and rates as high as 400 kg/ ha have been used (Moody 1977b). Moody (1977c) reported a significant decrease in weed weight as the seeding rate was increased from 50 to 250 kg/ha. Broadleaf weeds were the most affected and sedges the least affected by the increase in seeding rate.

Ramamoorthi et al (1974) reported that weed weights decreased and the amount of nutrients removed by the weeds 90 days after seeding decreased as the seeding rate increased from 40 to 80 kg/ha.

For dry-seeded rice, increasing seeding rates has little influence on weed suppression, probably because of intense weed pressure. In trials conducted in the Philippines, weed weight was unaffected by cultivar grown, row spacing, or seeding rate (Moody 1980). In Sri Lanka, Siriwardana (personal communication) reported that there was no decrease in weight of weeds growing in association with a dwarf rice cultivar when seeding rate was increased from 50 to 400 kg/ha. With a tall cultivar, there was a 59% decrease in weed weight as a result of increasing the seeding rate. But, considering the cost of seed, it is highly unlikely that many farmers would be willing to use high seeding rates to suppress weeds in dry-seeded rice (Moody 1980).

Guh and Lee (1974) reported a significant decrease in weed weight as rice seedling number increased from 1 to 3/hill. Further increase in plant number per hill did not result in additional decrease in weed weight. The weight of individual weed species varied with increase in plant number per hill: *Cyperus* spp., *M. vaginalis,* and *Potamogeton* spp. decreased; *Eleocharis dulcis* increased; and *Rotala* spp. was unaffected.

On the other hand, Kim (1979) reported that weed weights were not affected by seedling number per hill for four seedling ages and two plant spacings.

## SEQUENTIAL RICE CROPPING

The use of minimum and zero tillage has also been evaluated as a possible way to reduce the turnaround time between rice crops. Reduction in turnaround time is possible if the number of tillage operations is reduced or chemicals are substituted for the standard tillage treatments of one plowing followed by two or three harrowings (Moody and De Datta 1980).

Bolton (1980) reported that it was possible to reduce from three to one the number of harrowings following an initial plowing for a second crop of rice in rainfed or irrigated areas, without a serious reduction in yield. Further reduction in tillage by elimination of the plowing operation led to an increase in weed weight and in the time required for weeding. Yields from these treatments were significantly lower than the yield from the standard tillage treatment. Plowing followed on the same day by a single harrowing was the most promising reduced-tillage treatment. The lowest total costs for tillage and hand weeding were obtained when the plots received only a harrowing. Yields, though, were lower than those from the plots that were plowed, and as a result returns were lower.

The weed flora growing in association with the rice crop and the degree of control achieved may also be affected by the degree of land preparation used. Pablico and Moody (1981) reported 11 weed species growing in plots that were plowed and harrowed once and 12 in plots that were harrowed once, compared with 7 species in plots that were plowed and harrowed 3 times and only 5 species in the zero-tillage plot. Weed weights were significantly greater in the plots with zero-tillage or with one harrowing than in the plots that received an initial plowing.

In the zero-tillage plots, *E. colona* was the principal weed; in the harrowed plot, *M. vaginalis* dominated the weed flora. The most important weeds in the plot that received one plowing plus one harrowing were *E. colona, M. vaginalis,* and *C. iria,*

**Table 5. Relative dry weight 35 days after transplanting of the different weed species growing in the unweeded plots as affected by degree of tillage.** [a]

| Weed species | Relative dry wt of weed species | | | |
|---|---|---|---|---|
| | 1 plowing + 1 harrowing | 1 plowing + 3 harrowings | Harrowing only | Zero tillage (paraquat 0.75 kg a.i./ha) [b] |
| *Monochoria vaginalis* | 21.1 | 20.1 | 53.4 | 7.1 |
| *Echinochloa glabrescens* | 0 | 30.9 | 12.9 | 13.6 |
| *E. colona* | 29.1 | 0 | 11.3 | 44.0 |
| *Cyperus iria* | 20.6 | 16.2 | 0.1 | 0 |
| *Fimbristylis littoralis* | 18.1 | 13.3 | 0.6 | 5.9 |
| *Paspalum paspalodes* | 7.5 | 8.8 | 5.0 | 0 |
| *C. difformis* | 0.1 | 5.5 | 4.4 | 29.4 |
| *Sphenoclea zeylanica* | 0.4 | 5.2 | 0.4 | 0 |
| *E. crus-galli* ssp. *hispidula* | 1.9 | 0 | 8.2 | 0 |
| Others [c] | 1.2 | 0 | 3.7 | 0 |
| Total weed wt g/0.5 $m^2$) | 20.6 | 7.7 | 39.6 | 32.4 |

[a] From Pablico and Moody (1981). [b] a.i. = active ingredient. [c] *Ludwigia octovalvis, Cyperus rotundus,* and *Lindernia anagallis.*

while *E. glabrescens, M. vaginalis,* and *C. iria* were most important when plowing was followed by three harrowings (Table 5). The long-term effects on the weed flora of reduced tillage for the second crop of rice when the first had conventional tillage need to be studied in detail (Moody and De Datta 1980).

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## DISCUSSION

MATTHEWS: If my figures are correct, in plowing up to 10 cm you are turning over 2,000 t soil/ ha and for deeper plowing up to 6,000 t/ha. How can you justify that in terms of a palliative treatment for weed control?

*SARKAR:* I have presented the data from the weed control point of view, but when we speak in terms of energy your comments are relevant.

EASTIN (comment): Dr. Matthews, are you saying it takes less energy to plow and harrow than to put on herbicide?

MATTHEWS (comment): No. What I am saying is that the difference between the amount of weed growth in plowing to 10 cm and plowing to 40-50 cm cannot be measured statistically. I think it is dangerous for that type of data to go out when *it is not interpretative.*

DE DATTA (comment): When you show fewer weed problems with increased seeding rate, closer spacing, and taller plants, these are not free. You must consider the cost of other weed control methods compared with increased seeding rate and very close spacing. Taller plants will have less yield, more lodging problems, and other quality reductions. These things have to be discussed.

*SARKAR:* This has been taken care of in the paper.

SYARIFUDDIN: In Table 4, why is the yield of the second crop and also the weed growth less compared to that in the first and also the third crop?

*SARKAR:* What we have tried to emphasize is that after 2 years of zero tillage, the weed intensity was very high, but when the land was converted back to conventional tillage, then in the following crop (the fourth crop) the effect showed up on the weed flora as well as on the yield.

ISLAM: In one of your slides you showed that harrowing 6 days before transplanting gave significantly better weed control than harrowing 2 days or 3 days before. What was the probable cause of this?

*SARKAR:* When the land is harrowed and left, even if for only 2 days, *Echinochloa* sp. and other weed species merge fast. Within 4 days they can completely cover the land. If planting is delayed, these weeds come up, take over, and the rice plants cannot compete.

ISLAM: Is this under direct-seeded conditions or transplanted conditions?

*SARKAR:*Transplanted.

ISLAM: Do you think that this sort of difference will occur when the interval is between 24 and 48 hours?

*SARKAR:* Within 2 days *Echinochloa crus-galli* comes up. These plants are very vigorous and they take over.

HERDT (comment): There was a comment that suggested that maybe some of these data are not appropriate to be displayed and that we might mislead administrators. Rather than having the weed scientist worry about economics and what the administrators are going to think, this is exactly the kind of exploration that has to be done in terms of technology development. We have to know what the technical relationships are and how far you can stretch things. We already know that farmers are doing a pretty good job of weed control with the technology they have available to them; but is there some new kind of weed control combination or can we substitute some other techniques or inputs for those that are already being used? For that reason I found it very interesting from a technical point of view to see what we can do to expand the range of possible techniques.

*SARKAR:* In this paper we have tried to reflect the different crop establishment techniques on weeds.

SETH (comment): In relation to the minimum- and zero-tillage data that were presented, it would be helpful if we were to clarify that this change-over from zero tillage to conventional tillage becomes particularly important when there are perennial weeds. If the perennial weeds are not there, then there is no need to revert back.

GREENLAND (comment): The paper and the discussion illustrate the problems of site specificity in weed research, and hopefully a meeting such as this can start to clarify some of these difficulties. Not only the sequence of crops but the depth of plowing and water content of the soil at the time of plowing are important. If the soil is really wet, plowing to 20 cm rather than to 5 cm does not really make much difference. Some of these specific factors need to be clarified, and one wants to get weed science into a state where one is not dealing with very empirical, location-specific problems but with the more general ones of the type of ecology that occurs. I think if we can move a bit toward this during the week it will be a great help to some of us administrators who sit in concrete boxes.

EASTIN (comment): It has been my experience that it does not matter how much interpretation you put on a table; someone is going to look at that table and make his own interpretation of it and he is going to interpret it the way he wants to interpret it to further his purpose whether he is an administrator, an environmentalist, or a chemical company representative. They are all going to look at one or two pieces of data and pull out of them what they want to see, not necessarily what is there.

# THE ROLE OF CROPPING SYSTEMS ON WEEDS IN RICE

K. Moody and D. C. Drost

A knowledge of the life history of weeds and their interrelations with soil, climate, and associated cropping and agronomic techniques is indispensable for developing suitable weed control methods. In any rice field, only three or four weed species comprise the major portion of the weed flora. The role of cropping systems on weeds of rice is reviewed. Land preparation during the dry season, rainfall distribution and time of flooding, weeding, and crop rototillage are discussed. Future research directions are suggested.

Rice fields can be colonized by terrestrial, semiaquatic, or aquatic plants depending on the type of rice culture and also on the season. Rice fields in general support a diverse flora, with diversity decreasing with increased flooding and puddling. This colonization occurs despite the drastic intervention required to prepare the fields for planting (Fernando 1980).

There may be more than 100 weed species that cause problems in rice, but many are of little concern to the farmer. The number of species that comprise the major portion of the weed flora in any rice field is usually less than 10, and rarely are more than 3 or 4 species important. This has been shown for irrigated transplanted rice by Kim and Moody (1980) and for rainfed rice cultures by Ahmed (1979) and Ahmed and Moody (1980) (Table 1). When weed control is used, diversity decreases.

Ecological studies of weed-crop interactions are fundamental to enhance the success of weed control methods. A knowledge of the life history of weeds and their

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**Table 1. Weed species and percentage of the total weed weight accounted for by the major species in dry-seeded rainfed rice grown at different landscape positions.** [a]

| Landscape position | Weed species (no.) | Percentage of the weed flora accounted for by | | | |
|---|---|---|---|---|---|
| | | 1 species | 2 species | 3 species | 4 species |
| Well-drained upland | | | | | |
| 1977 | 16 | 35.4 | 59.0 | 71.6 | 77.1 |
| 1978 | 13 | 50.5 | 71.2 | 80.2 | 85.9 |
| Very low ponding potential | | | | | |
| 1977 | 17 | 65.9 | 85.5 | 88.3 | 90.9 |
| 1978 | 15 | 28.3 | 50.2 | 71.9 | 84.7 |
| Low ponding potential | 11 | 76.4 | 87.5 | 93.5 | 97.0 |
| High ponding potential | 9 | 59.3 | 77.4 | 95.5 | 97.3 |

[a] Adapted from Ahmed 1979.

interrelations with soil, climate, and associated crop and agronomic techniques is indispensable for evolving suitable methods of weed control.

Elimination of weeds from crop fields is possible through proper manipulation of soil moisture, cultivation procedures, date of planting, and crop spacing, and by maintenance of desirable ecological conditions. Even minor changes in the eco-climatic, edaphic, and agrobiotic factors or tillage treatments cause important changes in plant associations. Floristic composition and distribution of weeds often serve as indicators of field conditions. For example, differences in microtopography due to uneven land preparation or natural slope in bunded, leveled toposequences within a rice field can affect the distribution of weed species. We observed that when a dry period was encountered after wet-seeding rice under rainfed conditions, the downslope side of the paddy remained flooded or saturated longer than the upslope side. As the soil dried, *Leptochloa chinensis* established first on the upslope (Drost and Moody 1981). As the water receded across the field, establishment of *L. chinensis* followed. When wet-seeded rice was permanently flooded 5 days after seeding, *L. chinensis* did not occur in the flora. Delay in flooding the field allowed weed establishment (Drost and Moody 1981, unpubl.) (Table 2).

Multiple cropping is a practice that has been used for centuries by farmers throughout the tropics. Nevertheless, in much of the rainfed rice area throughout Asia even today, only one crop of rice is grown. In that area, increased cropping is

**Table 2. Weed density and biomass of *Leptochloa chinensis* growing in association with wet-seeded rice as affected by time of flooding.** [a] **IRRI, 1981 dry season.**

| Time of flooding (DS) [b] | Weed density (no./$m^2$) | Weed weight (g/$m^2$) |
|---|---|---|
| 5 | 0 a | 0.0 a |
| 10 | 2 a | 0.0 a |
| 15 | 42 b | 25.0 b |
| 20 | 72 b | 45.8 b |

[a] Av of 4 replications. In a column, means followed by a common letter are not significantly different at the 5% level. [b] DS = days after seeding.

possible. The potential cropping pattern — the yearly sequence and spatial arrangement of crops on a given piece of land—depends largely upon the availability of water as rainfall or irrigation, or both, assuming that other climatic factors such as temperature and day length are not limiting for crop growth. In areas where water resources are unlimited throughout the year, the growing of three or more rice crops in succession during the same year is possible.

## DRY SEASON LAND PREPARATION

A common practice in rainfed rice-growing areas is to leave the field fallow during the dry season. Most fallow fields become covered with weeds, the seeds or vegetative reproductive parts of which become incorporated into the soil in the course of land preparation. The quantity of weeds incorporated prior to planting depends on a number of factors, the more important of which are cropping pattern; climatic, edaphic, and biotic influences; and ecological characteristics of the species constituting the weed flora. Reducing the fallow period can minimize vegetative reproduction and reseeding of weeds (Hammerton 1974).

In the People's Republic of China, intense land preparation by rototilling and maintaining of fields as a clean fallow during the dry season are two methods used to control weeds in dry-seeded rice (Zandstra et al 1977).

A weed-free fallow during the dry season conserves soil moisture, allows earlier establishment of dry-seeded rice, reduces land preparation time, and reduces weed problems in dry-seeded rice compared to a field maintained as a weedy fallow in the dry season (Bolton and De Datta 1977, Villegas et al 1978, Hundal 1980). On the other hand, Moody (1980a) stated that land preparation during the dry season would have only limited use in reducing weed problems in the subsequent dry-seeded rice crop. A dry season weed-free fallow will have the greatest weed-suppressing effect on the subsequent wet season crop when the weed floras in both seasons are similar.

In Sri Lanka (Siriwardana as cited in Moody 1980a), the growing of a crop during the dry season or maintaining the land weed free by herbicides did not reduce weed weight in the subsequent crop.

## FACTORS AFFECTING COMPOSITION OF WEED FLORA

The distribution of rainfall affects the weeds growing in association with dryland crops. Maiti (1977) reported that weed vegetation correlates well with meteorological conditions such as temperature, rainfall, and humidity. Hanafiah et al (1973) concluded that weed community distribution is determined by variation in environmental factors such as soil, climate, altitude, and cultural techniques. It is common knowledge that certain weed species which are present in the wet season are absent in the dry season and vice versa.

Radanachaless (1978) reported that in the dry season 16 weed species were present in San Ildefonso, Bulacan; 17 in Muñoz, Nueva Ecija; and 29 in College, Laguna, Philippines. The dry season weed flora was dominated by grasses such as *Paspalum* sp., *Cynodon dactylon,* and *Echinochloa colona* as well as the sedge

*Cyperus rotundus.* Fifty to 60 days after transplanting rice in the wet season, only 5 weed species were present at all the sites, *Monochoria vaginalis* being the only common weed. Except for *C. dactylon* in San Ildefonso, Bulacan, none of the weeds in transplanted rice was observed in the dry season. The presence of *C. dactylon* was attributed to low rainfall early in the rice crop growth cycle and to lack of flooding later in crop growth. Ahmed (1979) observed very little similarity between the weed floras growing in association with dryland crops and those growing in association with rice in different cropping systems in a welldrained upland and in land with a low ponding potential.

## WEED RESPONSE TO INTENSIVE CROPPING

Even though there may be little similarity in weed flora between the dryland crops grown after rice in the dry season and the subsequent rice crop, some weeding is usually done in the dryland crop to minimize re-seeding (Moody 1980b).

William and Chiang (1976) reported that in Taiwan farmers repeatedly weed soybean to eliminate *E. colona* when no apparent economic or biological response is expected in the soybean. The farmers want to maintain a low population level of this weed in soybean so as to reduce its population in rice, where it is considered to be a serious problem. Suvanjinda (1980) observed that tillage treatment in the preceding mungbean crop significantly affected the weight of weeds in dry-seeded rice 20 days after emergence. Weed weights were highest in the plots that had received zero tillage in mungbean.

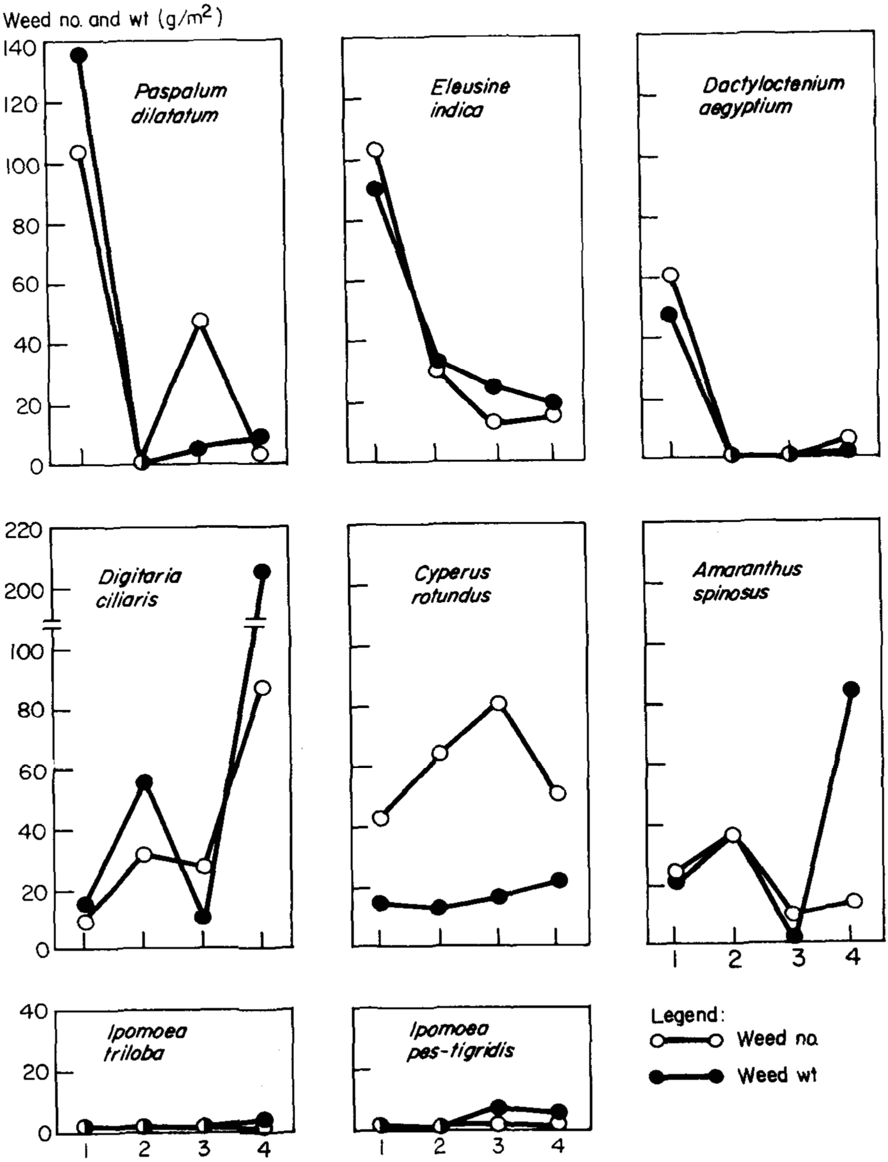
Buildup in the populations of different weed groups may be a problem in some intensive cropping patterns. Grassy weeds may increase because of the use of herbicides (Moody 1976). More frequent tillage can also increase weed populations (Anderson and Whan 1974).

The response of weeds to intensive cropping may be species specific. Ahmed (1979) reported that *Paspalum dilatatum* was nearly eliminated in the unweeded plots after three crops (rice - maize - mungbean) were grown in sequence in a welldrained upland. Over the same interval, *Digitaria ciliaris* increased in importance (Fig. 1). *C. rotundus* has been reported to increase in certain rice-based cropping patterns (Moody 1976, Lacsina 1980).

## CROP ROTATION

Crop rotation can be used to minimize crop damage from weeds. Rotation procedures recognize that certain weeds are often associated with specific crops. Rotating crops having drastically dissimilar life cycles or cultural conditions — so as to break the cycle of the weeds — is among the most effective of all weed control methods. Harwood and Bantilan (1974) reported that intensive cropping systems can increase the competitive ability of crops, thereby reducing weed pressure.

Rotating rice with a dryland crop results in reduced infestations of water-tolerant weeds in the rice crop. Crops commonly rotated with rice are maize, soybean, peanut, mungbean, sweet potato, and pasture. Takahashi (1966) reported that weed growth in rice declined in inverse proportion to the length of time that the




**1.** Number and weight of weed species sampled at maximum flowering of the weeds occurring in the unweeded plots of crops grown at different seasons. IRRI, 1977-78. 1 = dry-seeded rice, 1977 wet season; 2 = maize, 1977 wet season; 3 = mungbean, 1977 dry season; 4 = dry-seeded rice, 1978 wet season.

field was in dryland conditions. Weeds in rice increase as the length of time after reconversion to a wetland field increases. It is therefore recommended that the reconverted wetland field be returned to a dryland field within a certain time.

De Datta and Jereza (1977) and Moody and De Datta (1977) demonstrated that various cropping, soil, water, and weed control practices bring about changes in the weed community. For example, *Scirpus maritimus* persisted in continuous transplanted irrigated rice. The number of *S. maritimus* plants remained relatively constant but annual weeds tended to increase, and thus yields decreased. When dryland crops were rotated with wetland rice without any weed control. there was less *S. maritimus* than in continuous rice culture. *S. maritimus* decreased dramatically during the dryland crop, then increased during the rice crop (Table 3). Yield depressions due to weeds in transplanted rice in this rotation were lower than under continuous wetland conditions. For example, in the 1976 wet season, rice grown under continuous wetland conditions failed to yield whereas that in the dryland crop - wetland crop rotation yielded 1.3 t/ha (Moody and De Datta 1977).

Thus, the tendency for difficult-to-control weeds to build up is less in a crop rotation involving both wetland and dryland crops than in continuous wetland culture. In the absence of weeding, yield losses are less when dryland and wetland crops are rotated.

Caution should be exercised, however, in the use of crop rotations for weed control. Just as weed problems increase in monoculture systems when the same crop and the same weed control practices are used over years, similar problems may arise in a crop rotation that is initially introduced to overcome problems in the monoculture system if the same crops and weed control practices are used year after year. Plucknett et al (1977) warned that weeds associated with certain cropping systems may, in fact, be favored by the systems' continued practice. Any changes in cultural practices for 2 years or more will generally solve some weed problems but will also generate new ones. Even with crop rotation, change in both crops and weed control practices is essential if problems are to be avoided.

**Table 3. Number of annual and perennial weeds and yield of rice and other crops in the untreated check as affected by cropping system.[a]**

| Year and season | Crop[b] | Weed density (no./m$^2$) | | | Yield[c] |
|---|---|---|---|---|---|
| | | Annuals | Perennials | | |
| | | | *Scirpus maritimus* | *Cyperus rotundus* | |
| | | *Cropping system I – continuous wetland* | | | |
| 1975 dry | Rice | 725 | 406 | 0 | 1.6 |
| wet | Rice | 340 | 325 | 0 | 1.7 |
| 1976 dry | Rice | 990 | 205 | 0 | 0.2 |
| wet | Rice | 1168 | 300 | 0 | 0 |
| | | *Cropping system II – alternating dryland - wetland* | | | |
| 1975 dry | Maize/mungbean | 1008 | 36 | 32 | 10,500/107 |
| wet | Rice | 364 | 167 | 0 | 2.2 |
| 1976 dry | Maize/mungbean | 1571 | 60 | 30 | 0/0 |
| wet | Rice | 639 | 191 | 0 | 1.3 |

[a]Adapted from Moody and De Datta (1977). [b]/ = planted at the same time. [c]In t/ha for rice, marketable ears/ha for maize, and kg/ha for mungbean.

## CHANGES IN WEED FLORA AS AFFECTED BY CROPPING PATTERNS

The equilibrium in plant communities is not a static relationship. New weed species germinate and grow, replacing those that senesce and die. Individual species are continually changing places in the community (Walter 1979), as Kim and Moody (1980) have demonstrated for irrigated transplanted rice.

Cropping systems in which weeds are found are always ecologically unnatural (Sagar 1974). Characteristics of these systems include frequent disturbance, high production-to-biomass ratio with emphasis on the quantity of production, linear food chains with low species diversity, and open mineral cycles with poor conservation of nutrients (Odum 1969). Weeds are ideally suited to these cropping systems because they complete their life cycles rapidly, are responsive to fertilizers, and can survive under various levels of competition.

The study of different weed communities interacting with rice grown in different seasons under different cultural practices is still in its infancy. Less has been done with different weed communities in rice-based cropping systems. Basically, knowledge of rice weed communities is inadequate, as Barrett and Seaman (1980) have pointed out.

### Dryland crops

Pablico and Moody (1979, 1980) tested several cropping patterns and weeding treatments for their effects on weed populations over time. At 5 weeks after rice emergence in the cropping sequence of rice followed by maize, *Amaranthus spinosus, C. rotundus,* and *Eleusine indica* were the major weeds (Table 4). In the subsequent maize crop, there was a dramatic change: *Ipomoea triloba,* which was not present in rice, accounted for 82% of the weed flora on the basis of weight; *C. rotundus* remained about the same as in the first crop; and *A. spinosus* was a minor weed. In the third crop — a rice crop established in the following year — *A. spinosus* regained dominance and C. rotundus was insignificant; *Rottboellia exaltata* invad-

**Table 4. Relative dry weight of various weed species as affected by cropping pattern and year.**[a]

| Year | crop | Relative dry wt (%) | | | | |
|---|---|---|---|---|---|---|
| | | *Amaranthus spinosus* | *Ipomoea triloba* | *Rottboellia exaltata* | *Cyperus rotundus* | Others |
| | | *Rice – maize rotation* | | | | |
| 1978 | Rice | 84 | 0 | 0 | 6 | 10 |
| | Maize | 4 | 82 | 0 | 12 | 2 |
| 1979 | Rice | 42 | 3 | 47 | 0 | 8 |
| | Maize | 1 | 47 | 21 | 12 | 19 |
| | | *Maize monoculture* | | | | |
| 1978 | Maize | 77 | 0 | 0 | 15 | 8 |
| | Maize | 65 | 0 | 2 | 12 | 21 |
| 1979 | Maize | 65 | 1 | 21 | 0 | 13 |
| | Maize | 6 | 0 | 39 | 18 | 37 |

[a] Adapted from Pablico and Moody (1979,1980).

ing from an adjacent area comprised 47% of the weed flora on the basis of weed weight (Pablico and Moody 1980). In the fourth crop — maize — *I, triloba* became important again but *R. exaltata* declined. These changes did not occur under parallel monoculture of maize (Table 4).

The importance of the different weed species reflected the effects of season and cropping pattern. Under rotation, *A. spinosus* and *I. triloba* were usually more important in rice and in maize, respectively. *I. triloba* usually appeared only after rice was grown; monocropping of maize resulted in little or none of this weed (Table 4).

**Wetland rice**

Weed communities of wetland rice have been partially characterized. Kim and Moody (1980) identified eight different weed communities in irrigated transplanted rice fields at IRRI. Such weed communities also existed in wetland rice fields in Korea and were attributed to soil nutrients, pH, and cultural factors varying from field to field (Kim, personal communication).

Tiwari and Nema (1967) reported that the primary causal factors for weed communities co-existing with the rice crop were habitat, water status of the field, and planting methods. *Ludwigia perennis* and *Ammannia baccifera* dominated in flooded fields; *Caesulia axillaris* and *Sphaeranthus indicus* prevailed in semiwater-logged conditions; while *E. colona, Eclipta prostrata, Commelina jacobi, Rumex dentatus,* and *Ageratum conyzoides* became predominant with further decreases in soil moisture. After rice harvest, several dicotyledonous annual weeds invaded the fields. These were eventually replaced by the same species that were present before land preparation.

**Dry-seeded rice - transplanted rice**

A probable change in cropping system is from transplanted to dry-seeded rice, partly for economy of labor but also for greater productivity. By sowing a dry-seeded crop at the start of the rainy season before there is sufficient water for transplanting, two rice crops may be grown instead of the usual one. Dry-seeded rice, however, is notoriously weedy and poses serious weed control problems whether traditional or chemical methods are used. Prabowo (1977) reported that efforts to intensify rice cropping through sequential cropping of dry-seeded rice and transplanted rice in Bulacan Province, Philippines, failed. Most farmers went back to their traditional system of transplanting the first crop. The major factor for the return to the traditional one-crop system was the problem of weed control in the dry-seeded crop.

Harwood (1979) and McIntosh (personal communication) stated that weed problems in dry-seeded rice would decrease as the period for a cropping pattern involving dry-seeded rice increased. For example, Biswas and Saraswat (1977) reported that the first crop of dry-seeded rice in a rice - rice - wheat rotation was badly infested with grasses and sedges. In the first rice crop in the second year, weed density was less.

In Texas, however, weeds were not a serious concern on the newly opened land when the rice industry first began. After a few years of continuous cropping, they became abundant (Laude 1918). If the deepwater land in Bangladesh (BRRI 1974) is continuously sown with dry-seeded rice for a number of years, it becomes so infested with weeds that the yield of rice is reduced to almost half the normal.

Water management alternatives and soil moisture contents regulate weed populations in dry-seeded rice. The rate of water accumulation in bunded fields following crop emergence is important (Moody 1977a). Harwood (1979) has suggested that dry-seeded rice be limited to fields in which water accumulates within 30 days after emergence. The longer the delay in flooding the fields after emergence, the deeper the depth of the water needed to suppress weeds (Civico and Moody 1979).

In a cropping pattern of dry-seeded rice followed by transplanted rice, there was a 50% reduction in weed density and 95% less weed weight in the transplanted crop than in the dry-seeded crop (Ahmed and Moody 1980) (Table 5). A major change in the weed composition was observed when the transplanted rice was compared to the dry-seeded crop. At maximum weed flowering, the transplanted rice crop had only 5 weed species but the previous dry-seeded crop had 14. The broadleaf weed *M. vaginalis* was predominant, accounting for 91% of weed density and 83.6% of dry weed weight. *E. colona* and *L. chinensis,* which were the major weeds in dry-seeded rice, accounted for only 14.7% of the dry weed weight in transplanted rice. There was also little similarity between the weed flora growing in association with transplanted or wet-seeded rice and that growing in association with a dry-seeded rice crop grown in sequence the following year (Ahmed 1979).

There was no indication that weeding practices in dry-seeded rice had a residual effect on weed growth in transplanted rice. Such effect would not be expected because of the dramatic change in the weed flora. Thus, the introduction of a dry-seeded rice crop before transplanted rice will neither increase nor decrease the weed problems in transplanted rice (Ahmed and Moody 1980) whenadequate water is present in the transplanted crop.

In cropping patterns involving two rainfed rice crops grown in sequence in puddled soil, Ahmed and Moody (1982) reported that the composition of the weed flora was strongly influenced by landscape position and time of flooding. The weed floras growing in association with the first crop in each field were similar, with *L. chinensis* predominating (Table 6). No similarity was observed between the weed floras growing in association with the second crop in each field. *L. chinensis* predominated in the upper field; weeds were few in the lower field. The reason given for the difference in the weed floras was the presence or absence of standing water in the fields immediately after transplanting of the second rice crop.

Table 5. Effect of degree of weed control in dry-seeded wetland rice (DSR) on weed weight and yield of the subsequent transplanted rice (TPR) crop.[a]

| Weed control method | DSR | | TPR | |
|---|---|---|---|---|
| | Weed wt ($g/0.25\ m^2$) | Yield (t/ha) | Weed wt ($g/0.25\ m^2$) | Yield (t/ha) |
| Unweeded | 154.1 b[b] | 0.3 b | 7.9 a[c] | 4.2 a |
| Weeded twice | 14.8 a | 4.1 a | 9.8 a | 4.1 a |
| Weeded thee times | 4.2 a | 4.4 a | 6.8 a | 3.8 a |

[a]Adapted from Ahmed and Moody (1980). Av of 2 replications and 2 planting methods. In a column, means followed by a common letter are not significantly different at the 5% level. [b]Major weeds: *Echinochloa colona, Leptochloa chinensis,* and *Ludwigia octovalvis.* [c]Major weed: *Monochoria vaginalis.*

**Table 6. Effect of cropping system and landscape position on weight of weed species and relative dry weights at maximum flowering of weeds in unweeded plots of rice crops.[a]**

| Weed species | Wet-seeded rice[b] | | Transplanted rice | |
|---|---|---|---|---|
| | Wt ($g/0.25\ m^2$) | Relative dry wt | Wt ($g/0.25\ m^2$) | Relative dry wt |
| *Land with low ponding potential (upper field)* | | | | |
| *Leptochloa chinensis* | 43.0 | 95.6 | 13.9 | 97.2 |
| *Cyperus iria* | 1.5 | 3.3 | 0.1 | 0.7 |
| *Eleusine indica* | 0.1 | 0.2 | 0.1 | 0.7 |
| Others | 0.4 | 0.9 | 0.2 | 1.4 |
| Total | 45.0 | | 14.3 | |
| *Land with high ponding potential (lower field)* | | | | |
| *Leptochloa chinensis* | 31.8 | 74.8 | 0.1 | 3.3 |
| *Monochoria vaginalis* | 6.9 | 16.2 | 0.2 | 6.7 |
| *Echinochloa colona* | 2.2 | 5.2 | 2.5 | 83.3 |
| Others | 1.6 | 3.8 | 0.2 | 6.7 |
| Total | 42.5 | | 3.0 | |

[a]Adapted from Ahmed and Moody (1982). [b]Transplanted rice in land with high ponding potential.

The diversity of weed species encountered at different landscape positions and the change in weed flora with more intensified cropping mean that identification of weed control methods for specific situations will become a key aspect of multiple cropping research.

Weed problems will be fewer when wet-seeded rice or transplanted rice is grown as the first crop than when dry-seeded rice is the first crop. In irrigated fields and in lower landscape positions in rainfed areas, greater similarity in weed flora between the first and second crops would be expected. Thus, any weeding done in the first crop would be expected to reduce weeding requirements in the second crop.

## Transplanted rice monocrop

In transplanted rice, fewer broadleaf weeds and more grass weeds occurred in previously weeded plots than in previously unweeded ones (IRRI 1977). Weeding had no appreciable residual effect on the sedge population. Plots that had been weeded in the previous crop yielded significantly higher than those that were not weeded.

In another trial, the effects of weed control treatments applied to one crop of transplanted rice were examined by not weeding in subsequent crops. Plots in which weeds were adequately controlled in the first crop had fewer weeds in the second crop than plots where weed control in the first crop was poor (Moody 1977a).

The lowest weed weight was associated with the plot where the first crop was hand weeded, and the highest with the plot that was not weeded. The weed weight from plots that had good control in the first crop tended to increase in the second crop; in the others it remained relatively stable. In the third crop, there was no significant difference in weed weight between the weed control treatments that had been applied to the first crop.

With respect to yield, plots that performed best in the first crop also did in the second. The yields reflected the degree of weed competition — generally the greater the weight of weeds, the lower the yield. Yields for the second crop were 30-50% lower than those obtained for the first.

Significant differences in yield were also observed in the third crop although treatments did not significantly differ in weed weights taken at harvest. Yields in all plots were less than 1.0 t/ha. Those plots which yielded highest in the first crop tended to yield highest in the third crop.

### Ratoon cropping

After harvest of short-duration rice cultivars, the field may be too wet to plant a dryland crop, and at the same time water may be insufficient to support another rice crop. Ratooning of the rice may be the logical answer (Moody 1977b). When weeds are adequately controlled in the plant crop, they will not be a major problem in the ratoon crop.

Failure to control weeds adequately in the plant crop will result in a significant reduction in tiller number, which will mean a reduction in the quality of the ratoon produced and lower yields in the ratoon. Weeds that are present when the ratoon is established may be highly competitive and decrease yield if they are not removed. The ratoon crop is less competitive against weeds because of reduced plant stand and reduced growth (Moody 1977b).

## WEED SPECIES RESPONSE TO WEED CONTROL

Ecological shifts of weed species from annuals to perennials have been observed in East Asia, where herbicides have been used continuously on rice for a number of years. In the Philippines, weeds such as *S. maritimus* and *Paspalum paspalodes* have become troublesome where herbicides have been used for years to control susceptible weeds such as *Echinochloa* spp. and *M. vaginalis.*

In South and Southeast Asia, such ecological shifts occur infrequently because herbicides are not widely used. Research, however, should be conducted to study the shift and to identify problems before they occur. Research to develop methods of preventing significant ecological shifts would be beneficial. Perhaps rotating both crops and herbicides would prevent such undesirable weed species shifts.

## FUTURE RESEARCH

As agronomic practices and cropping intensity change, so does the weed flora. It is our task to try to predict the changes, learn how to control the important weed species, and prevent the buildup of difficult-to-control species. Without this knowledge, weeds will continue to be one of the major factors limiting crop production throughout the tropics (Moody 1977c).

The nature of the ecological challenges that plants encounter and the genealogical and evolutionary responses that they evolve are complex and difficult to analyze, but in the future better records of changing weed populations resulting from change in the cropping system must be kept. We realize that such experimentation is difficult because of the tedious and painstaking effort involved and the great number of personnel needed, but it must be conducted if suitable answers are to be found.

But before this type of research can continue, we need a) more detailed studies on the ecophysiology of the major weeds infesting rice and dryland crops grown in rotation with rice, b) more information on the applicability of ecological research methods to rice ecosystems where cultural formations are of interest, and c) to recognize the problems associated with analyzing data matrices involving sites, species, and time as influenced by weed control treatment or cropping pattern. Such information is critical in answering the question: "What effect will intensification of cropping have on the weed flora?"

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## DISCUSSION

SCHREIBER: Have you ever considered the possibility of developing growth models of the various weeds?

*MOODY:* No. Maybe in the future we will go into some of that research.

KIM: You have mentioned that the weed flora is always dynamic and changeable. I agree with you, but what happens in terms of total dry matter of the weeds after a sequence of crops? For instance, this year you grow soybean followed by rice and maize or some other crop.

*MOODY:* We have found that if you are dealing with a dryland or a rainfed situation, the total weight of weeds does not necessarily change too much across years, but you get changes within a crop. There are, of course, instances where other things do occur. For example, we have been told that if we grow dry-seeded rice, then the weed weight should go down in the second crop, but we have found that it either stays level or increases in the second year. I don't think it is so much the weight that changes; it is the composition of the weed flora that changes with time, and it is difficult for me to make a statement at the present time as to whether that change is due to the cropping pattern we have used or whether it is just due to differences in the climate from one year to the next.

SYARIFUDDIN: Under dryland rice conditions in Indonesia, when we rotate crops we can improve the soil fertility a little bit and then we find a shift in the weed species in the plot. What are your comments on this?

*MOODY:* Weed species will shift according to the fertility that you are dealing with. In my experience. the broadleaf weeds will increase as the fertility level increases. This can be brought about by the fertilizer that is applied to the previous crops or if you put a legume into the rotational system.

MUKHOPADHYAY (comment): In wetland rainfed rice cultivation, especially in South Asia (India and Bangladesh) in the wet season where there is standing water, we have fewer grasses and more broadleaf weeds (semiaquatic weeds). In the same field if there is no water we have sedges. So it is the water that determines the type of species in that area.

VEGA (comment). I don't think the situation is water vs no water. I think there are changes in the water regime during the season and that is something that we have to think about.

MOODY- I indicated that with *Leptochloa chinensis* the time of flooding of the field after establishment makes a big difference with regard to development. The length of the dry period or maybe the length of flooding after you have transplanted a field can drastically change things around. You can also get environmental effects, so you can get changes that differ from year to year that cannot be related directly back to water.

OBIEN: Perhaps we should begin to study these weed changes in terms of the situation in the rice field. There are situations where we grow rice - rice - rice. I think we should now start to work out those situations suited for those kinds of fields or environments so that in another 5 years we know exactly what changes would happen. You have explained the role of water in weed growth or no growth as well as changes from rice to maize or mungbean to rice. I wonder if it is important for us to study whether these weed changes are also related to the soil types. You mentioned once that if there is Zn deficiency or Fe toxicity we may have an entirely different type of competition between the rice and the weeds. Would this be a reasonable part of the study on weed changes in rice?

*MOODY:* We do not have sufficient information on this and we definitely need to do more research in that area.

DE DATTA (comment): Even after a long history of soil science we are still reporting site-specific data. Weed science is relatively young and there is only a handful of weed scientists. Some of the questions that have been raised are really valid and we will look into them, but the real pressure for people in the international centers is that if you have a weed problem you have to learn how to get rid of that weed problem. More so in direct-seeded rice, which offers the greatest opportunity for crop intensification. On the one hand, we are pressured to develop technology which will have an immediate effect. At the same time we are not totally neglecting the long-term issues. Please bear in mind we are relatively young in this field.

*MOODY:* I'm glad that you brought that up, Dr. De Datta. I'm working not only on this type of research but on other subjects in weed science in addition to what I have shown you.

VEGA (comment): Maybe before all of us go back home we could agree on 2 or 3 experiments for all to carry out so that at the end of 2, 3, or 4 years we would have answers to specific questions that have now been raised. I think the organizers of the conference have made provisions for this. Dr. Plucknett will chair the session on research priorities. I hope that we can begin to think now about the kinds of experiments that will help us answer some of those questions that we are now raising.

MATTHEWS. How far off do you think we are in establishing weeds to control weeds?

*MOODY:* 1 really don't know. Some people regard azolla as a weed; others do not. We have done some work with azolla and have shown that you do get some suppression depending on the weed flora that you are dealing with. I can see what you are driving at, but I have no answer.

YAMASUE: Do your *Echinochloa colona* and *Monochoria* show dormancy? You showed that under dryland conditions, *Monochoria* completely disappears. What is the survival mechanism of that weed?

*MOODY:* This we believe is very strongly related to the moisture content of the soil. *M. vaginalis* needs saturated conditions before it will germinate so that it goes into an anaerobic condition. The anaerobic-aerobic situation is very critical when it comes to germination and growth of a large number of weed species. For example, *Leptochloa* chinensis will not germinate unless the soil is saturated or has been puddled; and when you dry the soil for a couple of days, the weed will germinate and come through, but if you keep standing water on that field, it won't appear or it will be very minor.

GREENLAND (comment): I doubt if the soil characteristics or the soil type per se often has a determinant effect on the weed flora except in so far as the soil type reflects the water regime. The first priority in characterizing the changes is to make sure that the water regime is adequately characterized, not just in terms of the surface water appearance but on the position of the water table within the profile. More often than not. this is the factor that really determines the change in the ecology of the plant types present, whether one is talking about a forest grassland change or a weed flora succession. The data that are collected on water table fluctuations and seasonal changes in water status usually are limited and are not so difficult to collect.

*MOODY:* In the trials we are presently running in the fields we are collecting data on both water depth in the field and depth to water table if there is no standing water in the field, and this is done three times a week.

*DROST* We have collected this information for the last 2 years and there is a very definite relationship between depth of water in the profile at a given time in the cropping season and the weed flora at that given time.

BAKER (comment): We do not have *Monochoria vaginalis* but we do have *Heteranthera limosa,* which is a strict aquatic. We have been curious about the fact that at times this weed is completely missing, while at other times it is quite heavy. We have found in some studies on germination that this weed requires strict anaerobic conditions for germination and it also requires light. Moreover, it is not light intensity, but light quality, that matters. If there is a shift in spectrum due to the presence of vegetation, germination will be inhibited.

*MOODY:* I think that we would find the same relationship in *Monochoria,* but I don't remember any work that has been done on it.

SHETTY (comment): As Dr. Greenland mentioned, moisture is one of the important factors which determine the dynamics of the weed flora, but the title of the paper is cropping systems. I think that this should be given equal importance. There are certain weed species that are associated with certain crops, and taking cropping systems into consideration one might develop a more effective weed control technology rather than be confined to one particular crop, especially in the rainfed situation.

*MOODY:* I tried to confine my statements almost exclusively to rice, although we have looked at the other situation, for example, the effect of rice on the dryland crop and of the dryland crop on rice as well. I tried to deal only with the rice crop, but your comments are appreciated.

# WEED CONTROL TECHNOLOGY IN IRRIGATED RICE

S. K. De Datta and R. W. Herdt

Recent advances in chemical methods of weed control combined with other cultural practices and direct methods of weed control provide excellent alternatives to hand weeding alone. Weed control technology made possible a wide choice of cultural practices. As a result, places with high labor costs and greater irrigation water control such as Japan, Korea, and Taiwan use herbicides in 75 to 100% of the rice areas. In South and Southeast Asia, farmers choose the combination of weed control inputs that provides the desired degree of weed control at lowest cost. The chosen combination of inputs is largely determined by their relative prices while the total expenditure on weed control is determined by its effectiveness and cost relative to the total value of the crop.

Yield losses caused by weeds in flooded rice fields vary with the time of weed infestation, soil fertility, rice cultivar, and planting method (De Datta et al 1969). The most serious competition is from grass or from a mixed weed population.

Generally, the weeds most common in transplanted wetland rice, such as *Echinochloa* and *Monochoria vaginalis,* are highly competitive because they have discontinuous germination, rapid growth, and high plasticity. Because of that competition early weed control is important to achieve high rice yields.

In Japan, where rice yields have increased steadily, a general rule for maximum rice yield is to keep the field weed free until the transplanted rice crop reaches the 4- to 6-leaf stage. Controlling weeds at the appropriate time often is more critical than the control method chosen.

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The problem of weed competition in the tropics is more difficult with semidwarf cultivars than it was with traditional cultivars. Modem rices, with their shorter stature, less vigorous early growth, and high fertilizer requirement, may require greater attention to weed control than traditional rices. Furthermore, the trend is toward even earlier maturing cultivars than the first modern rices such as IR8. The newest cultivars mature much earlier than did traditional rices, which makes early and timely weed control extremely critical for obtaining high yields.

However, with the higher rates of fertilizer applied to modern rices, weeds if unchecked use greater amount of nutrients. In one study in India, unchecked weeds removed 20 kg N, 3 kg P, and 33 kg K per hectare and caused a yield reduction of 1.4 t/ ha (Table 1). The competitive ability of modern rices can be increased by using cultural practices that favor rice growth at the expense of weed growth.

Weed control has always been a major input in rice production throughout monsoon Asia. A large portion of the total labor traditionally is required for weeding. Only recently have herbicides begun to play a role in minimizing yield losses to weeds.

The choice of the weed control methods depends on the technology available, the type of rice culture, and farmer's resources. The cost of the method must be compared with the value of the resulting yield increase (De Datta and Barker 1977).

## METHODS OF WEED CONTROL

No single weed control method will give continuous and effective control. In fact, no single method will effectively control weeds in all situations. Weeds vary in their growth habits and life cycles. Weed control is achieved through direct methods used within systems of indirect methods such as land preparation, water control, planting method, and even fertility management.

Farmers in most countries in monsoon Asia use some direct weed control, including hand weeding, mechanical weeding, and herbicides.

### Hand and mechanical weeding

In irrigated transplanted rice, hand weeding is the most common weed control method. In many locations in South and Southeast Asia, studies show that hand weeding and harvesting are two of the most labor-intensive operations in growing modern rice cultivars (Table 2).

**Table 1. Effects of weed control practiceson nutrient uptake by weeds and rice[a] (adapted from Reddy and Hukkeri 1980).**

| Weed control treatment | Nutrient uptake (kg/ha) | | | | | | Weed dry matter (t/ha) | Grain yield (t/ha) |
|---|---|---|---|---|---|---|---|---|
| | N | | P | | K | | | |
| | Weed | crop | Weed | Crop | Weed | Crop | | |
| No weeding | 20 | 45 | 3 | 6 | 33 | 55 | 2.9 | 2.6 |
| Manual weeding | 6 | 64 | 1 | 8 | 7 | 72 | 0.7 | 4.0 |
| Butachlor (G) | 13 | 56 | 2 | 7 | 20 | 68 | 1.9 | 3.6 |

[a]Average of 1974 and 1975.

**Table 2. Labor use for various operations in producing modern rice varieties by farmers in contemporary Asia.**

| Site | Year | Labor use (days/ha) | | | | | Source |
|---|---|---|---|---|---|---|---|
| | | Land preparation | Crop establishment | Fertilizer management, water, and insect control[a] | Weed control | Harvest, postharvest | |
| Bangladesh | 1979 | 52 | 77 | 15 | 62 | 74 | AERU 1979 |
| Nepal | 1978 | 33 | 27 | n.a. | 18 | 46 | Flinn et a1 1980 |
| Indonesia (Java) | 1980[b] | 31 | 45 | 7 | 41[c] | 57 | Collier et a1 1981 |
| Taiwan (central) | 1972 | 9 | 14 | 25 | 19 | 17 | Tsai 1976 |
| Philippines (Laguna) | 1978 | 14 | 10 | 7 | 21 | 28 | IRRI |
| Philippines (Central Luzon) | 1979 | 19 | 22 | 14 | 5 | 26 | IRRI |
| Malaysia (West) | 1979 | 16 | 55 | 18 | 20 | 80 | Taylor 1980 |
| Sri Lanka (mid-country) | 1974 | 43 | 51 | 19 | 5 | 40 | Amerasinghe 1975 |

[a] n.a. = not available. [b] Assuming 6 h/day. [c] Weeding, guarding, and water management.

Some simple machines have been developed, but machine weeding is feasible only when rice is planted in straight rows. Among the machines, the rotary weeder is by far the most efficient for controlling weeds of transplanted rice. It may be pushed manually or powered by a small gasoline engine. Human-powered rotary weeding combined with other methods of weed control is widely used in some provinces in the Philippines (Smith and Gascon 1979). Some modifications of this basic device are used in many countries in South and Southeast Asia, The rotary weeder is not used widely in India, despite being recommended (Ramiah 1954). Gasoline-powered small weeders have been popular in Japan.

As labor costs rise, less labor-intensive methods are needed to reduce the time and effort involved in mechanical and hand weeding.

## Chemical weed control

Chemical weed control combined with other cultural practices offers alternatives to mechanical means and, with improved water control, may be practical in reducing weed competition, crop losses, and labor costs. Several herbicides are now available to Asian rice growers at reasonable costs. Many more new herbicides being tested and developed will provide effective and economical weed control under the range of cultural practices used to produce rice in Asia.

In some instances, herbicides offer practical, effective, and economical means of reducing weed competition and production losses. Details on types of herbicides and their use in rice were discussed by De Datta (1981).

*Herbicides for transplanted rice.* The chlorophenoxy herbicides 2,4-D and MCPA have been available throughout most of Asia for 30 years. Rice growers routinely use them for postemergence control of annual broadleaf weeds such as *M. vaginalis* and *Sphenoclea zeylanica* and sedges such as *Cyperus difformis, C. iria,* and *Fimbristylis littoralis.* The most common formulations are the sodium and potassium salts available as water-soluble powder or water-soluble liquid. Preemergence applications of 2,4-D and MCPA also are effective for most annual weeds, including grassy weeds (De Datta et a1 1968).

Several granular formulations of phenoxy herbicides now available provide excellent control of most annual weeds at a reasonable cost where water control in the rice field is good.

The selective herbicide propanil, available for about 15 years, provides post-emergence control of annual grasses and some broadleaf weeds and sedges under most cultural conditions. But in a tropical monsoon climate, propanil has some distinct disadvantages. To drain the fields to expose the weeds before application and to reflood after spraying require a degree of water control not generally available in tropical Asia. Propanil alone or in combination with other herbicides or other methods of weeding has been used by a few farmers in India for a number of years (Mukhopadhyay 1978).

Other selective herbicides available in many tropical Asian countries for use on rice are butachlor and thiobencarb. Butachlor controls many annual grasses, broad-leaf weeds, and sedges and can be applied preemergence or postemergence. It is available in granular as well as in liquid formulations in tropical countries in South and Southeast Asia. Thiobencarb also is highly effective against most annual grasses, broadleaf weeds, and sedges. Remarkable selectivity against *Echinochloa* and other weeds and good residual effects make thiobencarb an excellent herbicide for flooded rice.

Chemical weed control has been extensively evaluated in many locations in South and Southeast Asia.

A number of advanced trials are conducted annually with irrigation at IRRI and at other experiment stations in cooperation with the Philippine Bureau of Plant Industry. In 1980 dry season irrigated experiments, most herbicide-treated plots yielded as well as hand-weeded check plots and significantly higher than untreated check plots. At Maligaya, herbicide-treated plots did not significantly differ in grain yield from untreated check plots. Infestations of *Echinochloa crus-galli* ssp. *hispidula, E. glabrescens, C. difformis,* and *M. vaginalis* were common at all sites. *Scirpus maritimus* and *Paspalum paspalodes* were present at the IRRI sites, *Cyperus imbricatus* and *S. zeylanica* at the Bicol site.

Chemical weed control has been extensively evaluated against hand weeding in India (Chauhanet a1 1975, Dubey 1976, Rangiahet a1 1976, Bhattacharya 1977, Gill et a1 1977). Bhan and Singh (1979) suggest that the herbicides effective in transplanted rice are propanil, butachlor, nitrofen, and fluchloralin (Table 3).

Pandey and Sharma (1980) found that a number of herbicides gave grain yields similar to those with one hand weeding and significantly higher than for no weed control treatment.

*Herbicides for direct-seeded flooded rice.* Direct-seeded flooded rice culture will become an increasingly attractive alternative to transplanted rice as the costs of labor rise, as less expensive selective herbicides become available, and as water control improves (De Datta 1977). Even under present conditions, in many areas yields of transplanted and direct-seeded rice are comparable.

The switch from transplanted to direct-seeded rice culture is extensive in some provinces in the Philippines. In the Bicol region, farmers are switching to direct seeding as early-maturing rices become increasingly available, as irrigation is improved, and as herbicides become available. The most common practice is to spray butachlor 4 to 8 days after seeding pregerminated rice, followed by 2,4-D spray 15 to 20 days after seeding.

In the tropics, butachlor, piperophos-dimethametryn, and butralin control weeds in direct-seeded flooded rice (De Datta and Bernasor 1973). Butachlor and thioben-

**Table 3. Amount and time of application of herbicides used in India.**

| Herbicide | Formulation | Application | |
|---|---|---|---|
| | | Rate | Time[a] |
| Propanil | Liquid | 8-9 liters/ha | 2- to 3-leaf stage of weeds |
| Butachlor | Liquid | 4-5 liters/ha | Preemergence of weeds |
| Butachlor | Granule | 30-40 kg/ha | 2-3 DT |
| Fluchloralin | Liquid | 1.5-2 liters/ha | Preemergence of weeds (2 DT) |
| Fluchloralin | Granule | 50-60 kg/ha | 2-3 DT |
| Nitrofen | Granule | 20-25 kg/ha | 2-3 DT |

[a] DT = days after transplanting.

carb are perhaps the most widely tested in direct-seeded rice. Some results are encouraging (Kannaiyan et a1 1981) but by no means uniformly positive (Ahmed and Hoque 1981).

**Water regime and chemical weed control**

The moisture regime is a key factor in weed growth and its control with herbicides. In Taiwan, where intermittent irrigation is common, heavy weed infestations are a problem in farmers' fields (Chang 1967). De Datta and Williams (1968) reported that the highest number of weeds in transplanted rice occurred in plots that were continuously flooded to a depth of 15 cm. But it is uncommon to have this much water in irrigated rice areas in the tropics.

On the other hand, in some areas with uncontrolled flooding, water 15 cm or deeper helps control weeds with little or no direct input. Navarez et a1 (1979) reported that, with continuous flooding, all treatments gave equally effective weed control. But the degree of control vaned significantly with moisture regime. Even hand weeding and rotary weeding (passed through the crop in two directions) could not effectively control more than half the weeds in the treatment that was dry the first 28 days after seeding.

Herbigation, a recent innovation in chemical weed control, meters herbicides into irrigation water. Control of *E. crus-galli* in rice was examined in the Murrumbidgee Irrigation Area of New South Wales, Australia (Barnett and Capper 1979). Yield data comparing application by herbigation and by conventional methods were taken at three sites. Herbigation gave weed control and yields equal or superior to those with conventional application methods. Herbigation should be evaluated under tropical monsoon environments before its use is suggested to farmers.

## INTEGRATION OF WEED CONTROL MANAGEMENT SYSTEMS

It is difficult to increase agricultural yields without effective integrated weed management systems that utilize the best combinations of principles, practices, technologies, and strategies. Each weed control method has advantages and disadvantages. None is applicable in all cases because of the wide variability of growth habits and life cycles.

There is growing concern that continuous use of one method of weed control, such as land preparation, interrow cultivation, or herbicides, will increase the number of weed species tolerant of the control method used. This happened in rice fields in Japan (Kataoka 1980) and Korea (Kim 1980). In the Philippines, research data clearly suggest that continuous rice production under a similar land and water management system would lead to buildup of the same or similar weeds — mostly perennials (De Datta and Jereza 1976). Therefore, it is essential to combine methods of weed control or to change from one system to another to avoid buildup of perennial weeds.

Effective systems that include herbicides and associated chemical weed control technology have accounted for more than 10% of the total increase in U.S farm output since 1940 (Shaw 1981). Advances in weed control technology gave a wide choice of row spacings, plant spacings in the row, and plant populations. They also made it possible to modify tillage and cultivation techniques that require large amounts of energy and other resources.

These benefits of the technology of integrated weed management systems led to the use of and increased research on combinations of weeding methods that are likely to prove more effective than any single factor in alleviating the buildup of a difficult-to-control weed or group of weeds.

## ECONOMICS OF ALTERNATIVE WEED CONTROL PRACTICES

Despite the evidence that herbicides are effective on rice, hand weeding is still the main method of direct weed control in tropical Asia. Table 4 illustrates the range of direct weed control inputs commonly used by Asian rice farmers in the 1970s. Labor and herbicide inputs at farm-level prices were converted to the equivalent value of rough rice. These data from farm surveys illustrate the combinations used and should not be interpreted as representing national levels, although they do suggest relative differences.

At one extreme are the studies from Bangladesh, which report more than 60 labor days/ ha used for manual control of weeds and no chemicals used. The data from Java, Indonesia, also show a high level of manual weed control, but only half that of Bangladesh. Taiwan and Philippine studies show intermediate levels of hand labor and herbicide use. Sri Lanka and Thailand studies show very little hand labor or expenditure for weed control.

Nearly 200 herbicides — often chemically and functionally diverse and highly selective — are available for use on various crops, including rice, throughout the world. In Asia, Japan, Taiwan, and the Republic of Korea lead in their use.

Development of weed control technology has led to significant changes in Japanese rice culture. Rice transplanting machines are used in 90% of the rice area and 2- to 4-leaf seedlings are transplanted, somewhat younger than when manual weed control was used. Recently, mechanical weeding has been considerably reduced (Kataoka 1980). Herbicide use has increased to an average 2.5 treatments per hectare of rice. Increases have been rapid since around 1960. In general, herbicides are applied two or three times in colder areas and one or two times in warmer areas. One application may be soil treatment during the puddling process, followed by foliar and soil applications after transplanting. Those may be followed by a combination of soil and foliar applications and a final foliar application. Timing of these multiple applications is shown in Figure 1. As a result of increased herbicide use, the ratio of weeding hours to total labor hours for rice has decreased (Fig. 2).

In Taiwan, herbicides to control weeds in rice were first registered in 1965. Their use was steadily increased since 1970. In 1978, more than 91% of the total rice area was treated with herbicides. Currently, 18 single herbicides and 22 formulation mixtures have been registered for rice in Taiwan (Chiang et a1 1980).

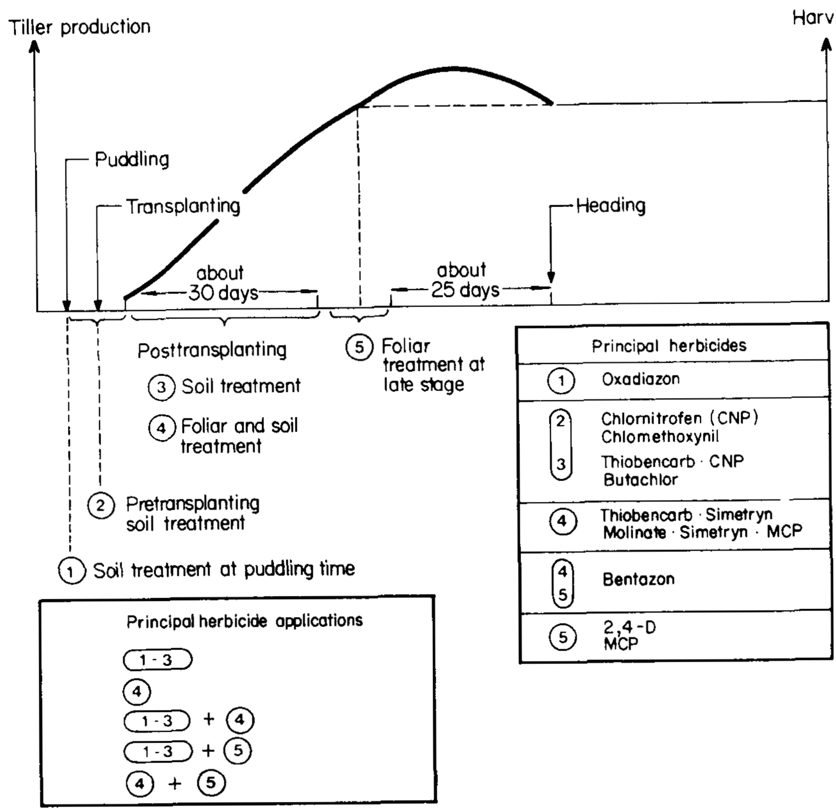
In the Republic of Korea, herbicide use increased from 127 t in 1966 to about 30,000 t in 1978 (Kim 1980). Recent estimates suggest that in at least 75% of the rice area herbicides are used.

Some herbicides are commercially available in India (Table 5). Butachlor is extensively used in areas of labor shortage, such as in the state of Punjab, where sales

**Table 4. Weed control inputs, yields, and value of outputs reported in selected countries of Asia, 1968-72.**

| Site | Year | Direct weed control inputs | | | | Yield (t/ha) | Value of output[c] (US$/ha) | Source |
|---|---|---|---|---|---|---|---|---|
| | | Labor (days/ha) | Value in kg rough rice/ha[a] | | | | | |
| | | | Labor[b] | Herbi-cide | Total | | | |
| Thailand (Central) | 1968 | 0 | 0 | 6 | 6 | 2.05 | 128 | Green 1970 |
| Philippines (Central Luzon) | 1979 | 6 | 79 | 30 | 109 | 3.37 | 488 | IRRI |
| Indonesia (Java) | 1980 | 36 | 108[d] | 0 | 108 | 3.34 | 641 | Collier et al 1981 |
| Bangladesh | 1979 | 62 | 232 | 0 | 232 | 2.69 | 380 | AERU 1979 |
| Malaysia (West) | 1979 | 20 | 263 | 25[e] | 288 | 2.31 | 419 | Taylor 1980 |
| Philippines (Laguna) | 1978 | 27 | 294 | 39 | 333 | 3.50 | 473 | IRRI |
| Taiwan (Central) | 1972 | 19 | 380 | 0 | 380 | 5.03 | 503 | Tsai 1976 |

[a]Rough rice valued at Tk 2.12/kg in Bangladesh, Rp 120/kg in Indonesia, NT$4.00/kg in Taiwan, ₱1.00/kg in the Philippines, $1.25/kg in Thailand, M$0.39/kg in Malaysia. [b]Labor valued at Tk 7.90/day in Bangladesh, Rp 360/day in Indonesia, NT$80/day in Taiwan, ₱12.80/day in Laguna, Philippines, ₱8.80/day in Central Luzon, Philippines, ฿10/day in Thailand, M$5.12/day in Malaysia. [c]Domestic currency per US$: Bangladesh Tk 15/$, Indonesia Rp 625/$, Taiwan NT$40/$, Philippines ₱7.40/$, Thailand ฿20/$, Malaysia M$2.15/$. [d]Using a real wage of 2 kg rice/day (3 kg rough rice) (Collier et al 1981). [e]Half of all insecticides and herbicides.




1. Herbicide application schedule during a transplanted rice cropping period in Japan (adapted from Kataoka 1980).

**Table 5. Herbicides available commercially in India, 1976.**

| Common name | Application time | Formulation available | | |
|---|---|---|---|---|
| | | Liquid | Granules | Wettable powder |
| Butachlor | Preemergence | x | x | |
| Fluchloralin | Preemergence | x | | |
| Nitrofen | Preemergence | x | x | |
| Propanil | Postemergence | x | | |
| 2,4-D (amine) | Postemergence | x | | |
| 2,4-D (ethyl ester) | Preemergence and post-emergence | x | x | x |
| 2.4-D (Na-salt) | Postemergence | | | x |

exceed $1 million. In areas of surplus labor and poor water control, such as northeast India, herbicides are seldom used (Mukhopadhyay 1978).

In the Philippines, a recent estimate suggests that herbicides are used on about 1.2 million hectares of rice land in the wet season and on about 0.8 million hectares in the dry season (total rice area = 3.4 million hectares). The herbicides include phenoxy acids, butachlor, thiobencarb with or without 2,4-D, and piperophos-dimethametryn. In most instances, they are used with other cultural practices such as hand weeding or rotary weeding (De Datta 1980).

The use of herbicides for rice is limited in Malaysia (Saharan 1977). But because of an increasing labor shortage and because rice is a high value crop, herbicide use is expected to increase.

In Thailand, chemical weed control in rice is not common except for the phenoxy acid-type herbicides used in some irrigated areas. Because much of the Central Plain has excess water during the monsoon season, chemical weed control may not be effective. Hand weeding once or twice is practiced in some transplanted rice (Noda 1979).

In Bangladesh, hand weeding is the most common practice for direct control of weeds in the transplanted wet season crop and the irrigated dry season crop. Several operations to prepare land often are used to minimize weed infestation. Some researchers have suggested that herbicides such as nitrofen can be used economically (Mian and Gaffer 1968, Ahmed and Talukder 1977), but farmers have not adopted them on any scale.

In Pakistan, where rice is entirely an irrigated crop, proper water management with selective herbicides has shown promising results (Ahmad et al 1975).

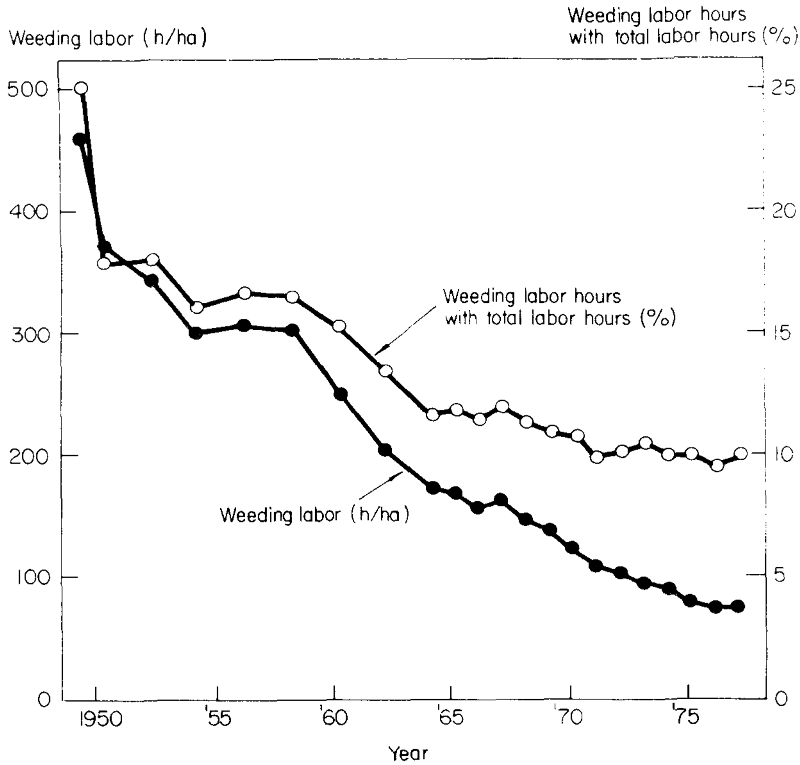
In South Sulawesi, Indonesia, some farmers started to use MCPA in 1976. In 1978, 2,4-D amine was introduced. In general, farm sizes are 1-2 ha in South Sulawesi, and an average of less than 0.5 ha in Java. Cost of hand weeding in South Sulawesi is US$12-16/ha; phenoxy acid herbicides cost US$4-6.50/ha. As a result, more farmers resort to low cost herbicides and spot hand weeding (Sundaru 1980).

In South and Southeast Asia, herbicide use is limited to 2,4-D type compounds that cost about US$10/ha. Use of selective herbicides is increasing steadily in some countries as more areas are brought under irrigation and direct seeding of pregerminated seeds on puddled fields increase. Newer and shorter duration cultivars that helped increase cropping intensity also have created an increased demand for timely and efficient weed control technology.

## THE IMPORTANCE OF WEED CONTROL

Many of the practices common in Asian rice production contribute indirectly to weed control (Fig. 3). Land preparation, especially harrowing and puddling, help. Transplanted seedlings have a headstart on weeds but they must overcome the transplanting shock. Keeping water standing in the field retards weed growth. Farmers may delay fertilizer applications beyond what would be optimal with complete weed control to keep the fertilizer from stimulating excessive weed growth.

However, unlike the creation of new cultivars or the application of fertilizer or the provision of optimal water, the best weed control can only prevent yield losses. Weed control can never raise yields beyond the potential set by the plant and the available nutrients, water, and solar radiation. Farmers seem to adjust the intensity of weed control in line with the potential productivity of the crop as it is grown under their

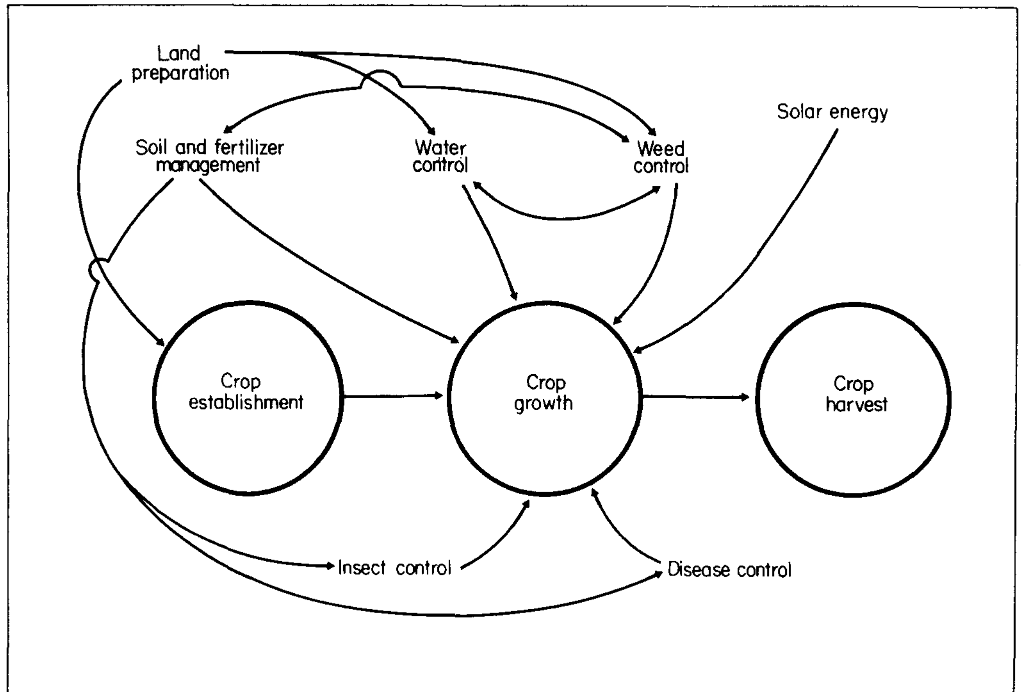



**2.** Labor hours for weeding and ratio of weeding labor hours to total labor hours in ricefields in Japan, 1950-70 (adapted from Kataoka 1980).

conditions. As a result, weed control is much more intensive where yields are high. But intensive weed control will not have much impact on yields where water control, cultivars, and other factors are limiting.

In the constraints project, the high levels of weed control, insect control, fertilizer, and sometimes other manageable inputs were compared with farmers' levels of the same inputs in farmers' fields. A high level of weed control generally contributed only modestly to increased yield.

In dry season boro trials in Bangladesh, high weed control increased yields by 0.26 t/ ha, 20% of the total yield gap of 1.33 t/ ha (Hoque et a1 1979). In dry season trials in Yogyakarta, Indonesia, high level weed control increased yields by 0.3 t/ ha, 25% of the total yield gap (Widodo et a1 1979). In trials in the Central Plain of Thailand, where farmers averaged less than one complete weed control treatment per season, a high weed control level of one hand and one chemical weeding increased yields an average of 0.28 t/ ha of the total yield gap of 1.5 t/ ha (Kamphol et a1 1979). At 3 sites in Sri Lanka, high level weed control increased yields an average of 0.1 t/ ha out of the total yield gap of 0.5 t/ ha (Jogaratnam et a1 1979). Similar results were obtained at four Philippine sites.

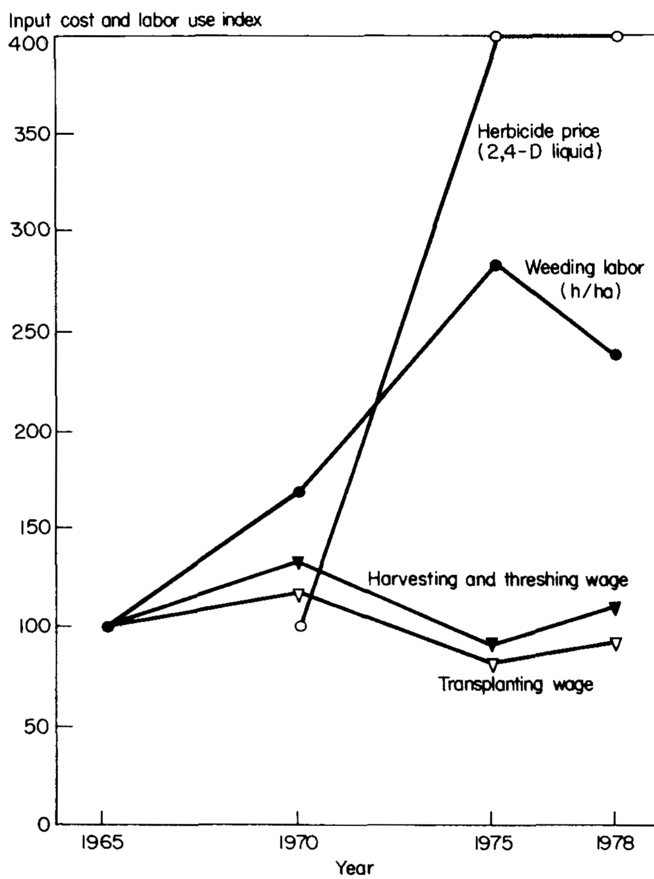



3. Key functions in rice production (adapted from Herdt 1981).

## FACTORS ASSOCIATED WITH FARMERS CHOICE OF TECHNOLOGY

Farmers choose the combination of weed control inputs that will provide the desired degree of weed control at the lowest cost. Therefore, input prices are an important factor determining input use.

In Laguna, Philippines, use of weeding labor increased when herbicide prices increased sharply and wages declined (Fig. 4). Weeding labor per ha decreased when wage rates increased and herbicide price remained fixed. The declining use of labor




**4.** Effect of relative input costs on weeding labor for 45 Laguna (Philippines) farmers, 1965-78 (adapted from Smith and Gascon 1979).

for weed control in Japan was also related to rising relative labor costs (Kataoka 1980).

Other factors also are associated with choice of technology. The extreme heterogeneity of input systems, even within irrigated transplanted growing conditions, suggests that given methods of control will perform with different effectiveness in different environments. One would expect even greater contrasts between rainfed and irrigated or broadcast and transplanted cultures.

As irrigation, fertilizer, and yields improved in Central Luzon, Philippines, between 1966 and 1979, the use of direct weed control methods increased on both irrigated and rainfed farms (Table 6). More farmers with irrigation used herbicides, both alone and in combination with hand weeding. Only 8% of the farmers with irrigation used no weed control, compared to 22% of the farmers with rainfed fields.

In Iloilo, Philippines, more of the farmers growing rainfed transplanted rice used weed control, either by hand or herbicides (Table 7). But those with irrigated rice who did weed, either by hand or with a combination of herbicides and hand, spent about twice as much per hectare as did the rainfed farmers.

Because weeds in broadcast rice are more difficult to control using mechanical or hand weeding methods, it would seem that farmers switching to broadcast wet- or dry-seeded rice would also switch to herbicides. But 5 years of farm records in Iloilo, Philippines, indicate that farmers adopt the 2 technologies somewhat independently. The top panel of Figure 5 shows that wet seeding (WSR) technology was rapidly

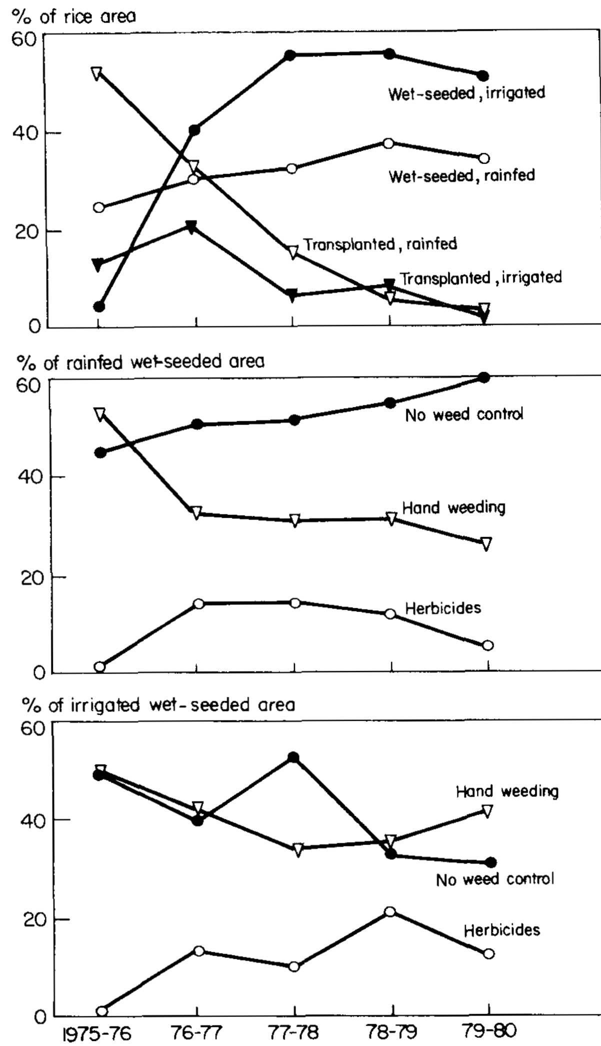
**Table 6. Use of 4 weed control methods (as reported by farmers in the Coop Survey in Central Luzon. Philippines, 1966[a] and 1979 wet seasons).**

| Weed control method | Irrigated | | | | Rainfed | | | |
|---|---|---|---|---|---|---|---|---|
| | 1966 | | 1979 | | 1966 | | 1979 | |
| | No. | % | No. | % | No. | % | No. | % |
| No weed control | 14 | 27 | 8 | 8 | 12 | 36 | 10 | 22 |
| Hand weeding only[b] | 31 | 61 | 26 | 26 | 23 | 63 | 21 | 47 |
| Herbicide only[c] | 2 | 4 | 25 | 25 | 0 | 0 | 8 | 18 |
| Herbicide plus hand weeding | 4 | 8 | 41 | 41 | 2 | 5 | 6 | 13 |
| Total surveyed | 51 | 100 | 100 | 100 | 31 | 100 | 45 | 100 |

[a]Of 4 farms that used a rotary weeder, 3 were rainfed and irrigated farms. [b]In 1979, 3 farms had mixed type irrigation. [c]In 1979, 1 farm had mixed type irrigation.

**Table 7. Use of weed control inputs by record-keeping farms in 2 villages of Iloilo Province, Philippines, 1975-79.**

| Weed control input | Irrigated | | Rainfed | |
|---|---|---|---|---|
| | % using | Cost/ha (₱) | % using | Cost/ha (₱) |
| No weed control | 65 | 0 | 41 | 0 |
| Hand weeding only | 18 | 134 | 39 | 75 |
| Herbicide only | 12 | 74 | 11 | 85 |
| Herbicide plus hand weeding | 3 | 63 | 7 | 30 |




**5.** Changes in rice stand establishment and weed control methods used by record-heeping farmers in 2 villages of Iloilo, Philippines.

adopted by the study farmers after 1975-76. The proportion of the rainfed WSR area that received no weed control input actually increased over time, from 45% to 65% of the area. The proportion of irrigated WSR that received no weed control decreased steadily, except for 1 year. The use of herbicides was erratic, suggesting that farmers were seeking an appropriate technology, but the use of hand weeding increased.

Amerasinghe (1975-76) reported that weeding labor increased from 3.8 to 7.1 days/ ha with the switch from broadcast-seeded traditional varieties to transplanted modem varieties in the Minipe Colonization Scheme in Sri Lanka.

Lokaphadhana (1976) compared the costs associated with producing broadcast and transplanted rice in the dry season in Chaochangsao, Thailand. Weeding labor cost US$2.7/ha on broadcast rice and US$2.2/ha on transplanted rice. There was no difference in the costs of material inputs used.

This suggests little difference in weed control practices between farmers with rainfed and irrigated fields or between farmers using transplanting and direct seeding in the same area. This may be because of habit or simply because economic forces are more important than differences in effectiveness. The speed with which farmers adopt a technology when conditions are right suggests that habit has less hold than many believe. In one study area in Thailand, for example, 80% of the farmers in all sizes of farms adopted herbicides over a 10-year period (Green 1970).

The combination of inputs chosen is determined by their relative prices, and the total expenditure on weed control is determined by its effectiveness and cost relative to the total value of the crop. Where technology is high and growing conditions are good, yields are high. If prices are also high, farmers put in high inputs. But where the level of technology is such that total output value is low farmers do not exert much effort on weed control.

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## DISCUSSION

BURRILL: In our efforts to promote weed science around the world we often find ourselves describing manual weeding as a very unpleasant task. Based on your observations, are we able to believe that the people actually doing this task also find it that unpleasant? Is the value they place on leisure time so low that it is something to consider in the evaluation of manual labor vs other technology?

*HERDT:* Clearly people do weigh the value of their time in deciding whether they will do hand weeding. When they have few alternatives for using their time and if they can make a daily wage sufficient to overcome their reluctance to do the work, they will do it. In fact, that happens very extensively throughout Asia; that is why we see so much hand weeding going on. Farmers are willing to pay a wage sufficient to induce people to do the weeding. If you ask them whether they would rather be weeding or sitting under a tree, I am sure they will tell you they would rather be sitting under a tree. But they still have to eat, so the wage being paid is sufficient to induce them to work. If the wage required to induce people to do hand weeding gets too high. the farmer may not be willing to pay it if he has some better alternative.

SETH: In fact, quite a number of people use family labor, and not hired labor, to do weed control. In that situation it is the availability of free cash which is the constraint. If the farmer had spare cash to buy herbicides, he would much rather use hebicides than use family labor.

*HERDT:* It is the same thing. It still depends on the value of that cash to him. He may want to reserve the cash for some other purpose.

SETH: That is why I said spare cash.

*HERDT:* What is spare cash? Who has spare cash? There is always an opportunity for that cash to be reserved or used for something. So the farmer is continually making judgments, such as: If I use my cash to buy herbicides, I won’t have it available for something else. If I don’t use my family labor for weed control, maybe I don’t have anything else pressing to do with the family labor at that time. Certainly, when cash becomes relatively more available when income levels rise, then we do see a tendency to replace family labor. However, if hired labor gets expensive, you don’t use it either.

*DE DATTA:* Whenever we say that hand weeding is a major system, it is not zero herbicide or zero other methods of weed control. Already in the Philippines one-third of the rice area farmers are using some kind of herbicide. Hardly any herbicide was used in 1965-67. Except in a few isolated cases, herbicides have moved in. Even where hand weeding is used, so are some chemicals. Dr. Barker mentioned Sulawesi. As recently as 1967-77, these farmers were using mostly hand weeding or no weeding. Now, herbicide cost is $4-$6.50/ha, against a hand weeding cost, if you put a cost figure, of $16/ha. As a result, a very large number of farmers in Sulawesi, where the holdings are larger than in Java, are using some phenoxy herbicides whereas in Java there is very little herbicide use. So, as labor cost is going up, farmers will be looking, not to completely replacing hand labor, but using it as a complementary practice.

VEGA: With respect to the yield gap, it may be useful to indicate that while weeds are responsible for 11% of the yield gap, farmers are using effective methods for controlling their weeds.

*DE DATTA:* We are not comparing zero weed control and researchers’ weed control. It is farmers’ weed control practices compared to what researchers can get with improved technology. It is hard to compete with hand weeding. If you use a herbicide, you show some increase but it is not dramatic. In the case of insect control, the farmer cannot remove those insects by hand. He doesn’t have any alternative but to use chemicals. The same is true for fertilizer. You can minimize the amount of fertilizer needed by using azolla or organic manure or organic recycling, but still you have to put on some fertilizer, especially in the dry season. As rice prices go up, even that 10% would be quite important. But right now the farmer seems to do a reasonably good job with the technology available to him. given the price of rice and the price of inputs.

EASTIN: With the technology we are using today, weeds are costing us 15%.

MATTHEWS: I think I am correct in saying that only 33% of the world's rice has controlled water application. I would like to see your diagram for where there is no water control.

*DE DATTA:* I think the next paper should address that issue. My mandate was irrigated rice.

*HERDT:* Exactly the same kind of results were shown for an area in the Bicol, Philippines, region which was strictly rainfed. The proportional reduction was almost exactly the same as Dr. De Datta showed. I think we should emphasize that we are comparing zero weed control, what the farmer is doing in weed control, what the researcher can do under farmers' conditions for weed control, and perfect weed control. If you want to talk about the difference between zero and perfect weed control, that is one thing. But we are talking about what the farmer is doing and what the researcher can do under the farmer's conditions. That is the yield gap that Dr. De Datta was talking about.

O'BRIEN: People are talking about the cost of weeds and these 15% reductions under existing practices or 95% reductions under no weed control. That is not the total cost of weeds. That is the cost of the weeds that remain in the field. There is also the cost of removing the weeds that you did remove. Both these add up to the total cost.

MATTHEWS: Our data are fairly complete on direct losses due to weeds. But there is very very little data on indirect losses, such as storage losses by weed seed contamination. We have just reviewed 714 references from Weed Abstracts for Tropical Agriculture and found fewer than 10 references to indirect losses. This is the field to which weed scientists need to pay more attention.

# WEED CONTROL TECHNOLOGY IN RAINFED WETLAND RICE

S. K. Mukhopadhyay

Weed control technology in rainfed wetland rice fields in all situations — transplanted, direct-seeded flooded. and initially dry-seeded then cultivated as a crop under submergence with heavy monsoon rains — is reviewed. Particular emphasis is given to the nature of weed problems and methods of weed control using substitutive-preventive methods. complementary methods, and direct methods by manual or mechanical means. A combination of cultural practices and rational herbicide use appears to be the reasonable weed control technology in wetland rainfed rice areas, particularly in developing countries such as India and those in Southeast Asia.

The rainfed wetland rice area includes all rice-growing areas except those that are irrigated, those where water exceeds 1 m in depth. and dryland fields where water normally is not impounded. Barker and Herdt (1979) estimated that about one-third of the world's rice land is rainfed. Most of the rainfed wetland rice is grown in South and Southeast Asia. The lowland plains and river floodplains probably account for half to two-thirds of the total rainfed rice area. The rainfed rice area is divided into shallow rainfed (5-15 cm deep water) and medium-deep rainfed (16-100 cm deep water). The medium-deep is further subdivided into intermediate deep rainfed (15-50 cm) and semideep rainfed (51-100 cm). About two-thirds of the rainfed rice area in

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Asia is shallow rainfed (Barker and Herdt 1979). The rainfed areas can be divided topographically into lowland plains, river floodplains, terraces, and plateaus. Much of the rainfed rice in the lowland plains and river floodplains of South and Southeast Asia is located in four major river deltas: the Mekong in Vietnam, Chao phraya in Thailand, Irrawaddy in Burma, and Ganges-Brahmaputra in India and Bangladesh. The soil and water problems in the deltas differ markedly from those of the terraces and plateaus.

Rainfed wetland rice in India, Bangladesh, and Southeast Asia is generally cultivated in the wet season as transplanted rice. In another type of rice culture, the land is cultivated and puddled, pregerminated rice seeds are broadcast, and the rice crop is grown as a rainfed direct-seeded puddled crop. In the third type of rainfed wetland culture rice is dry-seeded, but as the rainy season progresses water accumulates in the field and the crop frequently finishes its life cycle as a wetland crop.

Weeds are a more serious problem in the production of dry-seeded rice than in other rice cultures. A much wider range and intensity of weed problems can be expected in dry-seeded rice than in puddled wet-seeded or transplanted rice because of differences in land preparation, the lack of water at the early stage of crop growth, and because weeds germinate at the same time as dry-seeded rice. More weeds occur and the composition of the weed flora is different when rice is planted in dry soil than when it is planted in puddled soil. Variations occur in the weed flora growing in association with dry-seeded rice between and within sites and over time. In some instances weed competition in dry-seeded rice is so severe that failure to control weeds may result in complete crop failure. In the past, attempts to introduce dry-seeded rice have failed because of lack of appropriate weed control technology. In the case of direct-seeded rice in puddled fields, the weed problem is not as severe as in dry-seeded rice. In rainfed transplanted rice the weed problem is usually less than in other types of rice culture. In dry-seeded unpuddled rainfed fields *Echinochloa colona* and *Cyperus rotundus* are the major weeds. In the puddled direct-seeded rainfed rice, *E. colona* and *Fimbristylis littoralis* predominate. In transplanted rainfed rice algal weeds such as *Chara, Nitella,* and *Eriocaulon* spp. are usually predominant. In the coastal areas of South Bengal and Orissa they are a serious problem in transplanted rice fields. Studies at the Central Rice Research Institute of India showed that in the absence of weed control, the yield loss due to weeds was 46% if rice was direct-seeded in dry soil, 20% if direct-seeded in puddled soil, and only 11% when rice was transplanted in puddled fields (De Datta 1981). At Visva-Bharati University in India, yield loss due to weeds was 90% in direct-seeded puddled rice and 17% in transplanted rice (Mukhopadhyay 1981).

## WEED CONTROL METHODS

No weed control measure will give continuous and effective weed control when used in isolation. The final choice is largely a combination of two or more methods depending on their effectiveness and economy.

### Substitutive-preventive methods

*Stale seedbed technique.* The stale seedbed technique involves the removal of successive flushes of weeds before planting rice. Weeds that germinate after land preparation are destroyed mechanically, manually, or chemically. If mechanical or manual method is used, soil disturbance should be as shallow as possible. Chemicals have the advantage of not bringing more weed seeds to the soil surface where conditions are favorable for germination. Herbicides should be applied or the field cultivated when most of the weed seeds in surface soil have germinated and are in 2- to 5-leaf stage. Paraquat, which has no residual toxicity, is suitable.

This method has been used successfully for dry-seeded rice establishment in India and Sri Lanka (Moody and Mian 1979) and in Pangasinan Province, Philippines (Moody 1980).

The stale seedbed technique gives no advantage if planting is delayed after the start of rains. Delayed planting results in more weed control difficulties (Moody 1977a) and may mean that mechanical or manual weed control techniques cannot be used because fields become too wet soon after crop establishment.

*Land preparation and puddling.* A common practice in rainfed rice-growing areas is to leave the field fallow during the dry season following harvest. Weeds grow and shed their seeds or multiply vegetatively. As a result intense weed problems may be encountered in the following crop, particularly in a dry-seeded crop (Moody 1980). There may be an advantage in plowing immediately after the rice crop is harvested instead of at the beginning of the next rainy season. Repeated tillage during the fallow period to prevent weeds from seeding and to expose vegetative propagules to drying results in a significant depression of weed seed reserves in the soil (Moody and Mian 1979). In China intense land preparation by rototilling and maintaining the fields as a clean fallow during the dry season are two methods of weed control in dry-seeded rice (Zandstra et al 1977). Land preparation during the dry season led to a significant reduction in the number of *Cyperus rotundus* but had no effect on the annual grass population (IRRI 1980). In India, particularly Eastern India, sometimes a pulse crop (*Kheshari-Lathyrus* sp.) is broadcast into the rice crop 15-20 days before harvest. As soon as the harvest is over, the pulse crop covers the field in the dry season by its rapid vegetative growth. In India during the dry season, *Sesbania aculeata* is grown as a green-manure crop and plowed down before transplanting the next rice crop in the monsoon season. This results in lower weed infestation in the succeeding main crop.

*Water management.* Many weeds will not germinate under flooded conditions. Types of weeds and weed emergence are closely related to the moisture content of the soil and water depth (Yamada 1965). Lack of water control is a major management constraint that increases the labor required for weeding (Moomaw et al 1966). About 80% of the rice grown in South and Southeast Asia is subjected to uncontrolled water supply, which exposes the rice land to various degrees of weed pressures (De Datta 1981).

In dry-seeded rainfed wetland rice, there is heavy competition of weeds for moisture in the early stage when there is no standing water. In later stages of the crop when there is standing water from rains, water management is important. In direct-seeded flooded rice, a depth of 10-20 cm water at the seedling stage reduces infestation of *Echinochloa crus-galli* (Smith and Shaw 1966). Maintaining 10-20 cm water in the field has long been practiced in California where water seeding is a common method of stand establishment. Precise water management with continuous flooding is an ideal substitute method of controlling weeds in direct-seeded flooded rice.

Water management can substitute for weeding in transplanted rice. Grass weed problems can be completely eliminated if continuous 15-cm flooding is maintained throughout crop growth. Because of standing water in the monsoon in northeastern India, the rainfed transplanted rice crop does not have much competition from grass weeds.

In northwestern India, even in the wet season it is not possible to maintain continuous submergence because of scanty rainfall. Thus, irrigation and chemical or mechanical weed control are essential.

**Complementary weed control methods**

*Cultivars.* The short, high yielding rice cultivars are less competitive against weeds than the tall traditional cultivars. Yield losses are greater and more time is spent in weeding.

The widespread replacement of traditional tall cultivars with modem cultivars may have increased weed problems throughout tropical Asia. Unlike the traditional cultivars that have droopy leaves, semidwarfs have erect leaves, more light penetrates the crop canopy, and more weeds emerge and survive. Furthermore, the high fertilizer rates used on modern rice cultivars aggravate weed problems (De Datta 1981). For rainfed areas, heavy tillering cultivars of medium stature may be better suited than semidwarfs. Even on experimental farms, intermediate-statured IR442-2-58 competed better with annual and perennial weeds than semidwarf IR20 (De Datta 1977a, b).

*Plant spacing and seeding rate.* In all types of rice culture, close spacing is essential to minimize weed infestation and to obtain high yields — the closer the rice plants are sown, the better they can compete with weeds.

*Planting method and seedling age.* Crop competition with weeds and weeding methods determine farmers' choice of rice planting methods. Transplanting in puddled soil is the major system in Asia. The transplanting operation helps incorporate weeds and weed seeds into the soil as the transplanters trample them during planting. Furthermore, transplanting encourages effective use of preemergence herbicides. Therefore, the herbicide application rate is often less than that needed for direct-seeded rice.

In tropical Asia, many farmers use tall, older seedlings of traditional tall cultivars in transplanted rainfed or irrigated rice culture. With modern semidwarf cultivars, manipulation of seedling age for weed control is not important if preemergence herbicides are used.

*Fertilizer management.* Nitrogen application should be timed to prevent weed proliferation and yet obtain maximum benefit from the fertilizer applied (Moody 1977b). With dry-seeded wetland rice, the basal application of fertilizer should be delayed until weeds are removed. The application of nitrogen in dry-seeded rice is unwise unless preemergence herbicides are used. Topdressing nitrogen after weeding is desirable to maximize nitrogen fertilizer efficiency and to minimize weed growth (De Datta 1981).

In Laguna, Philippines, applied nitrogen increased grain yield in farmers' fields by a maximum of 0.5 t/ha where weeds were not controlled. Without nitrogen fertilizer. weed control alone increased grain yield by 1.5 t/ha. Where weeds were controlled and nitrogen was applied at the rate of 30 kg/ha, grain yield was 1.0 t/ha more than without fertilizer application (De Datta and Barker 1977).

Weeds will absorb as much as, or more nutrients than. the rice crop. Boerema (1963) reported that the crop plus the weeds on an untreated plot absorbed the same amount of nitrogen as the crop alone on a weed-free plot (Table 1). De Datta and Jereza (1967) found that increased application of nitrogen benefited the grass population but did not benefit broadleaf weeds and sedges much.

*Cropping systems.* Crop rotation minimizes the undisturbed development of weeds. In many situations, crop rotation eliminates or at least reduces difficult weed problems. Various crop and soil management practices cause the weed community to shift from weed species that are difficult to control to weeds that are easier to control (De Datta and Jereza 1976).

Rotation of herbicides used in continuous rice cropping is also essential. This puts pressure on various weed species so that no single species or group of species develops undisturbed. More effective treatments and relevant cropping systems need to be developed for different weed population compositions to provide several equally effective alternatives that make the most efficient use of the farmers' resources.

## Direct weed control methods

*Hand weeding.* Hand or manual weeding can be done in broadcast and row-seeded rice, whereas mechanical weeding generally is feasible only where rice is planted in rows. An exception to this is the common practice in Bangladesh and West Bengal. India, where spike-tooth harrows are passed over the broadcast-seeded fields 5 to 15 days after emergence of the rice seedlings. This kills some weeds and also thins the rice seedlings where they are too dense. The resulting seedling mortality is overcome by the high seeding rate.

To prevent yield loss from weeds in dry-seeded rice, we need a better understanding of the biology of weeds that infest dry-seeded rice fields in South and Southeast Asia and the conditions that favor a specific weed or weed population. Emphasis should be placed on the control of perennial weeds such as *C. rotundus* (Moody and Mukhopadhyay 1982).

In transplanted rainfed rice, hand weeding is the most common control method.

**Table 1. Nitrogen uptake of weeds growing in association with rice.**[a]

| Plant species | Nitrogen uptake (kg/ha) | |
|---|---|---|
| | Weeds present | Weeds few or absent |
| Rice | 26 | 106 |
| *Echinochloa* spp. | 75 | 0.6 |

[a]Adapted from Boerema (1963).

One or at most two hand weedings should be sufficient to adequately control weeds in transplanted rice. The differences in grain yields between one hand weeding within 21 to 42 days after transplanting (DT) and 2 hand weedings were not significant. This suggests that one properly timed hand weeding may be adequate to reduce the weed population enough to obtain high yields. Because the weed population at the earlier stage is lower, hand weeding at 21 DT requires fewer labor hours (Tauro 1970). Hand weeding in dry-seeded rainfed rice may be very effective if done frequently, but it is extremely time-consuming and laborious.

*Mechanical weeding equipment.* Several hand tools such as the hoe, narrow spade, swiss hoe, machete, and knife are used to control weeds in dry-seeded wetland rice. Animal-drawn spike-tooth harrows are used in dry-seeded rainfed rice in India and the Philippines. The implement minimizes weed density, but is not an ideal method of weed control in modern agriculture.

For transplanted and direct-seeded flooded rice in India, the push-type rotary weeder is used if seeding and transplanting are in straight rows.

In a 1966 study, the labor for 2 rotary weedings (115 hours/ha) was half that for 2 hand weedings, but the grain yield was lower (De Datta 1981). The slightly lower yield with the rotary weeding was perhaps caused by the inability of rotary weeding to remove weeds within or close to rice hills.

*Herbicide use in rainfed wetland rice.* Herbicide use is limited to areas where labor is not plentiful and the wage rates are high. Herbicides are used extensively in the U.S. (Baker 1978, Smith and Seaman 1973), Australia, and Europe. In Asian countries, herbicides are commonly used in Taiwan, Republic of Korea, and Japan (De Datta and Barker 1977). In India, herbicide use is small in the traditional rice belt of northeastern and South India, but has become popular in recent years in Punjab and Haryana in the North (nontraditional rice belt).

In dry-seeded rainfed rice, herbicide use is greater because of high labor requirements for hand weeding, high wages, the scarcity of labor during peak periods, and unfavorable weather at weeding time.

In rainfed wetland rice, both wet-seeded and transplanted, weed control is more difficult than in irrigated wetland rice, but the problems are not as great as with dry-seeded rice (Moody 1979).

In dry-seeded rainfed rice, where in the beginning of the season the field has no standing water for about a month, preemergence herbicides (butachlor or nitrofen) check weed growth in the germinating crop. Because preemergence herbicides require a moist or wet soil for activation, timely rains after herbicide application are necessary. The residual effects of most preemergence herbicides are usually too short to give control until the fields are flooded. Sometimes, a follow-up hand weeding is recommended to control weeds that have been inadequately controlled by herbicide treatment.

Propanil applied postemergence showed excellent control of grasses at the 2- to 3-leaf stage (Mian and Rahaman 1969, Mukhopadhyay 1978). In the Philippines, results have consistently shown that single herbicide treatments are unsatisfactory for weed control in dry-seeded rice (IRRI 1978, 1979, 1980). A combination of thiobencarb and propanil applied soon after emergence has given good weed control in Japan (Yamane 1976). Herbicide combinations applied preemergence (butachlor plus oxadiazon), soon after emergence (thiobencarb plus propanil), or sequentially (butachlor or oxadiazon followed by 24-D) showed promise in a recent trial (Moody 1980). Sometimes even combination treatments of herbicides are inadequate and need to be followed by hand weeding to guarantee optimum yield.

In direct-seeded flooded rice, butachlor, thiobencarb, piperophos — dimethametryn, and butralin effectively control weeds in direct-seeded flooded rice in the tropics (De Datta and Bernasor 1973). Propanil and molinate are extensively used in drilled and wet-seeded rice in the U.S. (Smith 1977).

An early method of chemical control of broadleaf weeds and sedges was to spray 2,4-D or MCPA postemergence 30 DT (Mukhopadhyay 1978). Later it was found that broadcasting granular formulations of 2,4-D or MCPA could control germinating grasses (Table 2) in addition to broadleaf weeds and sedges (De Datta et al l971, Mukhopadhyay and De Datta 1980). In case of heavy infestations of *Echinochloa* spp., particularly when fields get dry because of lack of rains, propanil is used when the weeds are at the 2- to 3-leaf stage. An application of propanil alone was not as effective as propanil followed by hand weeding (Mukhopadhyay 1978). De Datta and Bernasor (1973) reported that herbicides such as nitrofen, butachlor, methiocarb-2,4-D EXP 3316, and Prodotto-D75 appeared outstanding for weed control in rainfed transplanted rice. In recent trials at Visva-Bharati University, India, oxadiazon and fluchloralin effectively controlled weeds in transplanted rice (Mukhopadhyay and Chattopadhyay, unpubl.).

**Table 2. Effect of herbicide treatments on weeds, light transmission, yield components, and grain yield.** [a]

| Treatment | Weed population (no./m$^2$) | Weed dry wt 45 DT (g/m$^2$) | Light transmission at 30 DT (%) | Effective tillers/hill (no.) | Rice yield (t/ha) |
|---|---|---|---|---|---|
| Weed-free check | 21.7 | 1.69 | 31.51 | 13.0 | 5.31 |
| 2,4-D IPE 1.0 kg a.i./ha | 71.3 | 3.69 | 45.90 | 12.7 | 4.95 |
| Nitrofen (G) 2.0 kg a.i./ha | 75.7 | 6.25 | 30.87 | 11.9 | 4.92 |
| Hand weeding (twice) | 46.3 | 1.88 | 33.11 | 11.1 | 4.85 |
| 2,4-D IPE 1.5 kg a.i./ha | 63.3 | 2.06 | 44.03 | 12.5 | 4.62 |
| 2,4-D EE 1.5 kg a.i./ha | 38.8 | 4.63 | 43.06 | 12.6 | 4.33 |
| 2,4-D EE 1.0 kg a.i./ha | 81.3 | 2.63 | 37.54 | 11.7 | 4.24 |
| Butachlor (G) 2.0 kg a.i./ha | 32.1 | 25.50 | 50.29 | 10.7 | 4.06 |
| Propanil 3.0 titers ai. + 2,4-D Na salt 0.8 kg a.i./ha | 87.0 | 19.69 | 28.13 | 10.0 | 3.79 |
| Unweeded control | 39.6 | 33.13 | 31.70 | 9.8 | 3.68 |
| *F*-test | ns | S | S | S | S |
| C.D. at 5% | ns | 16.60 | 11.48 | 2.21 | 10.0 |

[a] DT = days after transplanting, S = significant, ns = not significant.

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## DISCUSSION

KIM: What are the types of herbicides you used In your experiments?

*MUKHOPADHYAY:* On rainfed wetland rice with standing water in the rice field (transplanted or direct seeded puddled), granular herbicides mere used. The application advantage here was that no sprayer was required. For dry-seeded rice, where rains come a month or more after sowing and water remains standing thereafter (the crop is ultimately harvested as a wetland crop). the EC formulation was used to control weeds at the earlier stage when there was no standmg water.

ISLAM: Have you used oxadiazon under upland dry-seeded rainfed conditions?

*MUKHOPADHYAY:* Yes. It is comparable to butachlor. For upland direct-dry-seeded rice. propanil is the best herbicide even though farmers are not using it and company people are discouraging its use.

SOONG: In one of your slides you showed bentaron at 1 liter. Should that be 1 kg a.i.?

*MUKHOPADHYAY:* Yes.

VONSAROJ: You mentioned applying oxadiazon 1 day before transplanting. I am concerned about the toxic effect on the transplanter.

*MUKHOPADHYAY:* We observed no toxicity.

VONGSAROJ: How about the toxicity of piperophos - dimethametryn to fish? We have observed toxicity in Thailand.

*MUKHOPADHYAY:* There was some toxicity in the south of Bengal. Farmers did not use PCP because it was toxic to fish. However, in the rice area only 20% of the farmers have fish.

VONGSAROJ: What is the effect of butachlor on *Sphenoclea zeylanica?*

MUKHOPADHYAY: *Spenoclea zeylanica* occurs in rainfed wetland rice. Butachlor did not give good results with this weed.

VONGSAROJ: Before any recommendation is made to farmers, we should report on the weeds that are controlled and advise the farmers about the toxicity — the $LD_{50}$.

EASTIN: Any time you use herbicides you need to know what you are going to apply them to. This goes back to your individual recommendations. We need to know the weed species. The recommendation is totally different if you have *Echinochloa crus-galli* or a *Cyperus* species to control.

YEH: I would like to point out when to apply bentazon; you mentioned about 30 DT. It depends on the temperature. In the high temperature areas I think 30 DT is too late. I think it is better to base application time on the leaf stage of the weeds. Normally, bentazon is applied for the control of perennial weeds such as *Sagittaria* spp. and *Scirpus maritimus* at the 3-4 or 5-7 leaf stage.

Bentazon is best for the control of perennial weeds. For the control of annual weeds like *C. difformis,* I think that if you apply bentazon at only 50% of the recommended rate at the 2- to 3-leaf stage you will get good weed control. Besides, you are talking about rainfed wetland conditions. Control will be very poor with bentazon if irrigation water is not introduced within 24-28 hours after application.

*MUKHOPADHYAY:* Thank you. With regard to your second point, in the area where we ran the trials we have water all the time because of regular rains. When we apply bentazon at the 2- to 3-leaf stage (20-25 DT) we always have water. In the northwest of India (Punjab, Haryana) where they do not have sufficient rain, they irrigate.

EASTIN: We are not really debating the effects of one herbicide over another here. The purpose of the presentation was to look at weed technology. and those herbicides that have been mentioned are used as illustrations rather than saying one is better than the other.

SUNDARU: You mentioned applying oxadiazon on irrigated rice. Have you also recommended sprinkler formulations, which are easier to apply?

*MUKHOPADHYAY:* We have tried oxadiazon in sprinkler formulations and obtained results comparable to those of other rice herbicides. In fact we have used sprinkler formulations in irrigated or direct-seeded puddled rice in 2-5 cm of standing water.

GREENLAND: For the rainfed and flooded areas, is there a depth of flooding at which weeds become unimportant?

*MUKHOPADHYAY:* In 5-10 cm of water we have sedges only — primarily *Fimbristylis littoralis.* In more than 10 cm we have semiaquatic weeds such as *Monochoria* and *Ipomoea* spp. With greater water depth we have *Eichhornia crassipes.*

GREENLAND: Is there a depth (30 cm or more) when you can stop worrying about weeds?

*MUKHOPADHYAY:* At depths greater than 30 cm, *Eichhornia crassipes* comes into the rice fields from the canals.

# IMPORTANT RICE WEEDS IN LATIN AMERICA

J. Gonzalez, E. Garcia, and M. Perdomo

The important rice weeds in Latin America are enumerated. The weeds are further classified by their distribution, severity, and difficulty of control.

Weeds are the most severeand widespread biological constraint to rice production in Latin America. Because weeds are found in all fields in all countries, it is necessary to invest in control practices to reduce yield losses caused by their competition with rice plants.

This paper summaries the distribution of the more important weeds in Latin American rice fields including the most widespread, the most severe, and the most difficult to control. The information presented was provided by two regional networks of rice workers from research, extension, production, and commercial companies. We acknowledge their cooperation in completing and returning the questionnaire to Centro Internacional de Agricultura Tropical (CIAT).

The objectives of this paper are to:

- contribute to the knowledge of the problem of rice weeds,
- stress the importance of weeds so as to stimulate research on their control,
- increase communication among weed specialists,
- encourage the search for improved weed control methods through cooperative work and information exchange.

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## LITERATURE REVIEW

Holm et a1 (1977) assert that the most important rice weeds in the world are *Echinochloa crus-galli, E. colona, Fimbristylis littoralis,* and *Cyperus difformis. E. colona* is found mainly in tropical areas and *E. crus-galli* in more temperate areas.

Del Pazo and Tay (1971) report that the common rice weeds in Chillan, Chile, are *Alisma plantago-aquatica, Sagittaria chilensis,* and *E. crus-galli.*

Dirven (1970) surveyed the distribution of weeds in uncultivated rice fields in Surinam. *Dichromena pubera, Digitaria violascen, Lindernia crus-galli, Tonina fluviatilis* and *Melostomaceae* sp. were commonly found on infertile, light soils. *Cyperus articulatus, Echinochloa crus-pavonis, Eriochloa punctum,* and *Ischaemum rugosum* were found on fertile, clay soils while *F. littoralis* occurred in fields difficult to irrigate.

Holm and Herberger (1970) studied the distribution and potential severity of 5,000 weeds in several countries. Of the 5,000 species, 200 were considered agriculturally important. The most important crops are infested with a highly competitive group of weeds wherever the crop is grown. A second group of weeds is equally competitive, but has limited distribution. Twenty-three distribution maps included these important weeds: *Monochoria vaginalis, Paspalum conjugatum, Cyperus rotundus, C. difformis, E. crus-galli, E. colona, Cynodon dactylon, Portulaca oleracea, Chenopodium album,* and *Rottboellia exaltata.* Of those *C. difformis, M. vaginalis,* and *E. crus-galli* were the most important weeds of rice.

## MATERIALS AND METHODS

Two-hundred fifty questionnaires were sent to cooperators in all the rice-producing countries of Latin America. They were asked to:

- list the weeds that are most common, most severe, and most difficult to control;
- group the principal weeds into grasses, sedges and Commelinaceae, dicotyledonous weeds, and aquatics for wetland and dryland rice systems; and
- mark a map to indicate the rice area covered in their countries.

The data were grouped by weed distribution, severity, and difficulty of control in wetland and dryland. Frequency graphs were prepared for each country to indicate the taxonomic category for each species in the two production systems. That provided a geographical distribution for each species throughout the Americas.

Rice-producing countries were grouped into four regions by similarities in ecology, geography, and cropping systems:

- Mexico and Central America,
- The Carribean area (Cuba and the Dominican Republic),
- Tropical South America (Surinam, Guyana, Venezuela, Colombia, Ecuador, Peru, Bolivia, and Brazil), and
- Temperate South America (Uruguay, Paraguay. Argentina, and Chile.)

Lists of weeds reported were prepared for the countries of each region.

## RESULTS AND DISCUSSION

In Latin America rice is produced under wetland and dryland conditions. The wetland areas from reporting countries are detailed in Figure 1 and the dryland areas in Figure 2.

Weeds that were reported at least twice from a given geographical area are presented by farming system and botanical classification in Tables 1 through 7. The large number of species reported indicates that many are locally important.

There are more rice weeds in the Americas than are reported in this paper, which is concerned only with the more important ones. Thus, non-inclusion of a species known to flourish in a given country indicates that the local workers do not consider it important.

Tables 8 through 11 provide details on weed species for each of the four geographical regions. Weeds that are most widespread, severe. and difficult to control in wetland and dryland are presented. Thirteen weed species are regionally important in Latin America.

Although researchers (Holm et al 1977) affirm that *E. crus-galli* is the most


**1.** Irrigated rice areas in Latin America.

important rice weed worldwide, this species is a yield constraint only in wetland rice in temperate South America. *E. colona* was the most important weed in Latin America and was reported from all countries surveyed except Chile.

## CONCLUSIONS

The responses to the CIAT questionnaire by scientists from rice-producing nations in Latin America confirm the observation that weeds constitute the most widespread and costly constraint to rice production in the hemisphere.

The data indicate that many weeds are locally important in different countries for both wetland and dryland rice. Of them, 13 were severe over broad geographical areas, with *E. colona* rated as the most important. An increased regional effort directed toward weed control would increase Latin American rice yields.


**2.** Dryland rice areas in Latin America.

**Table 1. Common Poaceae (Gramineae) in wetland rice in Latin America.**

| Species | Mexico | Hon-duras | El Sal-vador | Nica-ragua | Costa Rica | Pana-ma | Domi-nican Republic | Cuba | Vene-zuela | Colom-bia | Ecua-dor | Peru | Brazil | Uru-guay | Argen-tina | Chile |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Brachiaria mutica* | | X | | | | | | X | | | | | | | | |
| *Brachiaria plantaginea* | | | | | | | | | | | | | X | | | |
| *Brachiaria reptans* | X | | | | | | | | | | | | | | | |
| *Cynodon dactylon* | | | | | X | | | | X | X | | X | X | | | |
| *Digitaria* sp. | | | | | | X | | | | X | | | X | X | | |
| *Echinochloa colona* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | |
| *Echinochloa crus-galli* | | | | X | X | | | X | | | X | X | X | X | X | X |
| *Echinochloa crus-pavonis* | | | | | | | | | | | | | X | | X | |
| *Eleusine indica* | | | | | | | | | X | X | X | | X | | | |
| *Ischaemum rugosum* | | | | X | | X | X | X | | X | | X | X | | | |
| *Leptochloa panicea* | X | X | | X | | | X | | X | X | | | | | | |
| *Leptochloa uninervia* | | | | | | | | | | | X | X | | | | |
| *Oryza minuta* | | X | | | | | | | | | | | X | | | |
| *Oryza perennis* | | | | | | | | | | | | | X | | | |
| *Oryza sativa (red rice)* | X | X | | X | X | X | | | X | X | | | X | | | |
| *Paspalum notatum* | | | | | | | | | | | | | X | | | |
| *Paspalum paspalodes* | | | | | | | | X | | | | | | | | X |
| *Paspalum* sp. | | | | | | | | | | | | | X | X | | |
| *Rottboellia exaltata* | | | | | X | | | | X | X | | | | | | |
| *Sorghum halepense* | X | | | | | | | | | | | | | | | |
| *Tripogandra multiflora* | | | | | | | | | | X | | | | | | |

**Table 2. Common Poaceae (Gramineae) in dryland rice in Latin America.**

| Species | Mexico | Guate-mala | Hon-duras | El Sal-vador | Nica-ragua | costa Rica | Pana-ma | Vene-zuela | Colom-bia | Ecua-dor | Peru | Boli-via | Brazil |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Brachiaria plantaginea* | | | | | | | | | | | | | X |
| *Cenchrus echinatus* | | | | | X | | | | | | | | X |
| *Cynodon dactylon* | | X | X | X | X | | | X | | | X | X | |
| *Digitaria sanguinalis* | | | | X | | X | X | | X | | | X | X |
| *Echinochloa colona* | X | X | X | X | X | X | X | X | X | X | | X | X |
| *Echinochloa crus-galli* | | | | | | X | | | | X | X | | X |
| *Eleusine indica* | | | | X | X | | | | | X | X | X | X |
| *Ischaemum rugosum* | | | | | | | X | | X | | X | | |
| *Ixophorus unisetus* | | | | X | X | X | | | | | | | |
| *Leptochloa panicea* | | X | X | | X | X | | | | | X | X | |
| *Leptochloa univervia* | | | | | | | | | | | X | | |
| *Oryza sativa (red rice)* | X | X | X | X | | X | X | | | X | | | X |
| *Panicum fasciculatum* | | | X | | | | | | | | X | | |
| *Panicum maximum* | | | | | | | | | | | | | X |
| *Panicum repens* | | | | | X | | | | | | | | |
| *Paspalum* sp. | | | | | | | | | | | X | X | X |
| *Rottboellia exaltata* | | | X | | | X | X | X | X | | X | X | |
| *Sorghum halepense* | X | | | | X | | | | | | X | | |
| *Tripogandra multiflora* | | | | | | | | | X | | | | |

**Table 3. Common Cyperaceae, Juncaceae, and Commelinaceae in irrigated rice in Latin America.**

| Species | Mexico | Hon-duras | Nica-ragua | Costa Rica | Pana-ma | Domi-nican Republic | Cuba | Vene-zuela | Colom-bia | Ecua-dor | Peru | Brazil | Uru-guay | Chile |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Commelina diffusa* | X | | X | X | X | | | | | | X | X | | |
| *Cyperus sp.* | | | | | | | | | X | | X | X | | X |
| *Cyperus difformis* | | | X | | | | | | | | | | | |
| *Cyperus diffusus* | | | | | | | | | X | X | X | X | | |
| *Cyperus eragrostis* | | | | | | | | | | | | | X | X |
| *Cyperus esculentus* | | | X | | | X | | | X | | X | | X | |
| *Cyperus iria* | | | | X | | | X | | | | | | | |
| *Cyperus laetus* | | | | | | | | | | | | | X | X |
| *Cyperus luzulae* | | | | | | | | | X | | | X | | |
| *Cyperus odoratus* | | | | X | X | | | | X | X | X | X | | |
| *Cyperus rotundus* | X | X | X | X | | X | | X | X | | X | X | X | |
| *Cyperus strigosus* | X | | | | | | | | | | | | | |
| *Eleocharis filiculoides* | | | | | | | | | | | | X | | |
| *Eleocharis geniculata* | | | X | | | | | | | | X | X | | |
| *Eleocharis palustris* | | | | | | | | | | | | X | | |
| *Fimbristylis dichotoma* | | | | | X | | | | X | | X | X | | |
| *Fimbristylis littoralis* | | | | | | X | | | | | | X | | |
| *Juncus bufonius* | | | | | | | | | | | | | | X |
| *Scirpus sp.* | | | | | | | | | | | | X | | |

**Table 4. Common Cyperaceae and Commelinaceae in dryland rice in Latin America.**

| Species | Mexico | Guate-mala | Hon-duras | El Sal-vador | Nica-ragua | Costa Rica | Pana-ma | Vene-zuela | Colom-bia | Ecua-dor | Peru | Brazil |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Commelina diffusa* | X | | | | | X | X | | | | | X |
| *Cyperus* sp. | X | | | | | | | | | | X | X |
| *Cyperus ferax* | | X | | X | | X | X | X | X | X | X | X |
| *Cyperus iria* | X | | | | | | | | | | | |
| *Cyperus luzulae* | | | | | | | X | | | | | |
| *Cyperus odoratus* | | | | X | | | X | | | | | |
| *Cyperus rotundus* | X | X | X | X | X | X | X | | | | X | X |
| *Cyperus strigosus* | X | | | | | | | | | | | |
| *Fimbristylis dichotoma* | | | | | | X | | | | | | |
| *Maricus mutisii* | | | | X | | | | | | | | |

**Table 5. Common dicotyledonous weeds in wetland rice in Latin America.**

| Species | Hon-duras | Nica-ragua | Costa Rica | Pana-ma | Domi-nican Republic | Cuba | Vene-zuela | Colom-bia | Ecua-dor | Peru | Brazil | Uru-guay | Argen-tina | Chile |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Ammonthus* sp. | | | | | X | | | X | | X | | | | |
| *Ammannia coccinea* | | | | | | X | | X | | X | X | | | |
| *Ammannia latifolia* | | | | | | | | | | X | | | | |
| *Bidens pilosa* | | | | | | | | | | | X | | | |
| *Cassia obtusifolia* | | | | | | | | X | | | | | | |
| *Eclipta prostrata* | | X | | | X | X | | | X | X | | | | |
| *Ipomoea* sp. | X | | | | | | X | X | X | X | X | | | |
| *Ipomoea aquatica* | | | | | | | | | | X | | | | |
| *Ludwigia adscendens* | | | | | | | | | | X | X | | | |
| *Ludwigia erecta* | | | | | X | X | X | | | X | | | | |
| *Ludwigia hyssopifolia* | | | | X | | | | X | | X | | | | |
| *Ludwigia prostrata* | | X | | | | | | | | | | | | |
| *Malachra* sp. | | | X | | | | | | | | | | | |
| *Polygonum acre* | | | | | | | | | | | X | | | |
| *Polygonum acuminatum* | | | | | | | | | | | | | X | X |
| *Polygonum hydropiperodies* | | | | | | | | | | | X | | | |
| *Polygonum punctatum* | | | | | | | | | | | X | X | | |
| *Portulaca oleracea* | | | | X | | | | X | | X | X | | | |
| *Sesbania exaltata* | | X | | | | X | | | | | | | | |
| *Sida rhombifolia* | | | | | | | | | | | X | | | |

**Table 6. Common dicotyledonous weeds m dryland rice in Latin America.**

| Species | Mexico | Guate-mala | Hon-duras | El Sal-vador | Nica-ragua | Costa Rica | Pana-ma | Colom-bia | Ecua-dor | Peru | Boli-via | Brazil |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Amaranthus* sp. | X | | | | X | | | X | | X | X | X |
| *Amaranthus spinosus* | | | | X | | X | X | | | X | | X |
| *Bidens pilosa* | | | | | | | X | | | | | X |
| *Cassia obtusifolia* | | | | | | | | X | | X | | |
| *Eclipta prostrata* | | | | | | | X | X | X | | | |
| *Emilia sonchifolia* | | | | | | | | | | | | X |
| *Euphorbia hirta* | | | | X | | | | | | X | | |
| *Ipomoea* sp. | | X | X | | X | | X | X | | X | | X |
| *Ipomoea purpwea* | | | | | | | | | | X | | |
| *Ludwigia* sp. | X | | | | | | X | | | | | |
| *Ludwigia leptocarpa* | | | X | | | | | | | | | |
| *Malachra* sp. | | | | | X | X | | | | X | | |
| *Physalis angulata* | | | | | | X | X | | | X | X | |
| *Portulaca* sp. | | | | | X | X | X | | | | | X |
| *Sida rhombifolia* | | | | | | | | | | | | X |

**Table 7. Common aquatic weeds in irrigated rice in Latin America.**

| Species | Mexico | Nica-ragua | Costa Rica | Pana-ma | Dominican Republic | Colom-bia | Ecuador | Peru | Brazil | Uruguay | Chile |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Alisma plantago-aquatica* | | | | | | | | | X | | X |
| *Eleocharis* sp. | | | | X | | | | | X | | |
| *Eleocharis geniculata* | | | | | | | | X | | | |
| *Eleocharis tuberosa* | | X | | | | | | | | | |
| *Heteranthera limosa* | | | | | | X | X | X | | | |
| *Heteranthera reniformis* | X | | | X | X | X | | X | X | | |
| *Leersia* sp. | | | | | | | | | | X | |
| *Limocharis flava* | | X | | | | X | X | | | | |
| *Monochoria vaginalis* | X | X | X | | | X | X | | X | | |
| *Plantago lanceolata* | | | | | | | | | | | X |
| *Sagittaria chilensis* | | | | | | | | | | | X |
| *Sagittaria guayanensis* | | | | | | | | X | X | | |
| *Sagittaria montevidensis* | | | | | | | | | X | X | |
| *Sagittaria trifolia* | | X | | | | | | | | | |

**Table 8. Important weeds of rice in Central America.**[a]

| Species | Wetland | | | Dryland | | |
|---|---|---|---|---|---|---|
| | Distribution | Severity | Control difficulty | Distribution | Severity | Control difficulty |
| *Echinochloa colona* | W | E | M | W | M | – |
| *Oryza sativa* (red rice) | C | M | E | – | – | E |
| *Cynodon dactylon*[b] | C | – | – | C | E | E |
| *Leptochloa panicea*[c] | C | – | – | C | – | – |
| *Cyperus rotundus* | C | M | E | C | M | E |

[a]C = common, W = widespread, E = extreme, M = moderate, – = weed distribution, or severity and control problem so slight in reporting countries as to constitute no problem. [b]Not reported from Mexico or Panama. [c]Not reported from El Salvador or Panama.

**Table 9. Important weeds of wetland rice in the Caribbean.**[a]

| Species | Distribution | Severity | Control difficulty |
|---|---|---|---|
| *Echinochloa colona* | W | E | E |
| *Ischaemum rugosum* | C | M | M |
| *Ludwigia erecta* | C | M | – |
| *Eclipta prostrata* | C | E | – |

[a]C = common, W = widespread, E = extreme, M = moderate, – = control problem so slight in reporting countries as to constitute no problem.

**Table 10. Important weeds of rice in tropical South America.**[a]

| Species | Wetland | | | Dryland | | |
|---|---|---|---|---|---|---|
| | Distribution | Severity | Control difficulty | Distribution | Severity | Control difficulty |
| *Echinochloa colona* | W | E | M | C | E | M |
| *Eleusine indica* | W | M | M | W | E | – |
| *Leptochloa* sp.[b] | C | – | E | W | – | M |
| *Cyperus ferax*[c] | W | M | M | C | – | E |

[a]C = common, W = widespread, E = extreme, M = moderate, - = weed distribution, or severity and control problem so slight as to constitute no problem, [b]Not reported from Brazil. [c]Not reported from Bolivia.

**Table 11. Important weeds of wetland rice in temperate South America.**[a]

| Species | Distribution | Severity | Control difficulty |
|---|---|---|---|
| *Echinochloa crus-galli* | W | E | M |
| *Paspalum* sp. | W | E | M |
| *Polygonum* sp. | W | E | M |

[a]W = widespread, E = extreme, M = moderate.

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## DISCUSSION

DAS GUPTA: What are the weed control methods in dryland rice in Brazil?

*GONZALEZ:* The Brazilian rice growers use herbicides and hand weeding. They have several commercial herbicides for preemergence and postemergence.

BAKER: You sent out 250 questionnaires. How many did you get back?

*GONZALEZ:* 185.

MICHAEL: I think it is of the utmost importance that rice workers in various countries make weed collections so that they can be checked for proper identity. I suspect, for example, that the plants called *Echinochloa crus-galli* in your list may include a number of species, which vary in importance in various countries. It is inconceivable to me that in South America, extending from the rice fields of Chile and Argentina to the Caribbean, that the plants described as *Echinochloa crus-galli* could all be the same. There are undoubtedly a number of forms extending from the higher to the lower latitudes, and it is very hard to recognize plants by pictures, although we can get a fairly good idea. You really need to get the plants in your hands and have a dissecting microscope.

*PAMPLONA:* You mentioned in Table 1 that *R. exaltata* is an extremely important weed species in irrigated rice in Latin America, particularly in Colombia. Will you describe the conditions and cultural management used in these areas?

*GONZALEZ: R. exaltata* is an important weed in dryland rice in Latin America, mainly in dryland rice in Central America. Some people indicated that *R. exaltata* is likewise an important weed in irrigated rice in Colombia. It is an aggressive weed and difficult to control. I saw it in some irrigated rice fields that had been rotated from sorghum to rice. The cultural management practices used in these areas are: (1) broadcasting dry seed, (2) draining irrigated rice fields, (3) use of propanil herbicide, and (4) hand weeding if necessary.

MATTHEWS: What is the importance of *Sphenoclea zeylanica* in Central and South America?

GONZALEZ: *S. zeylanica* is an important weed in flooded rice fields in which standing water is maintained throughout the growing season. It is not important in dryland crops, in poorly irrigated rice fields. or in fields with poor water management.

# WEED CONTROL AND RICE PRODUCTION IN BRAZIL

A. Silveira Filho and A. R. L. de Aquino

The rice lands of Brazil are classified according to water regime. The major rice production problems are described by cultivar, disease, pest, and soil. Results of experiments on weed control systems in wetland and dryland rice are reported. Because of the severe labor shortages during critical weeding periods, a weed control system based on chemical control is recommended for wetland and dryland rice culture.

Rice is a major agricultural product in Brazil, with 92% of the total production in Rio Grande do Sul, Mato Grosso, Maranhao, Parana, Minas Gerais, Goiás, Saõ Paulo, and Santa Catarina States. The area under rice totals about 7 million hectares and 1979-80 production was an estimated 9 million tons.

Rice production in Brazil basically is characterized by four systems, classified according to water supply (Empresa Brasileira de Pesquisa Agropecuaria [EMBRAPA] 1981):

System I — wetland (flooded) with permanently controlled water level.
System II — wetland (naturally flooded) without controlled water level.
System III — wetland (not flooded) in naturally humid lowlands.
System IV — dryland totally dependent on rainfall.

System I is traditional in the south (Rio Grande do Sul and Santa Catarina). Its

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increasing importance in new areas of Central Brazil presents a large potential. These regions are being opened to cultivation through such government projects as Rio Formoso and settlement programs under the Program of Rational Utilization of Lowland Areas (PROVARZEAS).

Systems II and III predominate in the north and northeast where low areas near the rivers flood periodically, offering conditions suitable for cultivating rice. Currently both systems are less important because their proportion of national production is insignificant so far. The systems are less utilized by farmers, mainly because of the lack of adequate technology for local conditions. However, interest is high at government and technical levels in incorporating these areas into the total production scheme because of their high potential. The two systems potentially could add about 30 million hectares of land to total rice cultivation.

System IV is the most significant cultivation system. It represents more than 70% of the total rice cultivation area and covers more than 4 million hectares. Dryland rice is cultivated both in favored and in unfavored regions. In favored regions, climatic conditions, especially rainfall, are less variable and offer less risk. Farmers in those regions are encouraged to use the high technology that can lead to higher productivity.

In unfavored regions, risks are higher. Adverse environmental conditions such as extended dry periods (veranicos) during crop growth discourage the use of high technology and yields are low. In the unfavored regions of Central and part of Southeast Brazil, rice is typically a transitional crop. Rice cultivation as the first utilization of deep, highly permeable soils with low fertility and high levels of toxic aluminum is used as a means of decreasing land preparation costs for subsequent crops, such as soybean and pastures. Under these conditions, rice is planted for 1 to 3 years.

## MAJOR PROBLEMS OF RICE PRODUCTION

Each region and cultivation system has particular rice production problems in suitable cultivars, diseases, insects, nematodes, and soil types (CNPAF 1975, EMBRAPA 1981).

### System I — wetland flooded rice

*Cultivars.* Low productivity, susceptibility to lodging, diseases, and insects; poor grain quality.

*Diseases.* Rice blast, brown spot, narrow brown leaf spot, leaf scald, and seedling blight,

*Insects.* Rice water weevil, rice stem borer, and rice stink bugs.

*Nematodes.* White-tip nematodes.

*Soils.* Deficiencies of nitrogen, phosphorus, potassium, zinc, and sulfur; iron and manganese toxicity; salinity (EMBRAPA/CPAC 1976).

### Wetland rice without permanent water level and systems II and III wetland saturated

*Cultivars.* Lack of cultivars adapted to these conditions.

*Soils.* Manganese and iron toxicity.
*Harvest.* Lack of adequate mechanization for these cultivation systems.
*Seeds.* Lack of good quality seeds.

**System IV – dryland rice**

*Cultivars.* Low productivity; susceptibility to lodging, diseases and insects, grain shattering.

*Diseases.* Rice blast, leaf scald, brown spot, narrow brown leaf spot, glume blight, and basal node rot (Pradhu 1981).

*Nematodes.* Root-knot nematode and white-tip nematode.

*Insects.* Lesser corn stalk borer, grass spittle bugs, rice stink bugs, and rice stem borer.

*Drought.* Extended dry periods during crop growth.

*Soils.* Deficiencies of nitrogen, phosphorus, potassium, calcium, magnesium, and zinc; aluminum toxicity.

## MAJOR WEED PROBLEMS IN WETLAND AND DRYLAND RICE

**Wetland rice**

The major weed species occurring in wetland rice areas are:

*Grasses.* Red rice, *Echinochloa crus-galli, Echinochloa crus-pavonis, Echinochloa colona,* and *Paspalum* sp.

*Sedges. Cyperus odoratus* L., *Cyperus difformis, Fimbristylis littoralis,* and *Cyperus* sp.

*Broadleaf weeds. Aeschynomene sensitiva* var. *hispidula,* and *Monochoria vaginalis.*

**Dryland rice**

The most important weed species occurring in dryland rice areas are:

*Grasses. Digitaria sanguinalis, Setaria geniculata, Cenchrus echinatus, Eleusine indica, Cynodon dactylon, Brachiaria plantaginea,* and *Imperata brasiliensis.*

*Sedges. Cyperus rotundus* and *Cyperus* sp.

*Broadleaf weeds. Sida rhombifolia, Cassia obtusifolia, Cassia occidentalis,* and *Bidens pilosa; Amaranthus spinosus, Ipomoea* sp., *Portulaca oleracea, Ageratum conyzoides, Commelina* sp., *Galinsoga parviflora,* and *Solanum paniculatum.*

## WEED CONTROL AT CNPAF/EMBRAPA

**Wetland rice**

With the dependence on labor availability in the rice production regions, weed control during critical weeding periods often is too late to prevent substantial yield losses. Delay in weed control can cause a considerable loss of production. Herbicides are an important weed control measure in wetland rice, where weeds are the primary restraint to high productivity.

Herbicide trials so far show that herbicides bentazone, oxadiazon, butachlor, and propanil + 2,4-D promise effective weed control in wetland rice. They controlled grasses and sedges (Table 1). These trials will be extended to regions where rice is cultivated under controlled and uncontrolled irrigation.

**Table 1. Effect of herbicides on grain yield of wetland rice cultivar IAC899 (CNPAF 1980, unpubl. data).**

| Treatment[a] | Herbicide rate (kg a.i./ha)[b] | Time of application[c] | Grain yield[d] (t/ha) |
|---|---|---|---|
| Bentazone | 1.4 | 15 DE | 6.3 |
| Weeded twice | – | 15 and 30 DE | 5.6 |
| Butachlor | 3.5 | PE | 4.9 |
| Propanil + 2,4-D | 3.6 + 0.3 | 25 DE | 4.9 |
| Oxadiazon | 1.0 | PE | 4.7 |
| Oxadiazon | 0.75 | PE | 4.7 |
| Bentazon | 1.0 | 15 DE | 4.6 |
| Butachlor | 2.4 | PE | 4.4 |
| Unweeded | – | – | 4.4 |
| Pyridate | 2.0 | 15 DE | 4.4 |
| Propanil + oxadiazon | 0.8 + 0.6 | 10 DE | 4.4 |
| Pyridate | 1.4 | 15 DE | 4.4 |
| Pendimethalin | 1.75 | PE | 4.0 |
| Propanil + 2,4-D | 4.3 + 0.5 | 25 DE | 3.7 |
| Pendimethalin | 1.25 | PE | 3.7 |
| Propanil | 3.6 | 25 DE | 3.3 |
| Propanil + oxadiazon | 1.5 + 0.5 | 10 DE | 3.2 |
| Prouanil | 4.3 | 25 DE | 3.0 |

[a]A plus sign (+) between 2 herbicide names means they were tank-mixed prior to application. [b]a.i. = active ingredient. [c]DE = days after emergence, PE = preemergence. [d]Data are means of 3 replications.

**Table 2. Effect of herbicides on grain yield of dryland rice cultivar IAC47 (CNPAF 1980. unpubl. data).**

| Treatment[a] | Herbicide rate (kg a.i./ha)[b] | Time of application[c] | Grain yield[d] (t/ha) |
|---|---|---|---|
| Propanil + 2,4-D | 4.3 + 0.5 | 25 DE | 2.8 |
| Propanil + 2,4-D | 3.6 + 0.3 | 25 DE | 2.5 |
| Weeded twice | – | 15 and 30 DE | 2.3 |
| Pendimethalin | 1.75 | PE | 2.3 |
| Oxadiazon | 1.0 | PE | 2.3 |
| Butachlor | 2.3 | PE | 2.3 |
| Butachlor | 3.5 | PE | 2.2 |
| Oxadiazon | 1.25 | PE | 2.2 |
| Propanil | 4.3 | 25 DE | 2.1 |
| Propanil + oxadiazon | 1.8 + 0.6 | 10 DE | 2.0 |
| Propanil | 3.6 | 25 DE | 1.9 |
| Pendimethalin | 1.25 | PE | 1.9 |
| Propanil + oxadiazon | 1.5 + 0.5 | 10 DE | 1.8 |
| Unweeded | – | – | 1.7 |

[a]A plus sign (+) between 2 herbicide names means they were tank-mixed prior to application. [b]a.i. = active ingredient. [c]DE = days after emergence, PE = preemergence. [d]Data are means of 3 replications.

## Dryland rice

In the first year an area is planted to rice, weed populations are low and weed control does not constitute a problem. Beginning the second year of rice cultivation, weeds can reduce yields by 50% in years with good rainfall distribution and by 70% during extended dry periods. This is one reason farmers shift to crops such as soybean or pasture, which offer less production risk and safer profits.

Weed control should be done manually where labor is available.

The first weeding should be done during the first 20-25 days of the rice crop and the second at 40 to 45 days.

In areas of dryland rice cultivation where there is labor shortage, chemical weed control is recommended.

Herbicides pendimethalin, 2,4-D + propanil, and oxadiazon effectively controlled the predominant weed species in the area (Table 2). Dryland rice herbicide trials also will be extended to other rice production regions.

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## DISCUSSION

EASTIN: You listed red rice as a major weed in wetland rice but did not list it in dryland rice. Is it a problem in dryland rice?

*SILVEIRA:* No. This is a serious problem only in wetland rice in southern Brazil.

BAKER: What is the reason red rice is not a problem in dryland rice?

*SILVEIRA:* I think because rice has not been cultivated for a long time in the same area.

MUKHOPADHYAY: It is a shifting cultivation area.

MOODY: You mentioned that in the first year in your dryland rice area you had very few weed problems, but in the second and subsequent years an increase in weed problems was observed. What was the composition of the weed flora during those periods? Are you getting an increase in grasses with time?

*SILVEIRA:* Most are broadleaf weeds,

MOODY: So you have a very low broadleaf population in the first year that increases with time.

*SILVEIRA:* Yes.

ISLAM: How much yield do you get under dryland conditions with a moderate level of weed control?

*SILVEIRA:* The yield is very low — 1.3 t/ha.

YEH: You said that in wetland rice, bentazone is the best herbicide. Do you have a problem with *Echinochloa?*

*SILVEIRA:* Yes. Bentazone performed best in the trial conducted in central Brazil, where *Echinochloa* is not a major problem. *Echinochloa* is a major problem in the south.

MUKHOPADHYAY: You mentioned you had *Sida* and *Commelina* in the same field. Normally, in dryland rice you don't get *Sida* and *Commelina* together because *Sida* occurs in the dry areas on the bunds and the roads, whereas some moisture is needed for the growth of *Commelina.* I don't understand how you get these weeds together in the same field.

MOODY: In Nigeria, *Commelina* and *Sida* grow together in the same field in dryland rice. They grow quite well in the same environment.

MUKHOPADHYAY: What was the species — *benghalensis* or *nudiflora?*

MOODY: It was *Commelina benghalensis.* The *Sida* species include *S. acuta* and *S. rhombifolia.*

MATTHEWS: Is *Richardia scabra* ever a problem in rice in Brazil?

*SILVEIRA:* No.

# WEED CONTROL RESEARCH IN DRYLAND RICE IN THE IVORY COAST

H. Merlier

A general description of the type and role of weeds and their effect on the rice crop is presented to facilitate the establishment of objectives for chemical weed control. The most effective weed control programs are proposed according to the capabilities and needs of farmers.

A research program in the Ivory Coast in 1968-80 focused on the study of various weeds of dryland rice and their effects on the rice crop, as well as on the methods for control. Because manual and mechanical weeding are rapidly being abandoned, the studies concentrated mainly on chemical weed control.

## MATERIALS AND METHODS

Tests were conducted at six sites in three ecological zones: Man and Mangouin in the western forest zone, Bouaké and Béhéké in the central savannah zone, and Ferkes-

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sedougou and Kiemou in the northern savannah zone.

The soil in the northern savannah zone consists of a high proportion of fine elements (60-70% silt and sand). In the central savannah zone it is mainly coarse sand (60%). In the western forest zone there is a higher percentage of clay (25%). Organic matter content in all these regions is low, and the pH is about 6.

Rice is grown during the rainy season. It is planted in June and harvested in October or November. Rainfall during the cropping period varies between 500 and 1,000 mm, with a short dry period (July) in the central savannah zone.

The rice cultivars used were Iguape Cateto and Moroberekan. These are hardy cultivars, long stalked (1.2-1.5 m up to 1.8 m) and with medium productive tillering (120 panicles/$m^2$). Crop duration is from 130 to 140 days and maximum yield potential is 5 t/ ha.

The trials were conducted on deep-plowed soil (25 cm). Fertilizers were applied at the rate of 40 kg N/ ha, 80 kg $P_2O_5$/ ha, and 80 kg $K_2O$/ ha. The seedbed was then disc-harrowed. The seed was planted mechanically at Bouake and manually at the other sites at the rate of 60 kg/ ha in rows 25 cm apart. Supplemental nitrogen was applied 30 days after planting and again at the booting stage. Treatment plots measured 1.25 × 14 m, separated by 1.25 m alleyways. Paddy yield was estimated from the 4 center rows over 12 m of the plots.

The herbicide trials were conducted according to the recommendations of the Biological Trials Commission (C.E.B.). Screening trials were conducted without replications and without yield estimation in order to identify the most suitable herbicide. These were followed by performance trials to estimate the efficiency rate of the herbicide. The performance trials included three replications without yield estimation. Selectivity trials were subsequently conducted to ensure that rates would not cause crop damage, and they included six replications with yield estimation. Finally, efficiency trials were conducted with six replications and yield estimation to establish the effective application rate.

Observations on the weeds were made every 15 days for the first 2 months of the cropping period and, later, once a month until the crop was harvested.

## RESULTS

### Weeds

More than 100 weed species were found in the dryland rice crops. The following list includes only weeds considered important because of their vegetative growth and number. The name of the weed is followed by the code for the ecological zone where it was found (F = western forest zone, C = central savannah zone, N = northern savannah zone).

| | | | |
|---|---|---|---|
| Acanthaceae | : | *Monechma ciliatum* | C |
| Amaranthaceae | : | *Amaranthus spinosus* | FCN |
| | | *A.viridis* | FCN |
| | | *Celosia trigyna* | FCN |
| Asteraceae | : | *Acanthospermum hispidum* | FCN |
| | | *Ageratum conyzoides* | FCN |

| | | |
|---|---|---|
| | *Aspilia bussei* | FCN |
| | *A. helianthoides* | FCN |
| | *Bidens pilosa* | FC |
| | *Erigeron floribundus* | C |
| | *Synedrella nodiflora* | FCN |
| | *Tridax procumbens* | FCN |
| | *Veronica galamensis* | CN |
| | *V. perrotteti* | CN |
| Commelinaceae | : *Commelina benghalensis* | FCN |
| | *C. erecta* | FCN |
| Convolvulaceae | : *Ipomoea eriocarpa* | FCN |
| | *I. heterotricha* | FC |
| Cyperaceae | : *Cyperus sphacelatus* | FCN |
| | *Mariscus cylindristachyus* | FCN |
| Euphorbiaceae | : *Acalypha ciliata* | FC |
| | *Croton lobatus* | FCN |
| | *Euphorbia heterophylla* | CN |
| | *E. hirta* | FCN |
| | *E. hyssopifolia* | C |
| | *Phyllanthus amarus* | FCN |
| Fabaceae | : *Alysicarpus rugosus* | FCN |
| | *Indigofera dendroides* | C |
| Ficoidaceae | : *Trianthema portulacastrum* | FCN |
| Lamiaceae | : *Leucas martinicensis* | N |
| Loganiaceae | : *Spigelia anthelmia* | FCN |
| Malvaceae | : *Hibiscus aspera* | FCN |
| | *Sida alba* | CN |
| | *S. linifolia* | CN |
| | *S. stipulata* | FCN |
| | *S. urens* | CN |
| Molluginaceae | : *Mollugo nudicaulis* | FCN |
| Nyctaginaceae | : *Boerhavia diffusa* | FCN |
| | *B. erecta* | FCN |
| Pedaliaceae | : *Sesamum radiatum* | FCN |
| Poaceae | : *Brachiaria deflexa* | CN |
| | *B. lata* | FCN |
| | *Chloris pilosa* | FCN |
| | *Dactyloctenium aegyptium* | FCN |
| | *Digitaria horizontalis* | FCN |
| | *Eleusine indica* | FCN |
| | *Eragrostis aspera* | CN |
| | *E. pilosa* | CN |
| | *Hackelochloa granularis* | CN |
| | *Paspalum scrobiculatum* | FCN |
| | *Pennisetum polystachyon* | FCN |
| | *Rottboellia exaltata* | FCN |

| | | |
|---|---|---|
| | *Setaria barbata* | FC |
| | *S. pallide-fusca* | FCN |
| Portulacaceae : | *Portulaca oleracea* | FCN |
| | *P. quadrifida* | C |
| | *Talinum triangulare* | FC |
| Rubiaceae : | *Diodia scandens* | F |
| | *Mitracarpus scaber* | CN |
| | *Oldenlandia corymbosa* | C |
| | *O. herbacea* | C |
| | *Spermacoce stachydea* | CN |
| | *S. verticillata* | CN |
| Scrophulariaceae : | *Striga hermonthica* | N |
| Solanaceae : | *Physalis angulata* | FCN |
| | *P. micrantha* | FCN |
| | *Schwenkia americana* | C |
| | *Solanum nigrum* | FCN |
| Tiliaceae : | *Corchorus fascicularis* | FCN |
| | *C. olitorius* | FCN |
| | *C. tridens* | CN |
| Verbenaceae : | *Stachytarpheta angustfolia* | CN |

These are all common weeds found throughout the tropics. Therefore the ecological zone was not important as long as temperature and moisture conditions were adequate, enabling the standardization of the herbicide trials.

All these weeds are annuals or have an annual habit under the existing cropping conditions in the Ivory Coast. There are no true perennials: they are either absent or have been eradicated by mechanical cropping operations. Thus, *Imperata cylindrica* is not mentioned because it cannot survive tillage operations for more than 2-3 successive years and disappears automatically. It is a problem species only under manual cultivation. *Rottboellia exaltata* is not a serious problem in the Ivory Coast. It may infest fields during the initial cropping years after the land has been cleared for cultivation, but seeds lose their germinative faculty after 2-3 years, and good cropping technology is sufficient to eradicate the species.

Only a few of the weeds in the list are very important, accounting for more than 75% of the weed vegetative matter. These are: *Acanthospermum hispidum, Brachiaria lata, Commelina benghalensis, Digitaria horizontalis, Eleusine indica,* and *Trianthemaportulacastrum.*

Weeds do not seriously affect the crop during the first month. Productive tillering is reduced, but grain number and weight are higher and there is no yield reduction. However, weeding 30 days after planting can be carried out only manually and requires a heavy workload.

Weeds are especially dangerous during the second month of crop growth. If they are not removed at this time, yield loss may be 70%; in case of weed regrowth after this period, yield loss does not exceed 20%.

## Chemical control

More than 50 active ingredients, used alone or in combination for a total of 150 formulations, were tested on dryland rice at various application times.

The choice of herbicide for the Ivory Coast should take into consideration the following constraints and requirements:

- The seedbed should be prepared very well because selective herbicides for rice cannot destroy weeds that have not been properly buried at tillage.
- Weeds emerge 5-10 days after the last tillage operation.
- Weeds emerge about 10 days after a hand weeding or a contact-herbicide treatment.
- Rice fields should remain weed free during the first 2 months of the cropping period. Oxadiazon was considered the best herbicide because it kept the soil free of weeds for a period of 3 weeks to a month, compared to 10 days to 2 weeks for all other herbicides.
- Contact herbicides that are selective for rice should be applied before the grass weeds reach the 2- to 3-leaf stage, that is, about 10 days after weed emergence.
- With the increasing use of low-volume sprayers, which are fast replacing other types of equipment in West Africa, synthetic phytohormones such 2,4-D have been abandoned for rice because low-volume spraying makes them highly phytotoxic.

The contact treatments proposed in the next section are not totally selective for rice. They are applied when the crop is at the 4- to 5- leaf stage, and the older leaves may be scorched. However, those leaves normally disappear at an early stage with no effect on the yield.

Not one of the proposed treatments kept the crop weed free for the required period except under favorable or particular local conditions. But all greatly reduced the frequency of subsequent weed emergence, and future weeding operations could be carried out more easily and rapidly.

The herbicides were tested in heavily infested fields since weeds pose a severe constraint on crop production in Africa today. However, the regular use of herbicides on rice and other crops at experimental stations as well as soil maintenance between two cropping periods (this is being studied in the Ivory Coast) have greatly reduced weed infestation. The weed control programs proposed may therefore prove to be entirely satisfactory.

## PROPOSED WEED TREATMENT FOR DRYLAND RICE

Of the 150 formulations tested, 5 showed promise for application to control weeds in dryland rice in the Ivory Coast. To obtain maximum herbicide efficiency, the soil should be free of vegetation at planting.

*Before land preparation.* Cut the vegetation, if necessary, so that it is no taller than 10 cm and let it dry for 2 or 3 days. In the late afternoon apply 600 g paraquat/ha. Plow 2 days after treatment at the earliest, or 4 to 5 days after treatment at the latest.

*After land preparation.* If weeds have emerged or reemerged before planting, apply paraquat at the rate of 600 g/ha to weedy areas of the field. Although paraquat has no effect on planted seeds and can be applied after planting but before crop emergence, it is recommended that the soil be treated before planting. In this way, light tillage of the soil surface by the seeding implement supplements the action of the herbicide.

*Herbicide treatments.* Herbicide treatments can be applied to any type of rice crop, but they vary according to the type of efficiency required. The herbicide should keep the crop free of weeds over the required period (about 2 months) without any maintenance operation. Only one method approaches this objective:

- Application of 0.5 kg oxadiazon/ha when the plants start to appear or after 4-5 days, but not later.
- The same treatment should be repeated after 3 weeks. But if the field is still free of weeds, the treatment can be postponed until they reappear.

If the objective is to avoid only the initial weeding operations, and supplemental maintenance operations can be carried out mechanically or manually, the following alternatives are proposed:

1. Application of 1 kg oxadiazon/ ha when the weeds start to appear, or at the latest after 4-5 days.
2. Application of 0.5 kg oxadiazon/ha + 0 kg propanil/ha 10-15 days after the weeds start to appear.
3. Application of 0.8 kg bentazon/ha + 1.7 kg propanil/ha 10-15 days after the weeds start to appear.
4. Application of 1.2 kg fluorodifen/ha + 1.5 kg propanil/ha 10-15 days after the weeds start to appear.
5. Application of 0.76 kg thiobencarb/ha + 1.73 kg propanil/ha 10-15 days after the weeds start to appear.

NOTE. Treatments 2-5 should be repeated in case rains wash the herbicide from the leaves within 5-6 hours after the treatment.

## DISCUSSION

MUKHOPADHYAY: You mentioned that oxadiazon showed the best results. Was it oxadiazon plus propanil or oxadiazon alone?

*MERLIER:* We have two possibilities: a) Oxadiazon alone applied preemergence and again 3-4 weeks later, using 0.5 kg a.i./ha each time. This gave weed-free conditions for the first 2 months in the Ivory Coast. b) Oxadiazon plus propanil can be applied as a mixture 2 weeks after rice emergence but it is inferior to the first possibility. Not all the weeds are controlled.

DAS GUPTA: YOU mentioned that *Rottboellia exaltata* may infest fields during the initial cropping years but that their seeds lose their germinating ability after 2 or 3 years and good cropping technology is sufficient to eradicate this species.

Our observation on this weed in northern Ghana is different. This weed is spreading rapidly and it is a persistent, serious pest even after 4-5 years of rice cultivation. What good cropping technology are you following in the Ivory Coast to eradicate this weed?

*MERLIER:* In our area, *Rottboellia* eradication is obtained mainly by a 4-5 year rotation with yam, soybean, maize, rice, or cotton and by avoiding *Rottboellia* seeds through hand weeding.

SUNDARU: (1) How do you control *Imperata cylindrica,* by cultivation? (2) Do you use *I. cylindrica* as a mulch in dryland rice?

*MERLIER:* (1) *Imperata cylindrica* disappears in 2-3 years when you deep plow. (2) We have no *I. cylindrica* with the plowing technique used. This is an important weed only when manual land preparation is used.

YABUNO: I understand that dryland rice in the Ivory Coast includes *Oryza sativa* and *O. glaberrima;* is this true?

*MERLIER:* Yes, it is — mainly *O. glaberrima,* because *O. sativa* is susceptible to blast.

YEH: (1) What should be the moisture condition when oxadiazon is applied? (2) In your estimate, what was the percentage of weed control in completely dry soil compared to that in wet soil?

*MERLIER:* (1) Oxadiazon should be applied at the first emergence of weeds. The results are best if the soil is wet, but the results are good enough if the soil is dry. (2) No trial was conducted along these lines.

VONGSAROJ: (1) You mentioned that perennial weeds such as *Imperata cylindrica* can be controlled successfully by tillage operations. Why does *Brachiaria lata* not exist in spite of being a perennial? (2) How about Leguminosae weeds? You did not mention if you have any problem with those.

*MERLIER:* (1) In the cultural conditions in the Ivory Coast, *B. lata* has an annual habit. (2) We have few species of Leguminosae in rice crops, and they have never been abundant.

VEGA: Could you describe the weed control practices of a good dryland rice farmer in the Ivory Coast?

*MERLIER:* Rice needs to be free of weeds. Either a) you apply oxadiazon at 0.5 kg a.i./ha twice, the first application at the preemergence stage and the second application 30 days after emergence, or b) when you have sufficient manpower you need only to apply oxadiazon + propanil, bentazone + propanil, or thiobencarb + propanil 2 weeks after emergence, then hand weed later if needed. This treatment is equivalent to one hand weeding only.

GREENLAND: I was interested in your comment that most of the spray work in West Africa is done with low-volume sprayers. Could you mention the type of low-volume sprayer that is being used and the extent of sales in the Ivory Coast?

*MERLIER:* The model being used is sold by Ciba-Geigy. It applies 5-20 liters/ha. Last year more than 10,000 ha were treated with this sprayer, and its use is rapidly increasing. There is a big problem in Africa at the start of the rainy season. We have no water, and conventional application at the rate of 200-1,000 liters/ha is not possible. If it were not for the low-volume sprayer we could not apply herbicide in Africa.

MENCK: If you compare the results of the low-volume sprayer with the knapsack sprayer, do you recommend an increased rate of herbicide?

*MERLIER:* We use the same rate of herbicide. Actually there is greater efficiency with the low-volume sprayers and for certain herbicides more phytotoxicity to the rice also. The phenoxy herbicides became too phytotoxic when the low-volume sprayer was used, and with 2,4-D we killed the rice rapidly.

MATTHEWS: (comment): My concept of agriculture in Africa is that man is taking bush country where there is a high percentage of organic matter (5-6%) and within a matter of 2-3 years, with the cropping system given by Dr. Merlier, going down to bare sand with no soil and no moisture-holding capacity. We then pump nitrogen in to try and increase crop production. I believe that in a very short period in Africa and in other areas we are going to begin to place a higher emphasis on vegetation — live vegetation at all times. When we want to practice crop production we will have to turn that live vegetation into dead vegetation without going through these long, long dry summer fallows. Until this concept is practiced more widely in Africa we are going to have very hungry people and more deserts.

SUNDARU: Do you apply minimum tillage in the Ivory Coast?

*MERLIER:* We tried it in the Ivory Coast 3-4 years ago, but I cannot recall the results.

# FARMERS' WEED CONTROL TECHNOLOGY IN RICE IN MAINLAND EAST ASIA

Y. H. Li

The 28 most troublesome weed species that infest rice fields of mainland East Asia are identified. The weed control methods in Guan Zhuang Commune, Taixian County, Jiangsu, are taken as a case study to show the typical weed control systems employed by farmers. Common herbicide treatments for rice in mainland East Asia are given.

Rice is the principal cash crop in mainland East Asia, but the tremendous problem weeds present to rice production seems not to have received due attention on most farms. There are two agricultural production systems: large state-owned farms and people's communes. Weed control practices differ in these two systems. On the state-owned farms, herbicide usage in rice has steadily increased as effective herbicides have been developed. This paper will concentrate on weed control practices of farmers in the communes.

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## WEED IDENTIFICATION AND INVENTORY

Weed species making up the total weed complex in a field vary from region to region and often differ between adjacent fields. Our experience has been that to make accurate weed control recommendations, it is important to know the weed species present, their life cycle, and how they reproduce. Most problem weeds in rice fields are annuals or perennials; biennial weeds are seldom important.

About 208 weed species belonging to 110 genera and 49 families are found in rice in mainland East Asia. Two hundred of the species are angiosperms, 116 monocots, and 84 dicots. Five of the species are ferns, three are green algae. About 28 species are of major importance in rice (Table 1).

## WEED CONTROL TECHNIQUES

Some of the oldest weed control practices in mainland East Asia are physical. Because of the large amount of hand labor available, hand-pulling is the usual practice. Mechanical means include tillage, mowing, flooding, and smothering.

**Table 1. Weeds of major importance in rice in mainland East Asia.**

| Family | Species |
|---|---|
| Poaceae | *Echinochloa crus-galli* |
| | *Leersia hexandra* |
| | *L. japonica* |
| | *Paspalum paspalodes* |
| Cyperaceae | *Cyperus difformis* |
| | *C. iria* |
| | *Scirpus juncoides* |
| | *S. planiculmis* |
| | *Eleocharis aquisetina* |
| | *E. palustris* |
| | *E. yokoscensis* |
| | *Juncellus serotinus* |
| Hydrocharitaceae | *Blyxa japonica* |
| | *Hydrilla verticillata* |
| | *Vallisneria spiralis* |
| Lythraceae | *Ammannia auriculata* |
| | *Rotala indica* |
| | *R. rotundifolia* |
| Pontederiaceae | *Monochoria vaginalis* var. *pauciflora* |
| | *M. vaginalis* |
| Alismataceae | *Sagittaria pygmaea* |
| | *S. sagittifolia* var. *longiloba* |
| Potamogetonaceae | *Potamogeton distinctus* |
| Najadaceae | *Najas minor* |
| Marsileaceae | *Marsilea minuta* |
| Eriocaulaceae | *Eriocaulon sexangulare* |
| Zygnemaceae | *Spirogyra nitida* |
| Characeae | *Chara foetida* |

Herbicides are required to control weeds in rice when preventive, cultural, and mechanical methods fail. The amount of herbicides dissolved in the soil water depends on the solubility of the chemicals and the absorptive capacity of the soil. Herbicides vary a great deal in how long they remain active in the soil.

Herbicides used by farmers in mainland East Asia fall into two categories: selective and nonselective. Selective herbicides are used more widely than nonselective ones.

Nitrofen is a widely used rice herbicide that is highly absorbed, sticks very tightly to the clay and organic matter, and is not readily available for uptake by germinating weeds.

Herbicides such as PCP must be applied at preplanting and mechanically incorporated because they will be broken down by sunlight if left on the soil surface.

Herbicides such as MCPA and thiobencarb act on annual weeds through the soil and the foliage. They can be applied either at preemergence or early postemergence, but preemergence applications are usually preferred. Common herbicide treatments for rice in mainland East Asia are shown in Tables 2, 3, and 4.

## FARMERS' TYPICAL WEED CONTROL SYSTEMS

Because each weed complex that develops in various cultures requires a particular weed control program, I will take a production team in Houbao, Guan Zhuang Commune, Taixian County, Jiangu Province as a case study. The commune is located along the River Tongyang in a rice - wheat and dryland crop area. The upper soil layer is heavy clay. There are many problem weeds, which reduce the yield and quality of rice. Farmers expend much labor to eradicate weeds, but they are not completely successful. Moreover the entire farming program is disrupted because large numbers of the labor force are engaged in eradicating weeds. Problem weeds *Eleocharis yokoscensis, Fimbristylis littoralis,* and *Rotala indica* are abundant at the early growing stage of the crop; at the medium and late stages, *Cyperus iria, Potamogeton distinctus,* and *Echinochloa crus-galli* cause damage and lower the yield.

**Table 2. Common herbicide treatments for rice seedbeds in mainland East Asia.**

| crop | Herbicide | Application rate (kg a.i./ha) | Application time |
|---|---|---|---|
| | *Preemergence* | | |
| Early- and medium-duration rice | Thiobencarb | 1.25-1.5 | At seeding. Maintain water layer 1-5 days after treatment. |
| | PCP-Na | 5-6.4 | |
| | Nitrofen | 1-1.5 | |
| Late rice | Thiobencarb | 1.5-1.8 | At seeding. Maintain water layer 2-3 days after treatment. |
| | *Postemergence* | | |
| Early, medium-duration, and late rice | Propanil | 1.5 | At 1.5-2 leaf stage of *Echinochloa* spp. |

**Table 3. Common herbicide treatments for transplanted rice in mainland East Asia.**

| Field type | Herbicide | Application rate (kg a.i./ha) | Application time |
|---|---|---|---|
| Hilly and flat land | Thiobencarb | 1-1.25 | 2-3 days before or 4-5 days after transplanting. |
| | PCP-Na | 4.8-9.6 | |
| | Nitrofen | 1.25-1.8 | |
| | Prometryn | 0.15-0.25 | |
| Hilly and high land | Thiobencarb | 1.5-2.0 | 7-10 days after transplanting for early rice, 5-8 days for late rice. |
| | PCP-Na | 8-12 | |
| | Nitrofen | 1.8-2.7 | |
| | Prometryn | 0.2-0.3 | |
| | MCPA | 0.9-1.3 | At tillering. |
| | 2,4-D | 0.6-0.9 | |
| Along rivers | Thiobencarb | 22 | 3 days before transplanting, maintain water depth at 2.5-3.8 cm. |
| | Nitrofen | 4.5-6.0 | |
| | Thiobencarb | 15-22 | When rice plant is at the 1-2 leaf stage. |

In 1973, a 0.85-ha rice field yielded only 1 t rice; weeds had reduced the yield by 40%. Weeds were eradicated 2 or 3 times with 90-120 workdays/ha being spent weeding. In 1974, 12.5 workdays were spent weeding a 0.13 ha of Jiang-ai-zao rice cultivar, but on 2.4 ha of early rice treated with herbicides, only 5 workdays were spent weeding.

In 1974, chemical herbicides saved 75-90 workdays/ha compared to 1973 when hand and mechanical weeding were used. Also in 1974, chemical weed control saved 550 workdays on 230 ha of rice. Chemical weed control in seedbeds reduces the workdays required to clear the transplanted rice field of weeds that are transplanted with the seedlings.

The effectiveness of chemical weed control is shown in Table 5. Prometryn was 76-100% effective in controlling *Potamogeton distinctus* in rice and the plants grew

**Table 4. Common herbicide treatments for direct-seeded rice in mainland East Asia.**

| Herbicide | Application rate (kg a.i./ha) | Application time |
|---|---|---|
| | *Wet-seeded rice* | |
| Thiobencarb | 1.6 | 3 days before seeding, maintain water depth at 2.5-3.8 cm. |
| Nitrofen | 1.8-2.25 | |
| Propanil | 1.5 | When rice plant is in the 5-6 leaf stage. |
| | *Dry-seeded rice* | |
| Nitrofen | 1.8-2.25 | 2-3 days after seeding, spray on wet soil surface. |

**Table 5. Effectiveness of chemical weed control in transplanted rice during early growth stage.**

| Rice cultivar | Herbicide treatment [a] | Application rate (kg a.i.[b]/ha) | Inspection date (DT[c]) | Effectiveness (%) | | |
|---|---|---|---|---|---|---|
| | | | | *Eleocharis yokoscensis* | *Echinochloa crus-galli* | Other weeds |
| Jiang-ai-zao | Nitrofen (25% a.i.) +[d]<br>Prometryn (50% a.i.) | 0.95<br>0.15 | 42 | 100 | 70 | 90 |
| Nanjing 11 | Nitrofen (25% a.i.) +<br>Prometryn (50% a.i.) | 0.95<br>0.22 | 90 | 100 | 85 | 71 |
| 29 Green | Nitrofen (10% a.i.) +<br>Ammonium bicarbonate | 1.5<br>75.0 | 60 | 100 | 75 | – |
| Yejing 89 | Nitrofen (20% a.i.) | 1.5 | 75 | 100 | 100 | 77 |
| 29 Nan. 1 | Thiobencarb | 0.75 | 47 | 100 | 76 | 80 |

[a]All treatments applied 3-5 days after transplanting. [b]a.i. = active ingredient. [c]DT = days after transplanting. [d]+ indicates 2 liquid herbicides were tank-mixed and applied as a single treatment.

3-11.5 cm taller than the untreated control. In comparisons of hand weeding and chemical weed control, yields were consistently higher in fields that had been chemically treated: 9% higher in early rice, 13% in mediumduration rice, and 18% in late rice — an average yield increase of 13%.

## COMBINATIONS OF CONTROL MEASURES

A successful weed control program for rice will involve two or more types of control because relying on just one often results in failure. Rice growers who use proper cultivars, fertility levels, populations, planting dates, seedbed preparation, seeding method, and water management are well on their way to winning the battle with weeds.

Farmers have used cultural methods to control rice weeds since early times. These methods remain an integral part of successful weed control programs in rice. For instance, early rice seedbed preparation may hasten crop residue decomposition and decrease the incidence of algae and other weed problems. Plowing buries many weed seeds and may greatly reduce weed populations and the vigor of seedlings that do emerge. Deep plowing and crop rotation may reduce populations of perennial weeds in successive rice crops. Proper water management in a well-leveled field will provide partial control of most *Echinochloa* spp. for 3 or more weeks after planting if other environmental conditions are favorable. In addition to using herbicides, farmers should employ every known cultural practice to increase the competitiveness of the crop. To omit any component often results in inadequate weed control.

## DISCUSSION

YEH: (1) What is the formulation of 80% 2,4-D at transplanting stage? (2) How do you apply this chemical to the soil at tillering stage? (3) What is the exact time of application at the tillering stage?

*LI:* (1) That is a sodium salt of 2,4-D. (2) The farmers themselves mix the herbicide with the soil. (3) After 15-20 days or during the high tillering stage.

SMITH: Why is ammonium bicarbonate mixed with nitrofen and prometryn?

*LI:* That will increase the action of the herbicide as well as increase the fertility of the soil.

SUNDARU: Do you observe any PCP toxicity?

*LI:* You have to avoid using it near fisheries, but it decomposes rapidly in sunlight.

VONGSAROJ: I have been told that *Azolla pinnata* has been used as a nitrogen donor. Do you find an effect on control of weeds in the paddy?

*LI:* The covering of *Azolla pinnata* on the water surface may inhibit the growth of some weeds.

# FARMERS' WEED CONTROL TECHNOLOGY IN MECHANIZED RICE SYSTEMS IN EAST ASIA

H. Chisaka and K. Noda

In Taiwan, China, South Korea, and Japan, rice farmers have adopted mechanized, labor-saving agricultural practices with the advent of rapid industrialization. Although the degree of farm mechanization is different in each country, machine transplanting has become a common practice. Some perennial weeds are becoming dominant, in particular in Japan, resulting in intensive use of herbicides. It is estimated that in 1978 more than 90, 70, and 200% of paddy fields were treated with herbicides in Taiwan, South Korea, and Japan, respectively. Herbicide use in machine-transplanted rice, which is different in some respects from that in hand-transplanted, and weed control procedures of farmers in Japan are discussed.

Taiwan, China, South Korea, and Japan have among the highest rice yields in the world, although they do not have the most favorable climatic conditions for rice. Their high productivity in those countries is due mostly to good soil, good irrigation, sufficient supply of fertilizer, intensive pest control, and, especially, varietal improvement.

Increased total food production is still the main objective of today's farming, but a secondary objective is to minimize labor use. Thus mechanical land preparation, transplanting, and harvesting are practiced along with herbicides. But over-reliance

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on herbicides could have harmful effects on the environment and might permit some herbicide-resistant weeds to proliferate in croplands.

## THE RICE PRODUCTION SITUATION

### Status of rice production

Taiwan. Rice in Taiwan is produced twice a year — in the monsoon and the dry season — because of the subtropical environment and good irrigation systems. Total rice land has been 740,000-780,000 ha during the past 30 years, and mean rice yield has plateaued between 3.2 and 3.4 t/ha since 1970. About 97% of total rice land is transplanted, although direct-seeded rice is gradually gaining acceptance. As a result of the recent labor shortage, machine transplanting is gradually replacing hand transplanting. About 50% of rice land was transplanted by machine in 1980 (Chiang et al 1980).

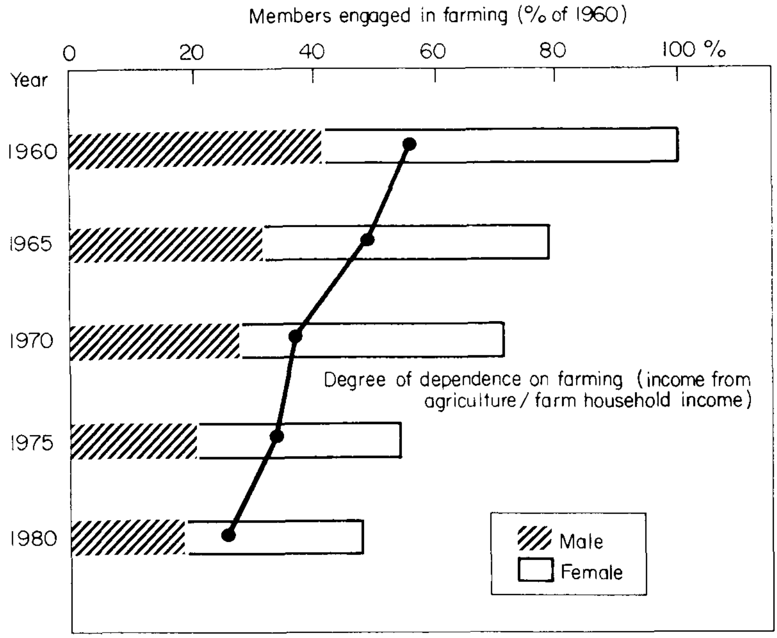
*South Korea.* The total area of paddy rice in Korea is about 1,200,000 ha. Most of that is transplanted by hand, machine-transplanting being practiced in only about 5% of paddies in 1980. Direct-seeded rice is negligible (Kim 1980). Yields have averaged 4.7 t/ha in recent years. The average holding per farm household is less than 1 ha, including dryland fields. Double-cropping is predominant, especially in the southern regions, and about 70% of paddies are planted to barley or other crops after rice. Seasonal peak labor requirements appear, especially during rice transplanting and harvest. It is expected that machine transplanting will dramatically increase in the near future because a major target of rice production is to save labor as well as to achieve higher and more stable yields.

*Japan.* Lowland paddy fields occupy more than 3,000,000 ha in Japan, but in recent years rice has been planted to about 2,500,000 ha because of the government's policy of restraining excessive production. Farms are generally small, about 0.7 ha of paddy and 0.4 ha of dryland field per farm household on the average. Productivity of rice is around 4.8 t/ha, but it fluctuates because of abnormal climate, especially low temperatures. Before the mid-1960s double-cropping of rice and winter crops was prevalent, but now most paddy fields are fallowed during winter because wage increases cause low returns from winter cropping. Agricultural practices have been highly mechanized since the 1960s, and the past decade has seen the rapid extension of machine transplanting of rice, reaching more than 90% of total paddies in 1980. Direct-seeded rice showed a temporary increase, but in recent years it has been practically replaced by machine-transplanted rice.

### Demand for saving labor

Rice production in East Asia in the past was characterized by abundant labor supply. The recent rapid expansion of industries, however, has caused an outflow of farm population to industrial sites and a corresponding increase in wages. For instance, the members engaged in farming and the farm household dependence on farming in Japan have decreased to half in the past 2 decades (Fig. 1). The farm population in South Korea also gradually decreased from 55% in 1966 to 36% in 1977, and the real farm wage increased by 3 times during these 10 years (Kim 1980).

Under these circumstances, saving labor in rice production is highly desirable.




1. Members engaged in farming and degrees of dependence on farming (MAFF 1981).

Farming is thus adopting labor-saving technology such as mechanization and herbicides.

The total labor required for rice production in Japan steadily decreased from 2,162 hours/ha in 1949 to 694 hours/ha in 1979 (Table 1). Such a drastic reduction came mainly from the mechanization of land preparation, transplanting, and harvesting and from the wide use of herbicides. Statistics of 1979 indicate that labor requirements for land preparation, transplanting, and harvesting were 49, 34, and 29% of the 1960 figures, respectively. Reduction of weeding labor has been extreme and correlates highly with the extension of herbicide use.

Mechanization and chemical weed control have also played important roles in minimizing the seasonal peaks of labor demand in South Korea (Kim 1980).

## MAIN WEEDS

Japan and South Korea are located in the temperate zone and Taiwan is in the subtropical and tropical zones; however, several principal weeds are common to all. Table 2 was compiled from data of Noda (1978), Kim (1980), and Chiang et a1 (1980).

Weed populations in paddies in Japan have been shifting from annuals to perennials. In the years when manual weeding was the only method of weeding, the dominant weed species were mainly annuals. The use of herbicides developed to combat annual weeds was followed by the cessation of manual weeding or frequent

**Table 1. Trends in weeding labor and herbicide treatment in rice.**[a]

| | 1949 | 1954 | 1960 | 1965 | 1970 | 1975 | 1979 |
|---|---|---|---|---|---|---|---|
| Total labor (h/ha) | 2162 | 1852 | 1740 | 1412 | 1178 | 815 | 694 |
| Weeding labor (h/ha) | 506 | 311 | 268 | 174 | 130 | 84 | 66 |
| Weeding labor as % of total labor | 23.4 | 16.8 | 15.4 | 12.4 | 11.0 | 10.3 | 9.5 |
| Herbicide-treated land as % of total rice land | 0.0 | 14.9 | 33.9 | 96.3 | 159.2 | 221.0 | 232.5 |
| Rice yield (brown rice, t/ha) | 3.22 | 3.09 | 4.01 | 3.90 | 4.42 | 4.81 | 4.82 |

[a] Sources of data: Ministry of Agriculture, Forestry and Fisheries, Japan; and Japan Association of Plant-growth Regulators.

**Table 2. Principal weeds in East Asia: Japan (J), South Korea (K), and Taiwan, China (T).**

| Scientific name [a] | Annual or perennial | Location |
|---|---|---|
| *Echinochloa crus-galli* | A | J,K,T |
| *Monochoria vaginalis* | A | J,K,T |
| *Cyperus difformis* | A | J,K,T |
| *Eleocharis acicularis* | P | J,K,T |
| *Rotala indica* | A | J,K,T |
| *Sagittaria trifolia* | P | J,K,T |
| *Eleocharis kuroguwai* | P | J,K |
| *Scirpus juncoides* var. *hotarui* | A or P | J,K |
| *Cyperus serotinus* | P | J,K |
| *Sagittaria pygmaea* | P | J,K |
| *Cyperus iria* | A | J,K |
| *Paspalum paspalodes* | P | J,K |
| *Potamogeton distinctus* | P | J,K |
| *Elatine triandra* | A | J,K |
| *Eclipta prostrata* | A | J,K |
| *Marsilea quadrifolia* | P | T |
| *Scirpus maritimus* | P | K |
| *Ludwigia prostrata* | A | J |
| *Alternanthera sessilis* | A | T |
| *Alisma canaliculatum* | P | J |
| *Ammannia baccifera* | — | T |
| *Aneilema japonica* | A | K |
| *Lindernia pyxidaria* | A | T |
| *Cyperus amuricus* | A | K |
| *Leersia japonica* | P | K |

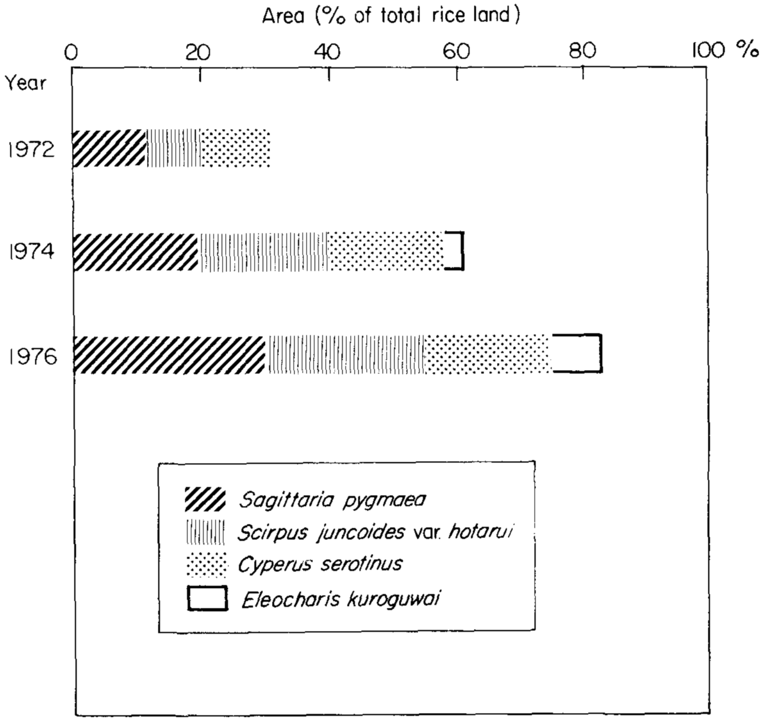
[a] In order of decreasing importance as estimated by K. Noda.

soil disturbance. Such circumstances could have been favorable to perennials. The most noxious and increasing perennial weeds are *Sagittaria pygmaea, Scirpus juncoides* var. *hotarui, Cyperus serotinus,* and *Eleocharis kuroguwai* (Fig. 2). In Taiwan and South Korea these weeds seem to increase according to the extension of herbicides effective against annual weeds.

Some tropical Asian weeds such as *Marsilea quadrifolia, Paspalum paspalodes,* and *Alternanthera sessilis* are beginning to invade Taiwan and southern Japan.

## HERBICIDE USE IN RICE

Chemical herbicides have become a substantial part of Japanese weed control management in rice (Table 3). The first step, stimulated by the success of 2,4-D, was the development of phenoxy herbicides as a foliage treatment. The second was the rapid spread of PCP and its mixtures with phenoxy compounds as preweed-emergence herbicides applied to the soil. The third was the development of more selective, less fish-toxic, soil-applied herbicides such as nitrofen, chlornitrofen, and thiobencarb. The fourth was the development of mixed herbicides containing two or three active ingredients having broad phytotoxic spectra. Recently, much attention and effort have been concentrated on the development of herbicides effective against perennial weeds. Table 4 lists the important herbicides in a recent year. The present




**2.** Estimate of rice land infested with some perennial weeds (JAPR 1977).

state of herbicide use in Japan will be described presently.

In Taiwan, nitrofen was registered in 1965 as the first herbicide in paddy fields, followed by propanil, PCP, and molinate during the next 2 years. In 1978, herbicides were applied in 91% of total rice land. Major herbicides in Taiwan are indicated in Table 4, butachlor and thiobencarb being the leading ones.

In South Korea, herbicide use in rice is behind that in Japan and Taiwan, but it is increasingly becoming common with the use of machine transplanting. The initial herbicide appears to have been 2,4-D, around 1950, although use was negligible until 1965. In 1978, about 70% of rice land was treated with herbicide. Kim (1980) estimated that total herbicide application would reach more than 150% within the subsequent 10 years. The major herbicides are shown in Table 4. Butachlor is the leading one, followed by nitrofen.

Herbicides in Japan, South Korea, and Taiwan, China, should be evaluated not only in terms of effectiveness of weed control but also in terms of nonphytotoxicity to rice plants. To ensure these principles, many recommendations for use directed to users fall under the following categories:

1. Susceptible weed species
2. Applicable period (days after transplanting, growth stage of weeds)
3. Applicable soil types and acceptable amount of loss of water per day due to leaching

**Table 3. Herbicide use in rice in East Asia, 1978.**

| | Taiwan, China[a] | South Korea[b] | Japan |
|---|---|---|---|
| Rice land (thousand ha) | 750 | 1220 | 2516 |
| Total of herbicide-applied land (thousand ha) | 680 | 850 | 5682 |
| Percentage to rice land | 91 | 70 | 226 |

[a]Estimated from Chiang et al (1980). [b]Estimated from Kim (1980).

**Table 4. Major herbicides in rice in Fast Asia, 1978.**

| Taiwan, China | | South Korea | | Japan | |
|---|---|---|---|---|---|
| Herbicide | Percentage of rice land treated | Herbicide | Percentage of rice land treated | Herbicide | Percentage of rice land treated |
| Butachlor | 46 | Butachlor | 56 | Chlornitrofen | 41 |
| Thiobencarb | 15 | Nitrofen | 8 | Thiobencarb/ simetryn | 32 |
| Chlomethoxynil | 11 | Thiobencarb | 3 | Chlomethoxynil | 23 |
| Thiobencarb/ chlornitrofen | 8 | 2,4-D | ? | Oxadiazon | 18 |
| | | | | Molinate/simetryn/ MCPB | 15 |

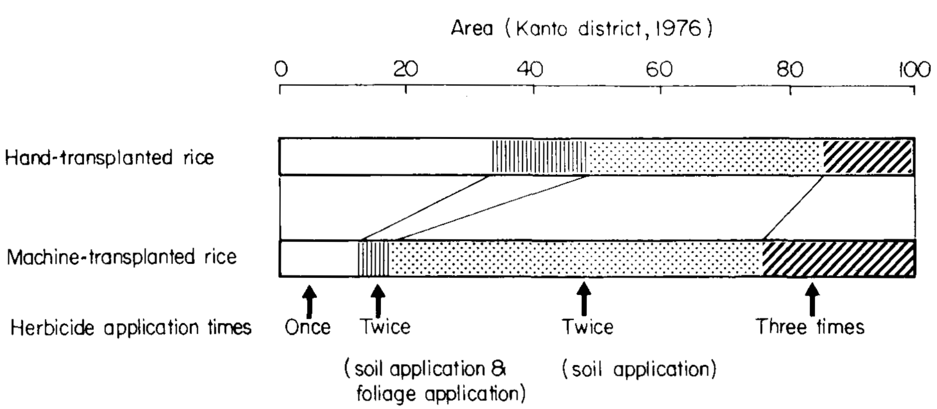
4. General concerns — water management, soil preparation, growth of seedlings, air temperature, etc.

## WEED CONTROL IN MACHINE-TRANSPLANTED RICE

In machine transplanting, younger and smaller seedlings are planted at a shallower depth than in hand transplanting. Furthermore, transplanting by machine is generally done 7-10 days earlier, under lower temperatures. These differences create some changes in weeding practice or herbicide application.

- The younger, smaller rice seedlings planted at a shallower depth are generally more susceptible to herbicides, particularly when factors unfavorable to healthy growth, such as low temperature and excessively deep irrigation, are added. Therefore, herbicides applied before weed emergence or soon after weed emergence have to be chosen for their selectivity. In Japan, in the process of changing from hand to machine transplanting, much effort was made to identify herbicides that are more selective and less toxic to rice.
- Planting smaller seedlings means that the crop is exposed to weed competition longer. Furthermore, lower temperature at the early growth stage is likely to result in a longer period of weed emergence. Thus, in machine transplanting, sequential weeding with repeated application of herbicides or the use of more persistent herbicides, or both, are required to obtain satisfactory weed control (Fig. 3).
- Because of dense and sometimes irregular transplanting by machine, it is generally difficult to control weeds manually or by means of a rotary weeder.

| | Year | | | |
|---|---|---|---|---|
| | 1973 | 1975 | 1977 | 1979 |
| Area of machine transplanted rice (% of total rice land) | 32.4 | 61.2 | 80.6 | 88.0 |




**3.** Increase in area of machine transplanted rice and comparison of herbicide application times for hand- and machine-transplanted rice (MAFF 1981, JAPR 1979).

Seedlings for machine transplanting are grown at a high seed rate in seedling nursery boxes filled with weed seed-free soil or artificial materials, so weeding is generally unnecessary during the nursery period.

## WEED CONTROL IN JAPAN

In Japan, *herbicide* is frequently a synonym for weed control. Farmers sometimes use a rotary weeder, either manual or powered, when herbicides cannot be applied because of the unhealthy initial growth of rice under abnormal conditions. Hand weeding is also practiced to remove the *Echinochloa crus-galli* and some perennial weeds that survive after herbicide application. These manual or mechanical weedings, however, only supplement chemical weeding. It is estimated that herbicides are applied to more than 200% of rice fields nowadays, meaning that farmers use them more than twice in a crop season on the average.

At present, more than 50 herbicides are registered for paddy rice. Half of them are mixtures of two or three active ingredients. They are classified into one of three groups according to their application time: preweed-emergence soil treatment (Type A), early postweed-emergence soil treatment (Type B), or foliage treatment (Type C), as shown in Table 5.

The kind of herbicide, time of application, and type of sequential treatment adopted by farmers differ from area to area depending on regional climate, trans-

**Table 5. Herbicide application times of farms and main herbicides (JAPR 1979).**

| Herbicide application | Type of herbicide[a] | Application area in 1978 (% of total rice land) | |
|---|---|---|---|
| Once | Type A | 7.7 | 13.9 |
| | Type B | 6.2 | |
| Twice | Type A and Type B | 37.7 | 51.6 |
| | Type A and Type C | 15.8 | |
| | Type B and Type C | 4.1 | |
| Three times | Type A, Type B, and Type C | | 28.4 |

Main herbicides of each type in 1980.[b]

| Type A | | Type B | |
|---|---|---|---|
| Chlornitrofen | (28) | Thiobencarb/simetryn | (31) |
| Chlomethoxynil | (19) | Moliate/simetryn/MCPB | (22) |
| Oxadiazon | (17) | Thiobencarb/simetryn/MCPB | (19) |
| Butachlor | (15) | Dimethametryn/piperophos | (13) |
| Thiobencarb/chlornitrofen | ( 9) | Molinate/simetryn | ( 5) |
| Chlornitrofen/dymrone | ( 7) | Simetryn/MCPB | ( 4) |

*Type C*

MCPA, 2,4-D, bentazone

[a]Type A = preweed-emergence soil treatment; generally applied between a few days before and a week after transplanting; Type B = postweed-emergence soil treatment, generally applied 2-3 wk after transplanting; Type C = foliage treatment, generally applied about 2 mo after trans planting. [b]Figure in parentheses indicates the percentage of application within a type.

planting season, and weeds to be controlled. The most prevalent type of sequential treatment is the combination of Type A and Type B herbicides (Table 5).

It is generally difficult for farmers to choose the right herbicide for their particular situations, so the agricultural experiment station of each prefecture or the regional branch of the agricultural cooperative union prepares specifications every year. An example is shown in Figure 4.

Soil-applied herbicides are usually formulated in granular form, so farmers apply them by hand or with a granular applicator. The power pipe duster is a more efficient applicator for large fields. Some herbicides applied before transplanting are emulsifiable concentrates which are applied directly to the water surface after puddling, as droplets, undiluted with water.

Herbicide use in Japan is more intensive than in other countries. Reasons for this, besides the labor shortage, rise of wages, and use of machine transplanting mentioned previously, are:

1. Farmers generally want to remove weeds completely from their fields. If herbicides fail to control weeds satisfactorily, farmers often remove the remaining weeds by hand. To minimize manual weeding, farmers are apt to use herbicide excessively.
2. Most conventional herbicides are not effective or are only partially effective against certain perennials. Furthermore, as the emergence pattern of perennials is commonly different from that of annuals, a single herbicide application could miss either annuals or perennials. Sequential application of two or three herbicides is thus needed to attain good control of perennial weeds. Some promising herbicides effective against perennial weeds are being developed, so it is feasible that one application of a mixed compound could satisfactorily control a wide range of weed species, including perennials, in the near future.

## THE BALANCE SHEET OF WEED CONTROL

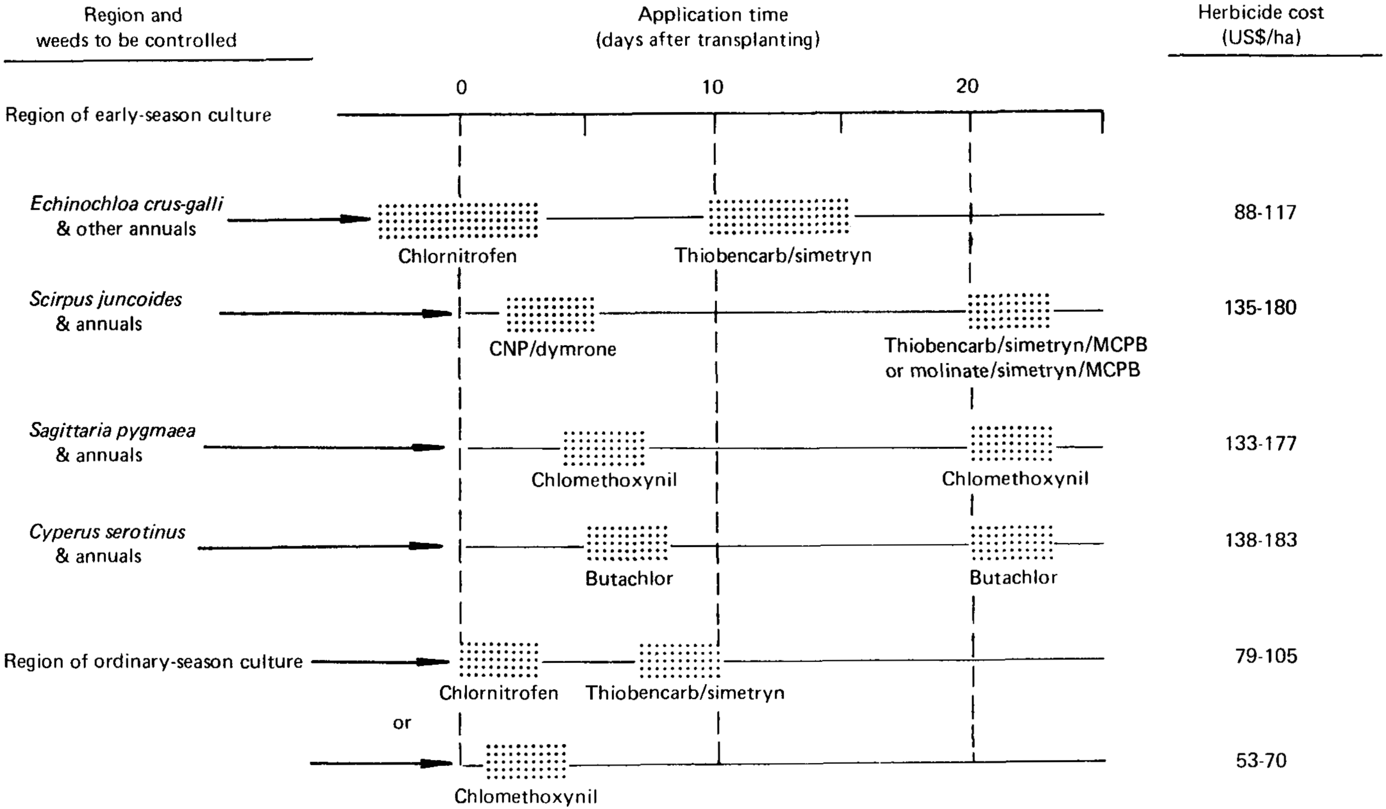
In the intensive small-scale farming of East Asia, new weed control techniques are evaluated according to how they save labor, not how they improve rice production.

In Japan, weeding of rice paddies required more than 500 labor hours/ha before herbicides became available. If 300 labor hours/ ha were needed for manual weeding, labor cost per hectare would be more than $260 in South Korea, $1,000 in Japan, and $200 in Taiwan (Chiang et a1 1980). If one application of a typical soil-applied herbicide gave similar control to hand weeding, chemical weeding would cost roughly less than $40/ha (materials and labor) in Taiwan and South Korea.

Japanese statistics indicated a cost of about $120 for herbicide (applied twice yearly on the average) and $222 for labor (herbicide application plus manual weeding), a total of $342, to control weeds in 1 ha of rice in 1979 (Table 6).

The labor requirement for weeding was 9.5% of total labor in 1979, whereas it was more than 20% in the early years of herbicide use. Such a reduction in the percentage of weeding labor implies that herbicides have contributed to labor saving to a greater extent than has mechanization.

Chemical weeding has thus provided much economic benefit to farmers. Further extension of herbicide use is expected in Taiwan and South Korea, as Kim (1980)




**4.** Directions for herbicide use in a Japanese prefecture in 1981.

**Table 6. Summary of weed control costs compared to other farm costs in rice production in 1979 (MAFF 1981).**

| Item | Value (US$/ha) | |
|---|---|---|
| *Weed control costs* | | 342 |
| 1. Labor (66 h/ha, including herbicide application) | 222 | |
| 2. Herbicides | about 120 | |
| *Other crop costs* | | 5104 |
| 3. Labor (628 h/ha) | 2111 | |
| 4. Heating and power | 132 | |
| 5. Fertilizer | 423 | |
| 6. Agricultural chemicals (except herbicides) | 131 | |
| 7. Farm machines | 1455 | |
| 8. Others (exclusive of land rent and interest) | 852 | |
| *Total costs* | | 5446 |
| *Crop production* (5.1 t/ha brown rice) | | 6900 |

Weed control labor = 9.5% of total labor
Cost of herbicides = 17.8% of sum of costs of chemicals and fertilizer
Cost of weed control = 6.3% of total cost

maintained that two herbicide applications for rice culture would still be comparable with hand weeding and that herbicide mixtures or combinations for preemergence and postemergence weed control look feasible in Korea. Herbicide use in Japan, on the other hand, seems to be maximal, although new, more effective, and safer herbicides may eventually replace current ones.

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## DISCUSSION

DE DATTA: Concerning the $342/ha cost for weed control in Japan, how much rice output would pay for the herbicide?

*CHISAKA:* A brown rice yield of 5.1 t/ha gives an income of $6,900.

MATTHEWS: If you ignore plant breeding as a method of controlling insects and plant diseases, are there any correlations between high use of herbicides and low incidence of insect and plant diseases?

*CHISAKA:* I do not know. Perhaps Dr. Matsunaka can answer.

MATSUNAKA (comment): We have done no such experiments.

SUNDARU: You mentioned that in Japan farmers apply herbicides on rice two or three times. Have you observed any problems of residual effect or water pollution by the several herbicides applied?

*CHISAKA:* If farmers use herbicides according to directions on the label then serious problems are not likely to occur, even from sequential applications. Surveys of chemical residues in rivers or creeks, however, sometimes show peaks of herbicide residue during the application season, but the levels are not high enough to influence the environment.

DE DATTA: Last year, during the weed control conference in Tokyo, there was some concern expressed about the thiobencarb toxicity. What is the situation with this?

*CHISAKA:* A metabolite causes an injurious effect on rice. It is not a big problem now.

SOONG: You have listed many reasons for the rapid development of herbicide use in Japan but you did not mention government subsidies. Could we know how much the government gives to the farmer or what the price structure is to make the price so high? How much is the government assistance to the rice farmer?

*CHISAKA:* This is because of the high wage cost.

MATSUNAKA (comment): The government buys the rice at a higher price than the consumer price. Our taxes are paid to the farmer. It is some kind of social security.

# FARMERS' WEED CONTROL TECHNOLOGY FOR WATER-SEEDED RICE IN NORTH AMERICA

D. E. Seaman

Water-seeding, a method of direct-broadcast planting of rice, began in California, USA, during the 1920s as a cultural method to control *Echinochloa crus-galli* var. *crus-galli.* Continuously flooded water management is the essential component of that weedy grass control system. The development of aerial seeding for rapid and economical planting was greatly responsible for the adoption of water-seeding of rice in all California rice fields, and in large percentages of the rice areas in Arkansas, Louisiana, Mississippi, and Texas. This planting method is now a major cultural component of integrated systems of weed control in which chemical components have become increasingly essential. Many aquatic weeds thrive under the water management practices used for water-seeded rice and they are controlled mainly by phenoxy herbicides. The recent introduction and spread of the aliens *E. oryzoides* and *E. phyllopogon* in California have caused rice farmers to rely greatly on herbicides such as molinate or propanil to protect the crop from serious losses in yield and grain quality. US rice farmers willingly pay about 7% of the crop production value for weed control.

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About one-third of the rice-production area of the USA is planted by water-seeding, a method of broadcasting the seed directly into flooded fields. Virtually all the rice in California is water-seeded, while the area planted by this method in the southern rice-growing states ranges from about 8% in Arkansas to about 60% in Louisiana. The purposes, the weed problems, and the concomitant crop management practices of water-seeding rice in the southern rice-growing states are rather different from those in California, but water-seeding is an important cultural component of integrated weed control systems in both areas.

## CALIFORNIA WATER-SEEDING SYSTEM

The present California system of water-seeding rice in continuously flooded fields began in the 1920s as a method to control severe infestations of *Echinochloa crus-galli* var. *crus-galli* (Adair and Engler 1955, Johnston and Miller 1973, Willson 1979). Early reports describe how the dry-broadcast or drill-seeded fields became so foul with *E. crus-galli* var. *crus-galli* that they were abandoned after 3 or 4 years when the accretion and competition of dense weed growth caused rice yields to decline drastically (Kennedy 1923, Dunshee and Jones 1924). This was regarded as a serious threat to the future of the young California rice industry.

Early research to mitigate this problem showed that continuous flooding controlled E. *crus-galli* var. *crus-galli* and other weedy grasses and that water-seeding gave the best rice stands in continuously flooded fields (Dunshee 1923, Dunshee and Jones 1924, Jones 1926, Dunshee 1928). The success of that work led rice growers to adopt this planting system during the late 1920s and early 1930s (Willson 1979). At first they used horse- or tractor-drawn wagons with endgate spreaders to water-seed. This method was slow and difficult in the flooded clay soils, but it enabled rice production without very severe weedy grass competition.

The development of aerial seeding gave impetus to water-seeding of rice in California. Rice was first water-seeded by aircraft in 1929, and previous methods soon were outmoded by this rapid and economical planting method (Willson 1979). The availability of World War II surplus aircraft enabled aerial seeding of nearly all California rice fields by 1950 (Jones and Davis 1950). Modern agricultural aircraft can carry up to 1,035 kg of soaked seed and plant about 177 ha/hour at a cost of only $12/ha.

Standard procedures now include land preparation by tractor-drawn implements (chisels, moldboard and disk plows, and harrows); installation of levees and other water depth and flow control structures (unless they are already in place as in monoculture rice areas); ground or aerial fertilization followed by harrowing; flooding to 5-15 cm deep; and aerial seeding of presoaked seed (Johnston and Miller 1973, Miller et al 1975). Seeds usually are treated first with a fungicide to protect seedlings from diseases caused by the fungi *Achlya* sp. and *Pythium* sp. (Webster et al 1973). Shallow flooding is maintained in the rice fields until crop maturity.

## SOUTHERN STATES WATER-SEEDING SYSTEMS

Water-seeding of rice in southern US rice-growing states followed its development in California. Some growers in Texas began aerial water-seeding in 1948, and many in

Arkansas, Louisiana, and Mississippi used this method during the late 1950s (Slusher 1953, Reynolds 1954, Faulkner 1960, Mullins 1960). One of the main reasons for their adopting water-seeding was to control weedy grasses (Adair and Engler 1955, Johnston and Miller 1973). However, many of these growers went back to their preferred drill-seeding practices after the introduction of selective grass herbicides for rice (Smith et a1 1977). For example, the water-seeded rice area in Arkansas decreased from about 50% to the present 8% of the total after propanil became available in 1962 for control of *E. crus-galli* var. *crus-galli* (B. A. Huey, pers. comm.).

In addition to *E. crus-galli* var. *crus-galli* control, there are other important reasons for continued water-seeding of rice in other southern states. It is the only planting option on the flat lands of southwestern Louisiana and southeastern Texas along the Gulf of Mexico where heavy rainfall during planting (March through May) combined with poor drainage causes soggy soils that must be prepared wet. The situation precludes drill-seeding, which requires dry seedbeds. Therefore the area of water-seeded rice varies in response to the severity of inclement weather in Louisiana and Texas. Aerial water-seeding is the most rapid and economical planting method after delays in land preparation or water leveling (Faulkner and Miears 1961), and for replanting. Water-seeding followed by either continuous flooding or a water management method called pinpoint flooding is an important component of integrated systems for control of red rice *(Oryza sativa)* varieties, which severely infest many southern US rice fields (Huey and Baldwin 1980, Sonnier 1978).

Except where seedbeds are prepared wet or water-leveled (which would be unusual in California), the procedures, implements, and materials used before aerial seeding of flooded southern US rice fields are similar to those used in California. Irrigation water management after water-seeding is one of the main differences between California and southern US rice areas. Postseeding drainage and reflooding are rare in California, but common in the south to improve rice stands where soils are silty, salty, or alkaline; to correct the nutritional disorder straighthead; to control filamentous algae; to apply fertilizers; and to expose young weeds to foliar herbicides.

## MAJOR WEED PROBLEMS

The most troublesome weeds likely to occur in California and southern US water-seeded rice fields are listed in Tables 1 and 2. In spite of their geographical separation, both areas have many native and alien rice weeds in common. This probably is a consequence of early exchanges of rice seed (contaminated with weed-seed) between rice-growing states and between the US and other countries (Barrett and Seaman 1980).

## RICE FIELD WEED PROBLEMS

### California rice field weed problems

The change to water-seeded rice culture to control *E. crus-galli* var. *crus-galli* has encouraged the development of many weed problems that were known or unimportant in the previously dry-seeded fields (Table 1). Most are common native aquatic plants and some recent adventives that thrive with continuously flooded water management. Furthermore, *E. crus-galli* var. *crus-galli* is still a serious problem in water-seeded rice fields where continuous flooding is not diligently maintained or where that weed emerges from moist soil after land preparation and grows precociously before flooding and rice planting (Barrett and Seaman 1980).

A 1976 survey (Barrett and Seaman 1980) showed that the annual weeds *Ammannia coccinea, Bacopa rotundifolia, Echinochloa oryzoides,* and *Sagittaria montevidensis* ssp. *calycina* were the most abundant and widespread in Californian rice fields. None of the other weeds in Table 1 was found as widely distributed, although many were locally abundant among scattered rice-field infestations. So far, no important shifts in predominance from annual to perennial weeds have been observed in Californian rice fields as reported elsewhere (Noda 1977). Present patterns of herbicide usage and land preparation apparently have controlled or contained the local infestations of the perennials *Eleocharis palustris, Potamogeton nodosus, Sagittaria longiloba, Scirpus fluviatilis,* and *Typha latifolia.*

A very serious weed shift has occurred in California rice fields since the adoption of water-seeded rice culture. This was the replacement of *E. crus-galli* var. *crus-galli* mainly by *E. oryzoides,* and in a few localities by *E. phyllopogon,* as the most

**Table 1. Major weeds of California rice fields.** [a]

| Taxon | Kind [b] |
|---|---|
| Aquatic weeds | |
| *Alisma triviale* Pursh | N, pe.(an.) |
| *Ammannia coccinea* Rottb. | N, an. |
| *Bacopa eisenii* (Kell.) Penn. | N, an. |
| *B. rotundifolia* (Michx.) Wettst. | A, an. |
| *Cyperus difformis* L. | A, an. |
| *Echinodorus berteroi* (Spreng.) Fassett | N, an. |
| *Eleocharis obtusa* (Willd.) Schult. | N, an. |
| *E. palustris* (L.) R. & S. | N, pe. |
| *Heteranthera limosa* (Sw.) Willd. | A, an. |
| *Najas guadelupensis* (Spreng.) Morong | N, an. |
| *N. graminea* Del. | A, an. |
| *Potamogeton nodosus* Poir. | N, pe. |
| *Sagittaria longiloba* Engelm. | N, pe. |
| *S. montevidensis* Cham. & Schlect. ssp. *calycina* (Engelm.) Bogin | N, an. |
| *Scirpus fluviatilis* (Torr.) Gray | N, pe. |
| *S. mucronatus* L. | A, pe.(an.) |
| *Typha latifolia* L. | N, pe. |
| Semiaquatic weeds | |
| *Echinochloa crus-galli* (L.) Beauv. var. crus-galli | A, an. |
| *E. oryzoides* (Ard.) Fritsch | A, an. |
| *E. phyllopogon* (Stapf) Koss. | A, an. |
| *Leptochloa fascicularis* (Lam.) Gray | N, an. |

[a] Adapted from Barrett and Seaman (1980). [b] A = alien, N = native, an. = annual, pe. = perennial, pe.(an.) = perennial growing mainly as an annual.

troublesome weed (Barrett and Seaman 1980). The large seeds of these Asian grasses enable them to germinate and emerge through rather deep (up to 30 cm) water. They are better adapted to survive continuous flooding than the small-seeded *E. crus-galli* var. *crus-galli.* Both *E. oryzoides* and *E. phyllopogon* were introduced before water-seeding began in California, but *E. oryzoides* became the more widespread. Dense infestations of *E. oryzoides* or *E. phyllopogon* (or both together) can cause more than 50% rice yield loss if not controlled. Since these weedy grasses are only partially controlled by continuous flooding, California rice farmers rely greatly on herbicides to protect the crop from losses caused by these weeds.

## Southern US rice field weed problems

Many southern US rice farmers drain and reflood their fields after water-seeding to obtain satisfactory rice stands (Johnston and Miller 1973). Consequently, many semiaquatic weeds typical of discontinuously flooded, dry-seeded fields are found in water-seeded rice fields (Table 2). They include the weedy grasses *E. crus-galli* var.

**Table 2. Major weeds of southern U.S. rice fields.**[a]

| Taxon | Kind[b] |
|---|---|
| Aquatic weeds | |
| *Alternanthera philoxeroides* (Mart.) Griseb. | A, pe. |
| *Ammannia coccinea* Rottb. | N, an. |
| *Bacopa rotundifolia* (Michx.) Wettst. | A, an. |
| *Cyperus erythrorhizos* Muhl. | N, an. |
| *C. iria* L. | A, an. |
| *Eleocharis obtusa* (Willd.) Schult. | N, an. |
| *E. parvula* (R. & S.) Link | N, an. |
| *E. quadrangulata* (Michx.) R. & S. | N, pe. |
| *Heteranthera limosa* (Sw.) Willd. | A, an. |
| *H. reniformis* R. & P. | A, an. |
| *Lindernia anagallidea* (Michx.) Penn. | N, an. |
| *L. pyxidaria* L. | A, an. |
| *Rhynchospora corniculata* (Lam.) Gray | N, pe. |
| *Sagittaria montevidensis* Cham. & Schlect. | A, an. |
| *Sphenoclea zeylanica* Gaertn. | A, an. |
| Semiaquatic weeds | |
| *Aeschynomene indica* L. | A, an. |
| *A. virginica* (L.) B.S.P. | N, an. |
| *Brachiaria platyphylla* (Griseb.) Nash | N, an. |
| *Coperonia castanaefolia* (L.) St. Hil. | A, an. |
| *Commelina communis* L. | A, an. |
| *Echinochloa colona* (L.) Link | A, an. |
| *E. crus-galli* (L.) Beauv. var. *crus-galli* | A, an. |
| *Eclipta prostrata* (L.) L. | N, an. |
| *Fimbristylis miliacea* (L.) Vahl | A, an. |
| *Leptochloa fascicularis* (Lam.) Gray | N, an. |
| *L. panicoides* (Presl) Hitchc. | N, an. |
| *Ludwigia decurrens* Walt. | N, an. |
| *Oryza sativa* L. (red rice) | A, an. |
| *Sesbania exaltata* (Raf.) Cory | N, an. |

[a]Adapted from Smith et al (1977). [b]A = alien, N = native, an. = annual, pe. = perennial.

*crus-galli, Leptochloa fascicularis,* red rice, and broadleaf weeds such as *Aeschynomene virginica* and *Sesbania exaltata.* These semiaquatic weeds mainly are controlled where continuous flooding can be maintained after water-seeding rice. Water-seeding with more or less continuous flooding encourages growths of aquatic weeds such as *A. coccinea, B. rotundifolia, Eleocharis obtusa, Heteranthera limosa,* and *Sagittaria montevidensis* in southern US rice fields (Smith et al 1977). The perennial weeds in Table 2 are localized problems as others are in California. *Alternanthera philoxeroides* is troublesome in rice fields of southwestern Louisiana.

## INTEGRATED WEED CONTROL IN WATER-SEEDED RICE

Present systems of integrated weed control for water-seeded rice culture include many preventive, cultural, and chemical components (Smith et al 1977). With the water-seeded method, cultural weed control practices must be integrated with herbicide usage to effectively protect the crop from weeds.

### Preventive weed control

The most important preventive weed control method for direct-seeded rice is the use of high quality seed uncontaminated with weed seeds to avoid spreading or intensifying weed problems. Federal and state seed certification standards have reduced the efficacy of seed as a source of noxious weeds in many crops including rice. For example, previously severe red rice infestations in California (Randall 1951) have been practically eradicated by farmers' use of certified rice seed and continuously flooded rice culture. US rice farmers generally neglect other preventive methods such as control of weeds and their seed production on levees and field margins, screening weed seeds from irrigation water, and cleaning farm implements to avoid spreading weed seeds or propagules from field to field.

### Cultural weed control components

Appropriate water management and favorable rice stand establishment are the most important cultural components of weed control systems for water-seeded rice. The way that floodwater is managed before and after water-seeding greatly influences the density, uniformity, and vigor of rice stands; the kinds of weeds; and the efficacy of herbicides (Smith et al 1977). Rice stands of 100 to 200 plants/m$^2$ are desired for competitiveness with weeds. Faced with the dilemma that conditions favoring rice also favor semiaquatic weeds, rice farmers usually act to favor the crop and depend on herbicides for weed control. To facilitate the shallow-water growth requirement of new semidwarf rice cultivars in California, land is leveled by laser-guided equipment for precise control of water depth and movement in large (20-100 ha) fields. Southern US rice fields are smaller to enable rapid drainage and reflooding for satisfactory rice stands without severely encouraging semiaquatic weeds. This water-management method, when done carefully and precisely (pinpoint flooding), keeps soil capillaries filled with water, excludes atmospheric oxygen, and maintains the enforced dormancy of germinable red rice and other weed seeds below the soil surface.

Other important cultural methods are thorough seedbed preparation, fertilizer management with respect to application timing and rate, and crop rotation as discussed by Johnston and Miller (1973) and Smith et al (1977). Pertinent developments since those publications appeared are the recent small increase of multiple cropping with beans or winter cereals in California — made possible by new shortduration rice cultivars — and the well-organized educational program for red rice control in Arkansas (Huey and Baldwin 1980). The red rice control program features water seeding of rice in continuously flooded fields, rotation with soybean or grain sorghum, and appropriate herbicide usage in each crop. Other southern US rice-growing states use similar systems to control red rice infestations.

**Chemical weed control components**

In modern systems of direct-seeded rice production, chemical weed control methods are essential to increase the efficacy of other costly inputs and maintain profitability (Smith et al 1977). But water-seeding imposes more stringent requirements for herbicide selectivity than other planting methods. Herbicides available for California water-seeded rice are propanil and molinate for weedy grass control; MCPA, fenoprop, and bentazon for control of broadleaf aquatic weeds and sedges; a granular amine salt of endothal for control of submerged weeds; and copper sulfate for control of algae (Bayer et al 1979). To avoid spraydrift hazards to susceptible crops, propanil is prohibited in about 90% of the California rice areas and aerial application of phenoxy herbicides is prohibited in the remaining 10% where propanil is permitted (Miller et al 1969). A limited amount of granular thiobencarb became available to California rice farmers in 1981 through an emergency exemption from registration by the US Environmental Protection Agency. Thiobencarb appears effective in control of *Echinochloa* sp., *L. fascicularis, B. rotundifolia. C. difformis, H. limosa,* and *Najas guadelupensis.*

Southern US rice farmers have many alternative herbicides for drill-seeded rice, but those available for water-seeded rice are similar to those in California (Smith et al 1977, Univ. Ark. Co-op. Ext. Serv. Specialists 1981). The main differences in usage are that 2,4,5-T is the most widely used phenoxy herbicide and propanil is more freely available, but when red rice is among the weedy grasses molinate is the preferred herbicide. Granular thiobencarb was not allowed in southern US water-seeded rice, although, by emergency exemption from registration, its liquid formulation became available in 1981 for drilled rice in Arkansas, Mississippi, and Texas.

## COSTS OF WEED CONTROL IN WATER-SEEDED RICE

In 1981 it cost about $270 to produce a ton of rough rice in California. At a market value of $300, net profit was $30/t or 10% of the production value (Wick et al 1981). California rough rice yieldsaveraged 8 t/ha in 1981. A 10% loss of 0.8 t/ha meant no profit for average rice producers. Weed competition studies (D. E. Seaman, unpubl. 1979, 1980) indicated that only 16 *Echinochloa* plants/m$^2$ reduced rough rice yields by 1.0 t/ha. That is why California rice farmers are willing to spend $150/ha or more to obtain satisfactory weed control.

Tables 3 and 4 compare the weed control and other costs in producing water-seeded rice in California and Louisiana. The values in Table 3 relate to a typical yield

**Table 3. Weed control costs compared with other production costs of water-seeded rice in California.[a]**

| Operation | Cost (US$/ha) |
|---|---|
| Weed control by costliest alternatives: | |
| Thiobencarb, custom-applied, 4.5 kg a.i./ha | 81 |
| Bentazon, custom-applied, 1.1 kg a.i./ha | 53 |
| $CuSO_4 \cdot 5H_2O$, custom-applied, 13.4 kg a.i./ha | 27 |
| Total | 161 |
| Other crop-production costs: | |
| Cultural (land preparation to harvest) | 834 |
| Fixed (machinery, depreciation, etc.) | 361 |
| Total | 1,201 |
| Total production costs | 1,362 |
| Crop production value (7.85 t/ha yield) | 2,355 |
| *Net returns:* weed control = 12% of the total costs, = 13% of all other costs, = 7% of production value. | |

[a]Adapted from Wick et a1 (1981).

**Table 4. Weed control costs compared with other production costs of water-seeded rice in Louisiana.[a]**

| Operation | Cost (US$/ha) |
|---|---|
| Weed control by best available alternatives: | |
| Molinate, custom-applied, 4.5 kg a.i./ha | 73 |
| 2,4,5-T, custom-applied, 1.1 kg a.i./ha | 25 |
| Total | 98 |
| Other crop-production costs: | |
| Cultural (land preparation to harvest) | 779 |
| Fixed (machinery, depreciation, etc.) | 209 |
| Total | 988 |
| Total production costs | 1,086 |
| Crop production value (4.4 t/ha at US$30) | 1,320 |
| *Net returns:* weed control = 9% of total costs, = 10% of other costs, = 7% of production value. | |

[a]Adapted from Musick and Zacharias (1981).

of 7.85 t/ha in California. Even when the most costly chemical weed control alternatives were selected, the total weed control costs in California were only 7% of the value of the harvested crop. The values in Table 4 are related to Louisiana's average production of 4.4 t/ha in 1980, which was rather low because of poor growing conditions. Nevertheless, the total production costs were $276/ha less than in California, and the total weed control costs were 7% of the crop production value. Most US rice growers would regard this expenditure as a definite bargain in view of the loss they might sustain without weed control.

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## DISCUSSION

MUKHOPADHYAY: (1) You mentioned you had a problem with *Chara* in California. In South Asia, particularly in Bengal, the south of Bangladesh, and part of Orissa, we have saline (alkaline) soils so we have a problem with all types of algae. We tried copper sulfate. It did a very good job but it is expensive. We are trying to find other alternatives. Do you have any alternative to $CuSO_4$ for control of algal weeds? (2) You are using 2,4,5-T. There is a furor around the world about its causing cancer. Why are you using 2,4,5-T?

*SEAMAN:* (1) No. We do not try to control *Chara.* It is very difficult to control economically. We have controlled it experimentally with granular chloroxuron but it would be too costly. (2) We used 2,4,5-T in North America long before the Vietnam war and it is still legal, but there are some problems with the environmentalists who would like to have it banned. Dr. Roy Smith, could you tell them the present legal status of 2,4,5-T?

SMITH (comment): At. present, it can be legally used in rice. We treated a large area of rice in the southern US with 2,4,5-T this year.

*SEAMAN:* According to the scientific evidence, 2,4,5-T will not hurt you. It will not give you cancer.

MUKHOPADHYAY: A lot of reports from Australia say they have problems with cancer from 2,4,5-T. I would like to get clarifcation from Dr. Michael.

MICHAEL (comment): Those reports do not stand up to scientific inquiry.

Cox: I noticed *Typha* Occurred in a lot of your slides and you said that you had some success in controlling it with glyphosate through rope wick applicators. I noticed that you were doing this during the middle of the rice-growing season. How confident are you that that is the best time to apply glyphosate, and is there an opportunity to apply it with a high-volume sprayer after harvest?

*SEAMAN:* This is probably not the best way to apply glyphosate for *Typha* control. It would actually be better to spray than to use the rope wick applicator. Perhaps we will end up spraying with a directed spray to keep the glyphosate off the rice. Glyphosate is effective after flowering of the *Typha.* This seems to be the best time to get control when there is downward movement of the glyphosate to affect the rhizomes and thus control regrowth.

DE DATTA: You mentioned that thiobencarb is not going to be registered at all. Why is this so? It looked very good.

*SEAMAN;* I meant that it would not be registered as a water run application. Right now we have an emergency registration. In California, it can be used only for postflood granular application and so the preflood application has not been used. In the south, it is used as a liquid application usually mixed with propanil. It is still not fully registered.

COX (comment): We have been using thiobencarb on aerially seeded or water-seeded rice in trials for a number of years in Australia and we have found that phytotoxicity is quite strongly tied to formulation and time of application. Granular formulations are worse than the emulsifiable concentrates. The reason being that we have been getting higher water concentrations of thiobencarb with granular formulations and also quite a pronounced accumulation of thiobencarb with water flow. It looks as though there will be a registration or at least a temporary permit issued for thiobencarb in water-seeded rice in Australia in the coming season.

KIM: In direct seeding, what is the depth of the water and how long do you maintain that depth? What is the effect of the submerged condition on the germination of the rice?

*SEAMAN:* In California, we are trying to maintain 5-15 cm of continuous floodwater throughout the season. The soaked seed is sown into the water and sinks to the bottom because it is heavy or it may be coated with something to make it heavy. It germinates and emerges through the water. The flood is maintained until a few weeks before maturity to give the fields time to dry out so we can use mechanical harvesting equipment.

OBIEN: I believe you have 100% aerial seeding in California and only 7.9% in Arkansas. Why is this so?

*SEAMAN:* When 1 was in Arkansas in June, they told me that before propanil, up to 50% of their hectarage was water-seeded because this was their main nonchemical method of *Echinochloa crus-galli* control. Propanil was approved in about 1962, there was no longer a need for water-seeding so farmers went back to drill-seeding. In California, it was a weed problem that caused a cultural practice change. In Arkansas, it was a herbicide that caused a cultural practice change.

EASTIN: Why can't California dry-seed and use propanil?

*SEAMAN:* We had propanil in the early 1960s and then a number of prune growers started planting their orchards among the rice fields. The French prune is very sensitive to propanil. Propanil was banned by law in California on about 90% of our hectarage. The problem is drift when you apply it aerially.

DE DATTA: As you changed from somewhat taller to semidwarf cultivars, did you see any change in the weed composition or intensity?

*SEAMAN.* Since the change to the shorter cultivars, the weeds have in effect become more competitive. We have had a bigger job helping the growers keep clean fields.

PYON: Do you have any problems of aerial sprayed herbicide drifting to adjacent susceptible crops such as soybean?

*SEAMAN:* When herbicides are applied carelessly by aircraft, they may drift and injure nearby susceptible crops and ornamental plants. Most states have regulations to minimize the hazards of aerial pesticide application. For example, aerial application of 2,4-D is prohibited in some southern US rice areas where cotton and soybean are grown extensively. There are similar legal restrictions for aerial application of MCPA and propanil in California.

# FARMERS' WEED CONTROL TECHNOLOGY FOR WATER-SEEDED RICE IN EASTERN EUROPE

O. V. Podkin, R. G. Chanukvadze, and V.S. Frolova

Weed control in Eastern European rice fields is based on agrotechnical methods that involve limited use of herbicides. They include crop rotation, fall plowing and spring tillage, and water management. When herbicides are used, economic thresholds are first determined by vegetation mapping. That significantly reduces the number of chemical treatments and the amount of chemical used, which minimizes the negative effects of herbicides on the environment.

The 30 weed species of 20 families that are problems in Eastern Europe (USSR) rice fields include some grass weed species of *Echinochloa* (*E. crus-galli* and *E. phyllopogon*), species of Cyperaceae (*Scirpus maritimus, Bolboschoenus compactus*), *Sagittaria trifolia, Alisma plantago-aquatica, Typha latifolia, T. angustifolia. Phragmites communis,* and *Cyperus rotundus.*

An important element of agrotechnical weed control in rice is crop rotation. Both eight-course and seven-course crop rotations are used. Depending on the climatic zone and on economic considerations, perennial grasses, legumes, spring barley, and

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wheat may be used in rotation with rice. During cultivation of dryland crops, when there is no water layer on the fields, reduction of water-loving weed vegetation in the arable soil layer reaches 75-80%. During irrigation of perennial grasses, the seeds of water-loving weeds germinate, but weed seedlings die as the soil dries out.

The agrotechnical measures of weed control also include fall plowing, spring presowing tillage, and a specified irrigation regime. The methods used for fall and spring tillage differ depending on the type of weed and the degree of weediness. Perennial weed control is achieved by maximum desiccation of soil in the spring, followed by rakings to remove weed vegetation. Annual weed control is achieved by a presowing shallow cultivation to control seedlings and sprouts. Main soil tillage is done before herbicide application to completely control weed vegetative propagules and seedlings. Maps of weediness serve as the basis for decisions on herbicide application. Rice field vegetation mapping makes it possible to use the combined system of agrotechnical and chemical control measures eliminating uneconomical herbicide application. For example, in rice fields invaded by *Echinochloa* species, the economical expediency threshold for herbicides application is the number of weeds beyond 20 plants/$m^2$; for *Scirpus* and *Bolboschoenus* species, the threshold is 50-60 plants/$m^2$.

On rice fields where the application of herbicides is not planned, control of *Echinochloa* species is accomplished by a water layer 10-12 cm deep applied immediately after sowing. The water is removed at the beginning of rice seed germination. After seedling emergence, the field is again covered by a water layer 12-15 cm deep, which is maintained until weed seedlings die. Then the water layer is reduced to the level of the rice seedling leaves.

The assortment of herbicides applied on rice fields includes 10 proprietary compounds. The control of *Echinochloa* is accomplished with systemic herbicides such as molinate and thiobencarb and by contact application of propanil. Systemic herbicides are applied and soil incorporated 2-3 days before sowing and inundation, immediately after sowing with immediate irrigation, or before or after rice seedling appearance but not later than the 2-leaf stage of *Echinochloa.* The first two times of application are principally used. The herbicides are applied usually by ground apparatus and occasionally by airplane.

Phenoxy herbicides are applied at the 1- to 3-leaf stage of the weeds. The treatment is carried out when the soil is dry.

Propanil is applied according to the biological peculiarities of the rice cultivars grown. The yields of the cultivars Dubovsky 129, Kuban 3, and Kubanets 575 decrease when propanil is applied. Weed control in fields planted to those cultivars is obtained by applying molinate and thiobencarb before sowing. For swampy weed control, treatment is at the full tillering stage of rice using derivatives of chlorphenoxyacetic acid (2,4-D amine and MCPA). The herbicides of this group also are selected according to the biological peculiarities of the cultivars. The optimum stage for treating fields planted to rice cultivar Krasnodarsky 424 is at 7.5-9 leaves; for Uz ROS-59, 8.5-9 leaves; and for Dubovsky 129, 7-7.5 leaves.

Because herbicides with a 2,4-D and MCPA base are inadequate in controlling weeds of *Bolboschoenus* species and also have other shortcomings (phytotoxicity to other crops of the rotation and the need to apply at strictly determined dates), scientists at the All-Union Rice Research Institute are searching for more effective herbicides meeting current requirements. At present, systematic and contact herbicides mixtures are being developed.

# FARMERS' WEED CONTROL TECHNOLOGY IN RICE IN SOUTHERN EUROPE

P. Catizone

The climatic, agronomic, and technical characteristics of the main rice-growing regions in Europe are summarized. Discussion centers on the present problems and solutions currently adopted in weed control for rice crops. Information on the economic aspects of weed control, its costs, and benefits is also supplied.

Rice is grown in 10 southern European countries. The rice-growing area extends from 37° to 48° North latitude and occupies a surface area of 401,000 ha, equal to 2.5% of the world rice-growing areas (Table 1). Average yields are 4.5 t/ha. Total rice production in the area is equal to 1.8 million tons, 4.8% of world production.

Italy is the major European country producing rice, cultivating in fact close to 50% of the rice grown on the continent.

In this paper, reference is primarily to Italian rice production because, given its extent, it has most of the problems present in the other European countries. Recent studies in various European countries did not indicate any large-scale differences in rice farming between those countries and Italy.

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**Table 1. Yields and hectarage planted to rice in the principal areas in Europe where rice is cultivated (from FAO 1978).**

| Country | Surface area | | Av yield | Area cultivated |
|---|---|---|---|---|
| | ha x $10^3$ | % | (t/ha) | |
| Albania | 3 | 1.2 | 3.3 | Along the river Beart |
| Bulgaria | 17 | 4.3 | 2.9 | Maritza and Tundja Valleys |
| France | 13 | 3.2 | 3.6 | Camargue |
| Greece | 19 | 4.1 | 4.8 | Macedonia and Etoloacarnania |
| Hungary | 28 | 6.9 | 1.8 | Tibisco and Koros Valleys |
| Italy | 190 | 47.2 | 5.0 | Po Valley |
| Portugal | 32 | 7.9 | 4.1 | Tejo, Sado, and Mondego Valleys |
| Romania | 23 | 5.7 | 2.0 | Area of Bucarest, Galati, and Oltenia |
| Spain | 68 | 16.9 | 6.0 | Area of Valencia, Terragona, and Sevilla |
| Yugoslavia | 8 | 2.0 | 3.7 | Macedonia |
| Total | 401 | 100 | 4.5 | |

## CLIMATE AND AGRONOMIC CHARACTERISTICS

### Climate

Almost all rice produced in Italy is grown in the northern part of the country. The experimental station at Vercelli regularly collects climatological data in that area. Average data for the more important climatic parameters are given in Table 2. The climate of Vercelli is suitable for rice growing, except that rainfall is insufficient.

### Types of soil, paddies, and irrigation

The rice soils are heterogeneous. Some are characterized by a high clay content and others by a high quantity of organic matter. In both cases the soils are agronomic anomalies in that they have an acid pH, which is good for rice but unacceptable for many other crops. Other soils used for growing rice are medium to light, with normal fertility. They are good for many crops other than rice.

The rice paddies have higher bunds for organic or permeable soils than for clay soils or soils of low permeability. The size and shape of the paddies depend on the slope of the land and the size of the farm. Larger farms tend to have larger paddies. Paddies on steeply sloping land are usually less than a hectare. On flat land or gently sloping land, the paddies may cover surface areas of several hectares and at times reach as much as 10 to 12 ha.

Irrigation is by continuous submersion in 10 to 20 cm of water, begun a few days before sowing and terminated 30 to 40 days before harvest. Irrigation may be interrupted or reduced to promote root formation, or during propanil treatments when the rice plants have two to three leaves, or to allow fertilizer or herbicide applications when the rice is midway in stem development. This type of irrigation has high water requirements that vary depending on soil permeability and quality of maintenance of the bunds. In general, estimated water consumption per hectare is 0.9 to 1.0 liter/second for very clay soils, 1.2 to 1.3 liters/second in clay soils, 2.0 to

**Table 2. Average values of climatic data for the period 1941-70, Vercelli, Italy (from Russo 1980).**

| | Air temperature (°C) | | Relative humidity (%) | Precipitation (mm) | Days with precipitation (no.) | Hours of sunshine | Solar radiation[a] (cal/cm$^2$) | Wind velocity (km/h) |
|---|---|---|---|---|---|---|---|---|
| | Average | Variation (monthly average) | | | | | | |
| Spring | 12.4 | +7.4 to +17.3 | 66.8 | 232.6 | 25 | 5 h 51 min | 360.3 | 4.7 |
| Summer | 22.9 | +21.3 to +23.4 | 65.9 | 195.2 | 21 | 8 h 19 min | 345.9 | 3.5 |
| Autumn | 12.6 | +6.5 to +18.5 | 78.6 | 257.7 | 22 | 3 h 59 min | 252.3 | 2.6 |
| Winter | 1.4 | -0.2 to + 1.8 | 82.5 | 140.2 | 17 | 2 h 24 min | 143.4 | 2.6 |

[a] Data relative to the last 26 years.

2.5 liters/second in medium texture soils, and 3 to 4 liters/second in light soils. That means that seasonal irrigation water requirements range from 15,000 to 50,000 $m^3$/ha. Generally, however, the irrigation water required is in the range of 20,000-25,000 $m^3$/ha.

**Crop technology**

Cultivation practices used in rice growing are basically the same throughout Europe because the various environments are similar and for the most part rice growing tends to be carried out on relatively large farms. In Italy, for example, about half of the rice is grown on farms larger than 50 ha.

The fundamental aspects of rice cultivation in the Po Valley can be summarized as follows:

*Crop rotation.* Continuous cropping is found, but some form of crop rotation is the usual practice. Most frequently, rice is grown continuously for 4 to 6 years followed by another crop for 1 to 3 years. In areas where rice is the principal crop, rice cultivation is interrupted for only a year. During that time, wheat followed by an autumn-spring forage crop is grown; occasionally maize is grown. In other areas where rice accounts for 35 to 40% of the cultivated land and where the prevalent combination is rice cultivation-animal husbandry, the interruption of the rice crop is usually for 2 to 3 years, during which maize and multispecies pasture are grown. In other areas where animal husbandry is not common, interruption of the rice crop is still 2 to 3 years. There, the principal crops grown in rotation with rice are wheat, maize, vegetables, and watermelon.

Maize after rice has been found to give poor yields so that, where possible, the cultivation of wheat or pasture is preferred.

*Soil tillage.* Plowing to a depth of 25 to 35 cm is done in the autumn for clay soils and at the end of winter for light soils or those high in organic matter. Normally, multiblade plows are used. The farmers do not like to use rotary tillage because its use tends to increase the number of perennial weeds. Plowing is at the rate of 0.3 to 0.5 ha/h. After plowing, the land is harrowed and leveled. Only the light soils require compacting with rollers to reduce water loss due to percolation after the paddy has been flooded.

*Sowing.* The rice is sown in the flooded paddies during the last 3 weeks of April. Seed is broadcast at 180-230 kg/ha using centrifugal sowing machines. The working capacity of these machines is 3 to 4 ha/h.

*Fertilizer applications.* Normal fertilization procedure begins with presowing applications of nitrogen, phosphorus, and potassium. Usually, superphosphate or Thomas slag (100 to 150 kg P/ha) is distributed at the time of sowing. The highest doses are used on organic soils. More rarely, applications of 100 to 150 kg of K/ha are made using KCl as the source of potassium. Eighty percent of the total nitrogen (70 to 150 kg/ha) is applied at presowing and 20% during crop growth. The nitrogen fertilizers are mainly urea (rarely calcium cyanamide) at the time of sowing and ammonium sulfate or ammonium nitrate toward the end of June, during crop growth. Soils high in organic matter do not receive nitrogen applications. The time necessary to carry out the fertilizer applications is usually short — 4 ha/h — when granular products are used.

*Pest management.* The main pests are rice leaf miner, China mark moth, chironimid fly, and tadpole shrimp *Triopus cancriformis.* They are controlled with 0.5 to 1 kg/ ha of phosphorus-based esters.

The most damaging disease is blast. The more common means of control is to use resistant strains of rice.

*Harvesting and drying of rice.* Harvesting is usually done with rented combine-harvesters at a cost of US$50-60/t grain. Five to six tons can be harvested per hour.

At harvest (end of October-beginning of November), rice has 22 to 28% moisture content. It must be dried to reduce the moisture to 13 to 14%. Drying is carried out using both static and dynamic drying systems. The static systems are more economical and tend to be used more often than the dynamic ones.

## WEED CONTROL

Up to 1950, weed control was done manually with the help of suitable water management.

The first chemical herbicides, 2,4-D and MCPA, were introduced in 1951 and were effective for some types of weeds. In the early 1960s, herbicides active against *Echinochloa* were introduced. The use of chemical weed killers spread rapidly throughout Europe in the 1960s. During the 1970s, the area with rice in Italy was treated with chemical weed killers 1.6 times every year.

Transitory problems arose in 1971 when some European countries prohibited the use of fenoprop. Fenoprop was replaced with bentazon.

In the last 15 years, most European rice growers have relied entirely on herbicides for weed control. Most growers consider weed control today to be satisfactory, although there are still unresolved marginal problems, especially with algae.

### Principal weed problems

The main weeds of rice in southern Europe are given in Table 3. The genus *Echinochloa* represents the prime problem for growers, because of both the high cost of its control and extent of the damage caused. In some studies grain losses between 46 and 72 kg/ha were found for each 100 kg/ha of *Echinochloa* dry matter (Catizone 1973). The herbicides used are sometimes only moderately efficient because a long emergence period characterizes the genus, especially in clay soils. The period of emergence of *Echinochloa* tends to be shorter for light soils or soils high in organic matter. The germination times also depend on the amount of water in the paddy. In general, water levels of 3 to 4 cm immediately after sowing favor a rapid germination of the genus, while higher water levels tend to retard its emergence. Thus, a proper water level in the paddy is a fundamental element controlling *Echinochloa.*

Another problem is that of the Alismataceae and the Cyperaceae. These families are uniformly spread throughout the rice-growing areas and are relatively easy to control, with the exception of *Cyperus glomeratus* and the genus *Scirpus.*

Still another problem is caused by a vast range of weeds, which are nonuniformly spread over the European rice-growing areas, local infestations of which cannot be neglected. This is especially true for paddies where crop rotation often is not practiced. Efficient herbicides are available for these various weeds with the excep-

**Table 3. Principal weeds in rice fields in southern Europe.**

| Botanical family | Frequently found | Occasionally found |
|---|---|---|
| Poaceae | *Echinochloa crus-galli*<br>*E. crus-galli* ssp. *hispidula*<br>*E. crus-pavonis*<br>*E. phyllopogon* | *Leersia oryzoides*<br>*Echinochloa seratina*<br>*Oryza sativa* c.v. *silvatica*<br>*Paspalum paspalodes* |
| Cyperaceae | *Scirpus maritimus*<br>*S. mucronatus*<br>*Cyperus difformis*<br>*C. glomeratus* [b]<br>*C. serotinus* | *Scirpus supinus* [a]<br>*Cyperus fuscus* |
| Alismataceae | *Alisma lanceolatum* | *Sagittaria sagittifolia* |
| Typhaceae | *Typha latifolia* | *Typha angustifolia* [c]<br>*T. laxmanni* [c] |
| Butomaceae | *Butomus umbellatus* | |
| Lemnaceae | *Lemna minor* | |
| Sparganiaceae | | *Sparganium erectum* |
| Potamogetonaceae | | *Potamogeton crispus*<br>*P. natans* |
| Pontederiaceae | | *Heteranthera limosa*<br>*H. reniformis* |
| Marsiliaceae | | *Marsilea quadrifolia* |
| Elatinaceae | | *Bergia capensis* [a] |
| Lythraceae | | *Ammannia coccinea* [a] |

[a]Mainly in Spain. [b]Mainly in Greece. [c]Mainly in France.

tion of volunteer rice. The best technique against this weed is still to stop growing rice for a few years.

The growth of algae can be a serious problem, especially in the early phases of rice development, not only because the growth of the rice is retarded but because, when using products absorbed by the leaves, the algae reduces the efficiency of the herbicide treatments carried out just after emergence of the weeds. The more common algae belong to the Chlorophyceae and the Cyanophyceae. The genera *Spirogyra, Hydrodictyon, Sphaeroplea,* and *Oedogonium* belong to the first group and the genera *Anabaena, Nostoc,* and *Oscillatoria* to the second. Today the Cyanophyceae are more diffuse than in the past as a result of the repeated use of tin derivatives against the Chlorophyceae.

**Weed control practices**

Weed control in southern Europe is basically directed toward meeting four objectives: 1) control of the genus *Echinochloa,* 2) control of the Alismataceae and the Cyperaceae, 3) control of weeds peculiar to specific areas, and 4) control of algae.

Molinate is the most commonly used herbicide to control the *Echinochloa,* the exception being for soil with high permeability, where its use is not advisable because of its high solubility. Herbicides used to a lesser extent are tiocarbazil and propanil.

Molinate is used at rates of 3-5 kg/ha, depending on the nature of the soil. Generally, molinate is used in liquid form, applied to the dry paddy before sowing, and immediately incorporated into the soil using light harrows. After this operation, the paddy is flooded and the rice is sown, taking care to leave the paddy well flooded for at least 2 weeks. Molinate is also used, but less frequently, after the plants have emerged (1-3 weeks after sowing). In this case, the preferred practice is to distribute the herbicide in granular form directly into the water; more rarely, the liquid form is used, but water level is reduced to 24 cm. The efficiency of this treatment for postemergence control of *Echinochloa* spp. is guaranteed only if the weed has not passed the two- to three-leaf stage.

Tiocarbazil is used in granular and liquid forms. The granular form is used at rates of 4 kg/ha and is always distributed in water. It may be applied before sowing, before emergence of the plants, or after emergence, as long as the *Echinochloa* have not passed the three-leaf stage. In liquid form, tiocarbazil is used as a seed treatment. The usual practice is to soak the seeds in water for 48 hours. The seeds are then treated with tiocarbazil at doses of 4-60 liters/t seeds. The seeds must be sown within 48 hours after dressing. Rice growers favor the use of tiocarbazil because it not only controls *Echinochloa* but also is effective against the genus *Cyperus* as well as against some crustaceans (genus *Triops*).

Propanil is applied postemergence on perfectly dry paddies at doses of 4 liters/ha if the weeds are at the two- to three-leaf stage and at doses of 6 liters/ha if they are at the four- to five-leaf stage. (After the five-leaf stage *Echinochloa* can no longer be controlled with propanil.) The rice paddies are then flooded 24-36 hours after the propanil treatment. The water level is maintained high for a week to further hinder weed growth. The use of propanil is often preferable when seeking to control both *Potamogeton* and *Echinochloa.*

Several herbicides (MCPA, 0.8 kg/ha; mecoprop, 1.5 kg/ha; 2,4-D, 1.2 kg/ha; fenoprop, 1 kg/ha; and bentazon, 1.6 liters/ha) are used to control the Alismataceae and Cyperaceae. The herbicides are applied postemergence when the rice is midway in shoot development, on dry rice paddies or those with very low water levels.

The phenoxy-derivatives are used most frequently, but they are not always effective against a sufficiently wide range of weeds, except for fenoprop, the use of which, however, is prohibited in some European countries. In particular, MCPA does not control *Scirpus,* and 2,4-D and mecoprop are often ineffective against *Cyperus.* A wider variety of weeds can be controlled with bentazon. If used in association with small doses of propanil or MCPA, bentazon is effective against the Cyperaceae and Alismataceae and also against the genus *Butomus;* it is quite effective against the genera *Typha, Sparganium, Eleocharis, Marsilea,* and *Sagittaria.* Bentazon, then, is employed alone or in mixtures for all of those cases where the phenoxyderivatives are insufficient.

Specific techniques are required to control infestations of *Leersia oryzoides, Paspalum paspalodes,* and *Heteranthera.*

*Leersia* and *Paspalum* can be controlled by treatment with dalapon (8 kg/ha) or glyphosate (4 liters/ha) immediately after harvesting the rice or with TCA (20 kg/ha) in the winter. Applications of nitrofen in granular form (3 kg/ha) a week before sowing are used to control the genus *Heteranthera.*

Control of algae is practiced only for the Chlorophyceae because there are no effective chemicals for the control of the Cyanophyceae. The chemicals employed are: $CuSO_4$ $5H_2O$ diluted in water to give a rate of 200 to 300 g/ha per day for a period of at least a week; triphenyl tin acetate in doses of 1 kg/ha; and sodium ethylene bisdithiocarbamate in doses of 6 kg/ha. These last two products, which have recently been prohibited in some European countries, can also be used as seed dressings in doses of 3 kg/t seeds for triphenyl tin acetate and 1 kg/t for sodium ethylene bisdithiocarbamate.

## Weed control cost

The 1980 prices on the Italian market of the various herbicides used in weed control for rice crops are reported in Table 4.

The cost of distribution of herbicides (manpower + machine time) is around \$25/ha. The overall cost of rice production in the Po Valley ranges from \$1,700/ha to \$2,000/ha, while the gross marketable production for a yield of 5.5 t/ha reaches \$2,500/ ha.

The costs of two possible programs of weed control, established on the basis of the information given in this paper, are given in Table 5. One is based on use of the minimum possible amounts of herbicide and the other on a more complex use of herbicides. The minimum use of herbicides represents 5.5 to 6.5% of the overall costs and 4.4% of the gross marketable production. The more complex program of weed control, however, represents 12.4 to 14.6% of the overall costs and 10% of the gross marketable production. In terms of yield, the minimum use of herbicides costs 0.24 t of grain and the more complex program costs 0.55 t of grain.

**Table 4. Prices of herbicides used for rice crops in Italy, 1980.**

| Herbicide | Price of commercial product (US\$/kg) | Dose (kg/ha) | Price (US\$/ha) |
|---|---|---|---|
| Bentazon | 16.0 | 4 | 64.0 |
| 2,4-D | 3.5 | 2 | 7.0 |
| Dalapon | 3.5 | 15 | 52.5 |
| Glyphosate | 30.0 | 6 | 180.0 |
| MCPA | 2.5 | 2 | 5.0 |
| Mecoprop | 2.5 | 1.5 | 3.7 |
| Molinate, granular | 1.2 | 50 | 60.0 |
| Molinate, liquid | 11.0 | 5 | 55.0 |
| Nitrofen | 1.2 | 40 | 48.0 |
| Propanil | 4.2 | 12 | 50.4 |
| TCA | 2.5 | 25 | 62.5 |
| Tiocarbazil, granular | 1.0 | 80 | 80.0 |
| Tiocarbazil, liquid | 9.5 | 6 | 64.0 |

**Table 5. Cost of weed control based on two different programs of herbicide application.**

| Herbicide | Cost ($) of weed control | |
|---|---|---|
| | Minimum use of herbicides | Complex weed control program |
| Molinate, liquid | 55.00 | 55.00 |
| MCPA | 5.00 | – |
| Bentazon + MCPA | – | 66.50 |
| Dalapon | – | 52.50 |
| Two applications | 50.00 | – |
| Three applications | – | 75.00 |
| Total | 110.00 | 249.00 |

## CONCLUSION

In Europe, rice is considered a crop which supplies a relatively high income, but which requires consistent investments and a particular technical competence (Grillenzoni and Toderi 1974).

From a technical point of view, because of the particular habitat in which it grows, rice requires excellent soil preparation and accurate water management. These two factors are largely responsible for the final density of the rice plants, which in turn determines the production.

Weed control is a determining factor in rice production. High yields can be obtained only when the crop is free of weeds. In southern Europe, weed control is considered relatively simple because effective herbicides are available. Without these herbicides, it would not be economical to grow rice in Europe.

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# WEED CONTROL IN FARMERS' FIELDS IN THAILAND

P. Kittipong

Wet season and dry season rice crops are grown in Thailand. The wet season is the main rice-growing period and two types of rice culture are practiced: rainfed wetland rice culture and dryland rice culture. Weed control methods in wet season rice are 90% manual and 10%, chemical, but chemical weed control is on the increase because of the high cost of labor. Rainfed wetland rice is transplanted or pregerminated seeds are broadcast. Weed problems are more serious in broadcast rice. Land preparation and water management are effective cultural weed control practices in pregerminated direct-sown rice. Weed infestation is a serious problem in dryland rice where weed control is exclusively manual. Weeds are not a serious problem in dry season rice, which is grown in a manner similar to wet season rice. Manual weed control is the treatment of choice.

Thailand is a major rice-producing country with a total annual rice production of about 17.4 million tons. The agricultural area can be divided into four geographical regions:

- The Central Plain contains about 45% of the farmland with 37.6% of the national rice area and 53% of the rice production.
- The southern region includes most of peninsular Thailand, where rubber is the most important export crop.

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- The northeastern region, dominated by the dry Khorat Plateau and separated from the rest of the country by mountain ranges, is the least productive of the four regions. Rainfed rice yields are dependent on the amount and distribution of precipitation during the rainy season.
- The northern region has limited agricultural land, mostly in river valleys, where dryland rice is the most important crop.

The rice-growing areas and rice farmer production and income are shown in Table 1.

## RICE CULTIVATION

The wet season from May to October is the main rice-growing season. The length of the growing period differs across the regions, depending upon the amount and distribution of rain. Water management is difficult. About half-and-half photoperiod sensitive and photoperiod insensitive rice cultivars are planted. Fertilizer application and pest management are practiced by a small number of farmers.

### Rainy season rice production

Rainy season rice production can be grouped into two types: rainfed wetland and dryland.

*Rainfed wetland rice.* The primary form of rice cultivation — rainfed wetland rice —covers more than 80% of the rice-growing areas where irrigation is not practiced. Cultural practices include 1) transplanted rice, 2) deepwater rice, and 3) pregerminated direct sown rice.

Transplanted rice is the most common cultivation method under rainfed conditions. The planted area is about 9.09 million hectares, Both photoperiod sensitive and photoperiod insensitive rice cultivars are grown. Age of seedlings at transplanting is 25-30 days. Basal application of 16-20-0 fertilizer at 94 kg/ha is recommended 2-3 days before transplanting. Pest management is used when necessary.

Weed infestations are moderate (Table 2). Noxious species are sedges and aquatics (Suwatabandhu 1950). Weed control is about 90% mechanical and 10% chemical.

Manual weed control was a common method of weed control in transplanted rice, especially during 1965-1974 when labor costs were low and labor was easy to get. At the same time the price of rice was not high. Labor costs were US$0.50-0.75 per laborer per day; rice prices were US$60/t. Hand-pulling technique is common. Stepping on weeds and hand-hoeing are a common practice in transplanted rice in the northern section where soil conditions and water management are suitable.

Chemical weed control in transplanted rice has not been common because of the high cost of chemical products and farmers' lack of knowledge of weed control technology. But with labor costs now 3-4 times higher than 15 years ago (Fig. I), chemical weed control in transplanted rice seems likely to increase. With the difficult drainage in rainfed wetland rice fields during the rainy season, granulated formulations of herbicides seem to be more acceptable than liquid formulations. The groups of chemicals being used are phenoxy, amide, and carbamate. Application rates are about 1.0-2.5 kg a.i./ha applied 4-7 days after transplanting (IRRI 1978, Kittipong 1977).

**Table 1. Planted area, average yield, farm size, and income from rice in Thailand.[a]**

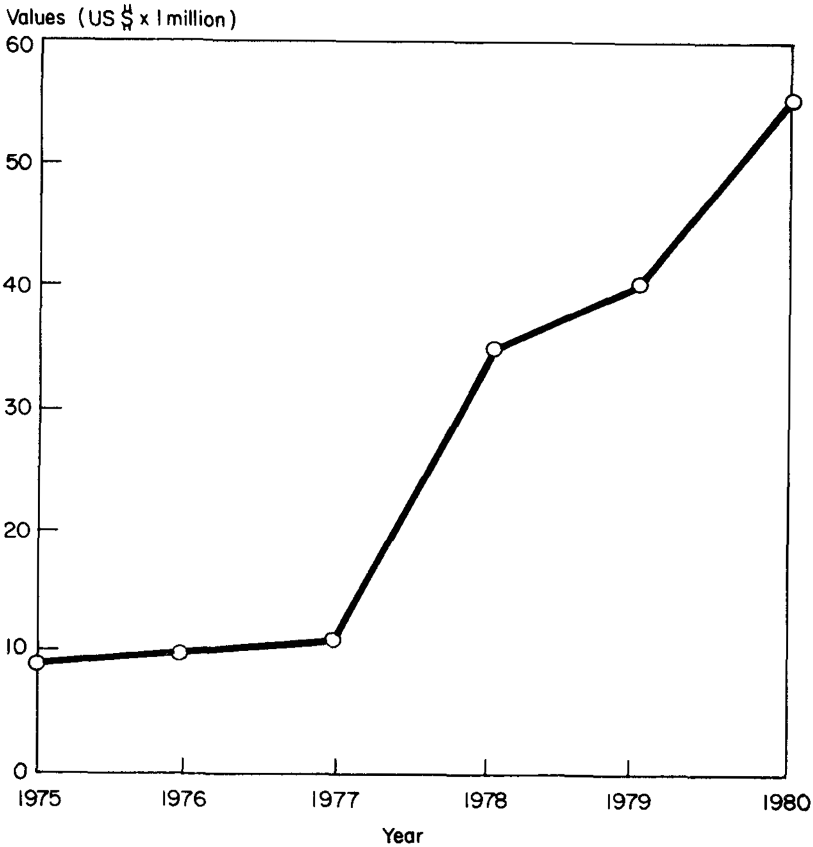
| Region | Rice planted area (million ha) | | | | Wet season rice yield (t/ha) | Dry season rice yield (t/ha) | Av farm sue (ha) | Income from rice (US$/farm) |
|---|---|---|---|---|---|---|---|---|
| | Trans-planted | Deep water | Germinated, direct-sown | Dryland | | | | |
| Northern | 1.95 | 0.18 | – | 0.23 | 2.4 | 2.6 | 3.39 | 199.2 |
| Northeastern | 4.51 | – | – | 0.07 | 1.3 | 2.6 | 4.43 | 13.7 |
| Central Plain | 1.97 | 2.42 | 0.032 | – | 2.1 | 3.5 | 5.26 | 501.3 |
| Southern | 0.66 | – | – | 0.02 | 1.6 | 3.2 | 3.65 | 46.6 |
| Total | 9.09 | 2.58 | 0.032 | 0.32 | 1.8 | 3.3 | 4.19 | 181.04 |

[a]Thailand Ministry of Agricultural Economics, 1979.

**Table 2. Weeds of rainfed rice in Thailand.**

| Weed | Degree of infestation[a] |
|---|---|
| *Chara zeylanica* | xxx |
| *Cyperus difformis* | xxx |
| *C. pulcherrimus* | x |
| *Echinochloa crus-galli* | x |
| *Fimbristylis littoralis* | xx |
| *Leptochloa chinensis* | x |
| *Ludwigia hyssopifolia* | x |
| *Marsilea minuta* | xx |
| *Mimulus orbicularis* | xx |
| *Monorhoria vaginalis* | xxx |
| *Seirpus juncoides* | xxx |
| *Sphenoclea zeylanica* | xx |
| *Utricularia aurea* | x |

[a]xxx = heavy, xx = moderate, x = slight.




**1.** Annual import values of all herbicides, Thailand, 1975-80.

Deepwater rice is grown predominantly in the central region. The planted area is about 2.58 million hectares. The growing season starts shortly after the first rain, in early May, and ends in December or January. Water depths vary from 1 to 3 m. Rice cultivars grown are native photoperiod-sensitive types such as Pin Gaew and Leb Mue Nahng. Dry seeds are broadcast on the soil after plowing. Fertilizer treatment is not practical because of heavy weed infestations.

The weed problem for deepwater rice is more serious than for transplanted rice. Heavy infestations of dryland weeds can be seen everywhere, especially early in the growing season before flooding. Problem species are grasses, sedges, broadleaf, and aquatics (Table 3) (Sadakorn and Sadakorn 1975, Suwatabandhu 1950).

Flooding starts around mid-September. The water level in the rice field averages 0.75-1.5 m for about 2 months, then is naturally drained intocanals orrivers. During flooding, aquatic infestation can be observed but the weed problem is less.

Manual control of weeds is practiced in deepwater rice cultivation. Hand mowing or cutting of rice plants and weeds before flooding is also common. Cutting serves as a weed control treatment and the green part of weeds and rice plants serves as animal forage.

**Table 3. Deepwater rice weeds in Thailand.**

| Weed | Degree of infestation[a] |
|---|---|
| *Aeschynomene indica* | x |
| *Alternanthera philoxeroides* | x |
| *Commelina diffusa* | x |
| *Cyanotis axillaris* | xx |
| *Cyperus pulcherrimus* | x |
| *C. rotundus* | x |
| *Echinochloa colona* | xx |
| *E.crus-galli* | xx |
| *Fimbristylis littoralis* | x |
| *Ipomoea aquatica* | x |
| *Ischaemum barbatum* | xx |
| *Leptochloa chinensis* | xx |
| *Melochia concatenata* | x |
| *Panicum cambogiense* | xx |
| *Paspalum scorbiculatum* | xx |
| *Pentapetes phoenicea* | xx |

[a]xx = moderate, x = slight.

Chemical weed control for deepwater rice is not well developed. Not many chemicals are effective for deepwater conditions. The main use of chemical control by deepwater farmers is to suppress some weeds prior to flooding. In general, weeds that farmers want to kill are *Melochia concatenata* L., *Aeschynomene indica* L., and *Ipomoea aquatica* species because these strong competitors of rice can survive in deep water. The chemicals being used are phenoxy-type herbicides. Their use alone has resulted in an accumulation of grass species in deepwater rice fields.

Pregerminated direct-sown rice, a new practice in Thailand, is grown on about 32,000 ha. The area is mainly in the rice basin of the Central Plain close to rivers and canals or to the ditch and dike program of land development projects where water management is possible. Land preparation and drainage are critical for this type of cultivation, which can be conducted in both wet and dry seasons.

Rice cultivars grown, such as RD7 and RD9, are usually photoperiod insensitive. The planting method is broadcasting germinated seeds on top of mud. Basal application 15-20 days after seeding of 16-20-0 fertilizer at 350 kg/ha is recommended. Topdressing nitrogen fertilizer at the tillering stage is important for maximum production.

Weed problems in direct-sown rice can be more serious than in transplanted rice. Mechanical weed control can start at land preparation, followed by water management at later stages. Good land preparation and proper water management can greatly reduce weed populations and cut the degree of weed infestation to nonsignificant. But in case of poor land preparation and water management, chemical treatment with preemergence herbicides, especially granulated formulation of thiobencarb, bifenox, and butachlor, at 1.0-2.0 kg a.i./ha 7-8 days after sowing, is required. Postemergence treatment is not practical because of the high toxicity of chemicals to young rice. Weed species found in pregerminated, direct-sown rice are similar to those found in transplanted rice.

*Dryland rice.* The area sown to dryland rice is about 0.32 million hectares, scattered in the upper part of the northern provinces where farmers are poor. The local, photoperiod sensitive cultivars can be divided into early (100 days), moderate (120 days), and late maturing (135 days). Common planting methods are broadcasting, hand drill-seeding, and trap-seeding. Broadcasting and hand drill-seeding are similar to the planting methods for deepwater rice. In trap-seeding, practiced only among hill tribes, holes are drilled by hand and dry seed is broadcast on top of the ground. Rain carries the rice seeds into the traps or holes, where germination occurs.

No fertilizer is used in dryland rice. Pest management is not practiced. Planting is changed from place to place if farmers think that soil fertility level is decreasing and insect or disease infestation increasing.

Weeds in dryland rice fields are serious compared to those in rainfed wetland farms. The weeds are grasses, broadleaf, and sedges (Table 4). Weed control operations start with land preparation. Garden hoes or grub hoes are used. Later, farmers use hand tools to do additional weeding, if necessary. With an average farm size of only 0.8 ha, the family is the labor pool. At present, chemical weed control seems to be impractical in dryland rice cultivation because of the poor economic status of the farmers (Chirasathaworn and Schiller 1977, Terry 1981).

## Dry season rice production

A dry season or second rice crop is becoming more important as rice prices increase and government land development and irrigation projects are funded. Rice cultivars are photoperiod insensitive — RD7 and RD9. Dry season rice farmers use fertilizer and pest management. The limiting factor for second crop rice is available water. The planting area is not large compared to that for wet season rice.

**Table 4. Dryland rice weeds in Thailand.**

| Weed | Degree of infestation [a] |
|---|---|
| *Ageratum conyzoides* | x |
| *Amaranthus spinosus* | xxx |
| *Commelina diffusa* | x |
| *Corchorus aestuans* | x |
| *Cyperus compressus* | x |
| *C. iria* | x |
| *C. rotundus* | x |
| *Dactyloctenium aegyptium* | x |
| *Digitaria ciliaris* | xx |
| *Echinochloa colona* | xx |
| *Eleusine indica* | x |
| *Euphorbia hirta* | x |
| *Heliotropium indicum* | x |
| *Leptochloa chinensis* | xxx |
| *Portulaca olerocea* | x |

[a] xxx = heavy, xx = moderate, x = slight.

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## DISCUSSION

AHMED: In Table 1, the yield of wet season rice is much lower than that in the dry season. Why?

*KITTIPONG:* a) Higher levels of fertilizer are applied in the dry season. b) The area planted in the dry season is very small when compared to the wet season.

MUKHOPADHYAY: In India in the dry season boro crop we always get higher yield than in the wet season main crop. The reasons are that the farmers all plant modern cultivars, very high rates of fertilizers and good water management, and excellent environmental conditions.

SUNDARU: The Philippine and Indonesian Governments subsidize farmers by giving credit to purchase insecticides, fertilizers, and herbicides. The farmer repays after harvest. Do you have this system in Thailand?

*KITTIPONG:* No. The person who gives the credit to the farmer is the middleman. The factor limiting inputs is the low price of rice ($150/t).

YEH: What is the annual per capita income?

*KITTIPONG:* What I am trying to show in the last table is that, when the cost of the labor increases, the farmer will substitute herbicides for hand labor.

YEH: This is what we found in Taiwan and Japan. When the annual income reached $500/year, consumption of herbicides increased dramatically. In Taiwan, the 1972 annual income reached $500, so herbicide use went up. A similar situation occurred in the Philippines last year when annual income reached $500/year and herbicide consumption suddenly increased. I don't know if there is any correlation between these two things.

ISLAM: In deepwater rice in Bangladesh, *Eichhornia crassipes* is a serious weed. You have not listed it as a weed in this type of rice culture in Thailand. Does this mean that *E. crassipes* does not exist in Thailand or that it is not a problem?

*KITTIPONG:* It is a serious weed problem in the canals and rivers but not in the floating rice area.

DAS GUPTA: Rainfed dryland rice production in Thailand is similar to that in West Africa, Do your farmers plant rice along with other dryland crops such as maize, millet, or cassava? If so, what is the percentage of other crops with rice?

KITTIPONG: No specific intercropping system is practiced by Thai farmers right now, but dryland rice workers are researching this.

DAS GUPTA: What is the yield of dryland rice per unit land area?

*KITTIPONG:* Average yield of dryland rice is about 2-2.5 t/ha.

DAS GUPTA: What is the sowing method on dryland sloping fields? Do you have any problem establishing an optimum plant population?

*KITTIPONG:* Dryland rice farmers with sloping fields practice drill seeding, using different types of hand tools.

# FARMERS' WEED CONTROL TECHNOLOGY IN INSULAR SOUTHEAST ASIA

A. Syarifuddin K., M. Sundaru, and Azis Azirin

The types of rice culture in Indonesia and weed control practices for each type are discussed. The factors that influence farmers' choice of weed control methods are examined, in particular the local customs of farm laborers and the lack of capital. The costs of various herbicide treatments are compared. Weed control is treated as a component of appropriate technologies for dryland, swamp, and deepwater rice culture to exploit the rice production potential of Sumatra, Kalimantan, Sulawesi, and Irian Jaya.

The first objective in the third Five Year Plan for the Indonesian agricultural sector is developing an adequate food supply for the population. Although rice is not explicitly named, it is still the major food crop.

Indonesian farmers recognize the importance of weed control in rice production. Some rice farmers, particularly those with rice fields in Java, weed their fields excessively. On the other hand, some farmers do not weed enough. This does not mean that they are ignorant of the importance of weeding, but rather, that they have some problems in controlling weeds. Their cropping environments and farming conditions can differ from those of farmers who practice extensive weeding.

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## TYPES OF RICE FARMERS

About 61% of the 1978 Indonesian labor force of 53 million were working in the agricultural sector (IADS 1980). The majority of the agricultural labor force live in the rural areas and most rural villagers work in food production, predominantly rice production. Some work on estates growing perennial crops.

Most rural villagers receive formal education through elementary school. Recently, the number of villagers receiving higher levels of formal education has increased. Most rural villagers receive informal education through the extension services, particularly education in rice production technologies. But this education does not guarantee that new technologies are put into practice. Many obstacles prevent farmers from adopting new technologies, even though they realize the benefits of such technologies. The differences in the technology developed at research centers and that used on farmers' fields are obvious.

The average farmer income in 1980 was US$327 (IADS 1980). We assume that rice farmers' incomes are less than the average. However, among those working in rice production are landless farm laborers, who belong to the lowest income groups. Farmers who own land have incomes close to the average.

## TYPES OF RICE CULTURE

Types of rice culture in Indonesia include:

1. irrigated wetland,
2. dry seeded wetland,
3. tidal and nontidal swamp,
4. deepwater, and
5. dryland.

The IADS (1980) lists 8.85 million hectares of wetland rice. Dryland rice covers about 1.19 million ha. The cultural practices and the conditions differ among the types of rice culture. These differences bring about differences in the methods of weed control used.

Rice culture is mainly irrigated wetland with some dryland, deepwater, or swamp rice in Java. Dry-seeded wetland rice is grown mainly in Java, with small areas on other islands, but the total area is relatively small. Dryland rice is grown mainly in Sumatra, Kalimantan, and Sulawesi. Swamp rice is cultivated in Sumatra and Kalimantan. Irian Jaya also has a large potential for dryland and swamp rice. Deepwater rice is grown in Sumatra and Kalimantan.

The rice area in Java may be increased mainly by double- or triple-cropping in the fully irrigated areas. Irrigated areas outside of Java are relatively small. The government policy for such areas is to develop simple, relatively cheap irrigation systems that can be directly applied in the rural areas. However, the increase in total irrigated area is small.

If appropriate technologies for dryland, swamp, and deepwater rice culture are found, rice production in Sumatra, Kalimantan, Sulawesi, Irian Jaya, and other islands could be increased significantly. Part of the needed technology is in weed control.

## WEED CONTROL IN FARMERS FIELDS

Weed control methods differ for different types of rice culture, and according to the local customs of farm laborers and the availability of capital.

### Irrigated wetland

The principal method of weed control for irrigated wetlands is hand weeding twice during the growing season. Weeds are pulled and collected on dikes. Some farmers simply push small weeds into the mud. Weed regrowth caused by poor water control sometimes occurs.

*Rotary weeder use.* Progressive farmers with farms larger than 1 ha use rotary weeders, particularly in Java. Rotary weeder types differ mainly in size, number of rotary weeders on one tool, types of rotary spikes, model, and materials used.

Some farmers do not use rotary weeders for these reasons:

- Using a rotary weeder is inconvenient if the dominant weeds are creeping grasses or sedges.
- If weeding is done late, rotary weeders cannot control weeds as well as hand weeding.
- If puddling is not done properly, the soil is too hard and too shallow for a rotary weeder to push the weeds into the mud. (This is particularly true for newly established paddy fields.)
- In many cases, the available rotary weeders do not fit the system. For example, the desirable plant spacing and the width of the available rotary weeders are not compatible.
- Small farm sizes make using a rotary weeder uneconomical.

In areas where farm labor is scarce, such as in many regions in Sumatra, Kalimantan, and Sulawesi, weed control is poor. Originally farmers in those areas (except for Minangkabau in West Sumatra and Bugenese in South Sulawesi) were perennial crop and shifting cultivation rice growers. They did not grow paddy rice, and recognized paddy rice culture only recently, with transmigration since just before World War II. Some areas learned paddy rice culture from immigrant Bugenese. Weeding of paddy rice in those areas is not as good as it is in Java. The farmers spend more time on perennial crops such as coffee and rubber than they do on rice. Very recently, however, there was a change to slightly more intensive hand weeding using either hired or family labor.

Because the population in the outer islands is still low, landholdings there are relatively large. Hand weeding is expensive because of an insufficient hired labor pool. Farmers have two alternatives: to let the paddy field remain improperly weeded or to change to mechanical weeding. Some farmers in North Sumatra and South Sulawesi Provinces have started to use rotary weeders.

*Use of chemical weed control.* Farmers in North Sumatra and South Sulawesi have started using herbicides (Sundaru 1979). In North Sumatra, herbicides are commonly used on perennial plantation crops. Observations of demonstrations conducted by agricultural chemical companies show that farmers are willing to use herbicides. The benefits are in time and labor allocation as well as in the cost of weeding. Hand weeding costs 2-3 times as much as herbicides. Most commonly used

**Table 1. Herbicide sales in North Sumatra, Indonesia. 1974-78.**

| Year | MCPA (liters) | 2,4-D (liters) |
|---|---|---|
| 1974 | 17,503 | 12,610 |
| 1975 | 2,673 | 7,560 |
| 1976 | 17,023 | 10,080 |
| 1977 | 7,000 | – |
| 1978 | 5,000 | – |

Source: PT. Agricon and PT. Chandrajaya, 1977.

herbicides are MCPA and 2,4-D (Table 1). Herbicide costs are $2.40/ha for 2,4-D dimethylamine salt, $5.60/ha for MCPA, and $4.00/ha for 2,4-D butyl ester. Weeding cost is about $8.00/ha with 2,4-D dimethylamine salt, and $24.00/ha with hand weeding.

In South Sulawesi, farmers using herbicides apply 2,4-D and MCPA, depending on the type of weeds to be controlled (Table 2). Farmers who use herbicides are more likely to have a large farmholding (1-2 ha), to lack farm labor, and to spend less time weeding because of other jobs.

The total area in which herbicides are used is difficult to determine. It is small in terms of the total irrigated wetland rice area.

Many problems occur as a consequence of herbicide use. Liquid herbicides require sprayers, which are difficult to manage under village and farmer conditions. Information about herbicide application is not fully understood. Improper application, resulting in ineffective weed control, occurs. Herbicide distribution and storage at the farmer level are not carried out properly, causing some danger to handlers.

## Dry-seeded wetland

Dry-seeded wetland culture is similar to dryland rice culture in its early stages (up to 4-50 days after seeding), then similar to irrigated rice to harvest. This makes weed control particularly important during the early crop stages. If early weeding is not done properly, weeds at later stages may harm production. Most farmers practice only hand weeding, once to three times. Sometimes the second or third weeding is done after the rice is flooded. Rotary weeders and herbicides are not used.

## Swamp rice

Hand weeding is the only weeding practice in swamp rice fields. Weeding before

**Table 2. Herbicide usage in South Sulawesi, Indonesia, in 1976, 1977, and 1978.[a]**

| Year | 2,4-D (liters) | MCPA (liters) | Paraquat (liters) | Paraquat - diuron[b] (liters) |
|---|---|---|---|---|
| 1976 | – | 836 | 5469 | 325 |
| 1977 | – | 3700 | 3046 | 330 |
| 1978 | 757 | 2154 | 6319 | 908 |

[a]Source: Diperta South Sulawesi, 1979. [b]The spaced dash (-) indicates that herbicide was formulated as a proprietary mixture.

planting or during land preparation is the most important. If proper weeding is done before planting, it is not important after planting.

Before land preparation sedges and grasses are tall and grow vigorously. They are cut to the soil surface with a big knife. Water is high enough at this time to cause weeds to rot. After about 1 month, the partly rotted weeds are collected into several mounds. A month later, the mounds are turned over. After the third month, the mounds are chopped and spread over the field. This kind of weed control and land preparation is laborious and expensive.

### Dryland rice

Hand weeding is still the only effective method to control weeds in dryland rice. No rotary weeders nor chemical means are used. Weeding operations vary from one to three times during the rice-growing season, depending on weed infestation, farm labor availability, and cash capital capability. The equipment commonly used is a small sickle or knife or a hoe. Weeding dryland rice fields is more expensive than weeding irrigated wetland rice, but total cost depends mainly on degree of weed infestation. Weeding is important both before and after planting for dryland rice.

## WEED CONTROL EXPERIMENTS

Research emphasis has been on irrigated wetland rice. Several weed control methods, such as hand weeding, rotary weeder, herbicides, and crop rotation have been studied. We are convinced of the usefulness of available mechanical technologies on irrigated wetland rice. However, herbicide application technology that needs study includes the testing of new herbicides, the use of one type or many types of herbicides, the long-term effects of herbicides, and methods for handling herbicides under farmer conditions.

## CONCLUSION

Because weed control technology is relatively more available for transplanted rice than for other rice cultures, studies on weed control in other rice cultures need to be increased. The future of other kinds of rice culture is important because any increase in the area planted to irrigated wetland rice will be slow and expensive. The land potential for new irrigated wetland rice is small compared with that available for swamp and dryland rice. Water resources for irrigation may not be available because of the topographical features of the outer islands. But new rice-growing areas can be found in Sumatra, Kalimantan, Sulawesi, and Irian Jaya.

Labor on those islands is relatively scarce and expensive. Therefore, mechanical or chemical weed control or a combination with lower labor costs is needed. Crop rotation may be taken into consideration.

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## DISCUSSION

WIRJAHARDJA (comment): In an inventory between 1976 and 1981 we found 250 weed species in rice fields in Indonesia. We studied the ecophysiological aspects of the common weed species, mainly germination, competitiveness, and dormancy, in order to get basic information for weed management. This will be published in a 600-page book with 250 illustrations and descriptions.

DAS GUPTA (comment): In West Africa, large areas of Sierra Leone, Gambia, Senegal, and Nigeria are in rice planted in mangrove swamp (acid sulphate) soil. Using a single-axle power tiller for weed control has been successful in on-farm trials when the soil is not too soft. The weed problem is minimal when land is prepared by power tiller before transplanting. In associated mangrove swamps, weeds are controlled by application of paraquat followed by burning and land preparation by power tiller. Significant yield increase in associated mangrove swamps was also noted with application of propanil after transplanting. WARDA can send you information on tidal mangrove swamp rice cultivation.

VONGSAROJ (comment): You said that dry-seeded wetland rice is grown dry for 15 days, then the field is flooded. I think that water can control the dryland weeds. Therefore, there should be no need to weed under dry conditions. You can make use of the water.

*SYARIFUDDIN:* If we do not weed dry-seeded wetland rice, some weeds will be suppressed by water but some will stay until harvest. Because of the heavy competition during the early stage, rice tillering is low and the rice suffers. If weeding is not done before flooding, we get a poor stand and poor production.

VONGSAROJ: How many days after transplanting do you do hand weeding?

*SUNDARU:* The first weeding is done 3 weeks after transplanting and the second 6 to 7 weeks after transplanting.

ISLAM: What is the cost of weed control in relation to the total cost of production?

*SYARIFUDDIN:* For irrigated rice, weed control costs about Rp 180,000 (US$300). This is the total cost of production.

ISLAM: What yield is usually obtained under farmers' conditions?

*SYARIFUDDIN:* About 2-3 t/ha.

SUNDARU: The cost of hand weeding varies from one area to another. An average figure would be about Rp10,000 (US$16.50) per weeding.

OBIEN: It appears to me that hand weeding will be a major weed control technique for a long, long time. Should we study how hand weeding can be made more efficient? I saw some time-saving hand tools. Is this a direction for the study of hand weeding as a system of weed control?

*SYARIFUDDIN:* In Java, where we have mostly wetland rice, we will continue with hand weeding because, if we change, there would be much unemployment. But outside Java, where we have mainly dryland and tidal swamp rice, I believe that chemicals will play an important role in the future.

VEGA: I think you should mention that in Java the size of rice fields is 300 $m^2$. This is an important consideration in the weed control method used by the farmer. If you add to that the population per unit area in Java, then you have the right situation for hand weeding. But when you move to South Sulawesi, that is an entirely different situation.

# FARMERS' WEED CONTROL TECHNOLOGY FOR DRY-SEEDED RICE

N. U. Ahmed and A. J. M. Azizul Islam

In dry-seeded rice culture, the land is prepared dry and dry seeds are either broadcast or sown in rows before or immediately after the beginning of the rainy season. Reliance on manual weeding, the lack of timely weeding, and the shortage of labor at peak periods keep yields low. This paper evaluates the effectiveness of farmers' weed control practices in dry-seeded rice in Bangladesh and compares them to alternative technologies that include the use of herbicides in addition to traditional weed control technology. Preemergence chemical weed control followed by hand weeding could increase the production potential of the 8 million hectares under dry-seeded rice in Bangladesh.

According to the Bangladesh Bureau of Statistics (1979), Bangladesh has 20.45 million hectares of net cropped areas, of which nearly 8 million ha (40%) are sown to dry-seeded rice in either double- or triple-cropping patterns. Only 10 to 12% of the total cultivated area has access to some form of irrigation.

Crop sequences in the rainfed areas are shown in Figure 1. Jute followed by

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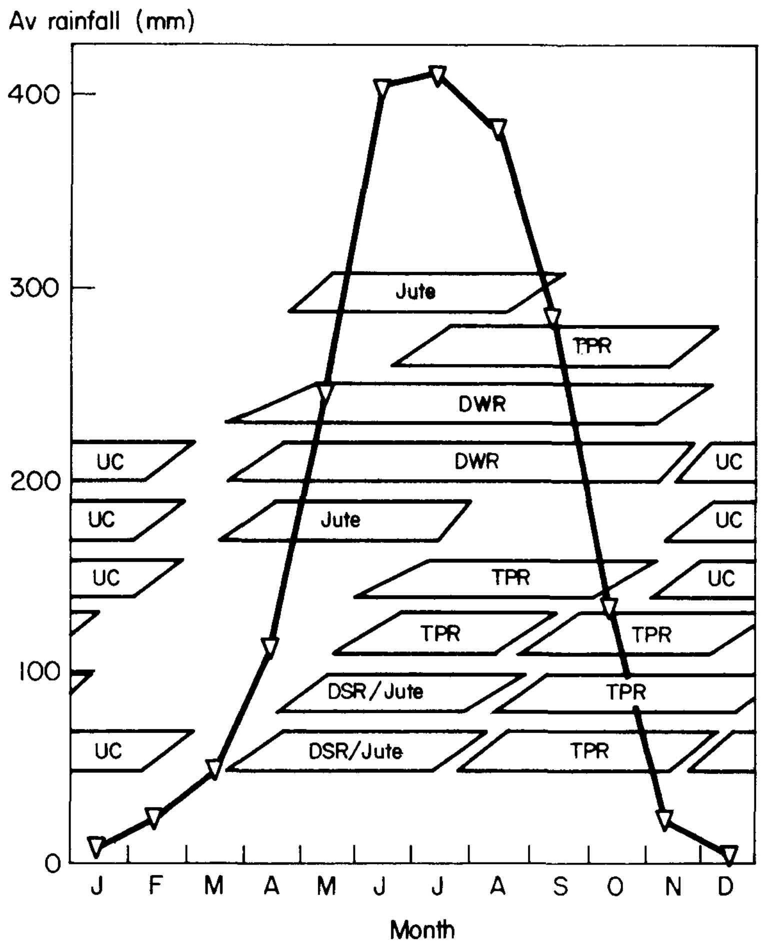


**1.** Average monthly rainfall and common crop sequences in the rainfed areas of Bangladesh. UC = upland crop, TPR = transplanted rice, DSR = dry-seeded rice, DWR = deepwater rice.

transplanted rice and dry-seeded rice, or transplanted rice followed by transplanted rice are the most common crop sequences.

Ninety percent of the farmers in Bangladesh are subsistence farmers who farm 0.6-1.7 ha (Bangladesh Bureau of Statistics 1979). Family size ranges from six to eight with at least two to three adult family laborers available. Adult members of landless families serve as a source of labor during peak labor periods.

Capital investment in buildings and machinery is practically nil. Some farmers have wooden implements such as a country plow; others rent implements along with draft animals.

Major purchased inputs are fertilizers and insecticides. Other purchased inputs are credit and hired human and animal labor.

## PRINCIPAL WEED PROBLEMS

As in other Asian countries, weeds in dry-seeded rainfed rice are a serious problem in Bangladesh. Yield losses due to weed infestation range from 80% to complete failure (BRRI 1981).

In the absence of a specific weed survey in the country, we estimate that in dry-seeded rainfed rice, grasses and sedges are the predominant groups of weeds. Broadleaf weeds are not significant.

Among grasses, *Echinochloa colona, Eleusine indica,* and *Digitaria sanguinalis* are the most important species. *Cyperus rotundus, C. iria,* and *Fimbristylis littoralis* are the most common sedges.

## FARMERS WEED CONTROL PRACTICES

Bangladesh farmers use no herbicides. Hand weeding is the only weed control practice by 90% of the farmers in dry-seeded rainfed rice. Farmers weed local cultivars two or three times, modern cultivars three to five times. About 300-350 labor hours per hectare are spent on hand weeding. From the number of weedings (Table 1) and total labor hours spent in weeding, it appears that the farmers are doing a good job. Unfortunately, that is not altogether true. Farmers often do weeding only in their spare time or when weeds grow taller than the rice plants. In reality, farmers do not get much return on their investment in weeding.

In light-textured soils, farmers often use a technique known as raking and laddering to control weeds 5-10 days after emergence (DE). Bullocks draw a spiked-tooth bamboo rake across the field followed by a bamboo ladder to lightly press and level the soil. The operation kills some weeds as well as thins the rice seedlings. Hand weeding is still required and it is difficult to determine the extent of weed control achieved by raking and laddering. Raking and laddering followed by hand weeding is practiced by about 10% of the farmers who grow dry-seeded rice.

## WEED CONTROL RESEARCH

In 1979 at Rajshahi Regional Station of the Bangladesh Rice Research Institute (BRRI), an unreplicated observational trial was conducted to evaluate the effect of postemergence raking and laddering on the performance of dry-seeded rainfed rice. Although the results were inconsistent, probably because of the difficulties of turning rakes and ladders in the field, raking followed by laddering increased seedling mortality to some extent (Table 2). In similar replicated trials in 1980, raking and laddering reduced the weed population considerably, but grain yields were higher when hand weeding followed raking and laddering. Monitoring of this technique in farmers' fields is, however, essential for correct evaluation.

At Joydebpur in 1974, eight herbicides were compared with hand weeding in dry-seeded rainfed rice (BRRI 1977). Butachlor and piperophos - dimethametryn, each applied at 2 kg/ha at preemergence, effectively reduced weed infestation and gave signifcantly better rice yield than other herbicide-treated plots. Hand weeding was as effective as butachlor or piperophos - dimethametryn for weed control as well as for grain yield (Table 3).

**Table 1. Farmers' management practices and productivity of dry-seeded rainfed rice in Rajshahi, Bangladesh, 1980 aus season.** [a]

| Management practice | Local cultivars | | | Modern cultivars | | |
|---|---|---|---|---|---|---|
| | Dharial | Hashikalmi | Purbachi | BR1 | BR3 | BR9 |
| Sample (no.) | 4 | 6 | 1 | 3 | 2 | 4 |
| Field duration (days) | 86 | 89 | 100 | 113 | 138 | 115 |
| Seeding date | 13-17 May | 10-17 May | 10 May | 10-13 May | 10-13 May | 10-17 May |
| Seeding rate (kg/ha) | 88 | 92 | 92 | 87 | 92 | 93 |
| Number that used N, $P_2O_5$, and $K_2O$ | 4 | 6 | 0 | 3 | 2 | 4 |
| Rate of N, $P_2O_5$, and $K_2O$ (kg/ha) | 41-38-30 | 34-44-40 | - | 92-43-19 | 64-49-39 | 72-54-33 |
| Number that did weeding | 4 | 6 | 1 | 3 | 2 | 4 |
| Av no. of weedings | 2 | 2 | 2 | 4 | 4 | 4 |
| Number that used insecticide | 0 | 0 | 1 | 1 | 2 | 2 |
| Times insecticide was applied (no.) | 0 | 0 | 1 | 1 | 2 | 2 |
| Yield (t/ha) | 2.2 | 2.3 | 2.5 | 2.8 | 3.2 | 2.2 |

[a] Data gathered by daily monitoring of farmers' fields.

**Table 2. Effect on yield of dry-seeded rainfed rice (BR3 and Khasia Panja) by postsowing raking and laddering. BRRI, 1979 aus season.** [a]

| Raking fb [b] laddering (no.) | Hand weeding (no.) | BR3 | | | Khasia Panja | | |
|---|---|---|---|---|---|---|---|
| | | Seedling [c] mortality (%) | Panicles (no./m²) | Yield (t/ha) | Seedling [c] mortality (%) | Panicles (no./m²) | Yield (t/ha) |
| 0 | 2 | 27.7 | 205 | 3.13 | 14.3 | 177 | 1.39 |
| 0 | 3 | 16.4 | 200 | 3.03 | 14.7 | 215 | 2.25 |
| 1 | 0 | 37.0 | 73 | 1.41 | 54.5 | 161 | 0.65 |
| 1 | 1 | 43.6 | 88 | 1.61 | 31.6 | 203 | 1.99 |
| 1 | 2 | 36.1 | 113 | 2.05 | 24.0 | 166 | 1.13 |
| 2 | 0 | 29.0 | 135 | 2.00 | 27.9 | 200 | 0.84 |
| 2 | 1 | 77.3 | 75 | 1.77 | 15.8 | 200 | 1.66 |
| 2 | 2 | 39.4 | 141 | 2.61 | 19.4 | 222 | 1.75 |
| 0 | Weed free | 13.4 | 209 | 3.21 | 2.7 | 229 | 3.04 |

[a] Unreplicated observational trial. [b] fb = followed by. [c] After first raking and laddering.

**Table 3. Effect of six liquid herbicides on yield of dry-seeded rainfed rice. BRRI, 1974 aus season.**

| Treatment | Visual weed control rating[a] | Yield[b] (t/ha) |
|---|---|---|
| Hand weeding | 5 | 3.6 a |
| Butachlor | 5 | 3.6 a |
| Piperophos - dimethametryn[c] | 4 | 3.5 ab |
| Butralin | 4 | 2.8 bc |
| Oxadiazon | 3 | 2.6 c |
| Flurodifen | 4 | 2.5 c |
| Prodiamine | 4 | 2.4 c |
| Unweeded check | 1 | 1.0 d |

[a]1 = no control, 5 = complete control. [b]In a column, means followed by a common letter do not differ significantly at the 5% level. [c]Herbicides were formulated as proprietary mixture.

## COMPARISON OF WEED CONTROL TECHNIQUES

We compared the cost of farmers' weed control practices — hand weeding alone or laddering and raking followed by hand weeding — with the cost of a preemergence treatment with butachlor followed by a single hand weeding. The farmers' practices cost about US$35.00/ha. A preemergence treatment of butachlor followed by a single hand weeding cost $25.21/ha when the chemical was applied at 0.5 kg/ha, and $31.32/ha when it was applied at 1.0 kg/ha. Farmers could reduce their weeding costs considerably if the chemicals were available locally.

When we compared the cost of manual weed control in local and modern rice cultivars, we found that weed control in both amounted to about 13% of the total production costs. Modem cultivars require more weedings because their canopy is less dense and they do not compete with weeds as well as local cultivars. Despite the higher yields of the modem cultivars, the increased weeding cost kept the returns to weeding about the same.

Weed control almost entirely dictates production of dry-seeded rainfed rice. Reliance on manual weeding practices, the lack of timely weeding, and the farmers' inability to hire weeding labor at peak periods keep yields low. Preemergence chemical weed control followed by hand weeding could tremendously increase the production potential of the 8 million ha under dry-seeded rice in Bangladesh.

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## DISCUSSION

MUKHOPADHYAY: There are two types of dry-seeded rice that are being referred to: 1) that which has no standing water on the field from planting until harvest, and 2) the field is dry for 1½ months after planting and then the fields are flooded. In the early stages, the dry-seeded rice is full of weeds. These must be controlled as they cannot be suppressed by the water.

We have weed problems in both types of rice culture, but problems are greater when there is no standing water during crop growth. That is the aus crop. In that crop, a high seed rate is used. Raking (a type of blind tillage) is done to control the weeds and to thin the rice crop. We don't have any modern weed control technology for this system. We have tried many herbicides, but unless we have persistent herbicides with a long residual effect, there is regermination of the weeds. I have tried many herbicides without success. This is a challenge for everyone.

DENNING: How important are rice weeds as animal fodder in Bangladesh? If they are important, then the use of improved weed control, particularly preemergence herbicides, may seriously reduce this feed source.

*AHMED:* Weeds as animal fodder are quite important in Bangladesh. The use of preemergence herbicides will reduce the weed growth, but at the same time will increase rice straw and grain yield. Straw may later be used as fodder for livestock.

# WEED, DISEASE, INSECT INTERACTIONS IN RICE

E. F. Eastin

Diseases and insects of rice and their control programs interact in many ways with weeds and their control programs. Many weeds are alternate hosts for pathogens and insects of rice; thus weed control becomes a necessary component in insect and pathogen control. Weed control programs not only reduce alternate host sites for insects and pathogens, but they may influence the environment favoring diseases or insects. Herbicides may directly affect insects or pathogens, influencing their expression or seventy. In similar fashion, insect or disease control programs, particularly those involving draining and drying the rice field, may adversely affect weed control programs. Crop injury due to herbicides or cultural practices may predispose the rice plant to pathogens. Herbicide-insecticide interactions may damage or kill rice plants.

Insects and pathogens of rice interact with weeds in many ways to cause yield and economic losses in the world's rice producing areas.

It is well documented that many insects transmit diseases to the rice plant (IRRI 1967, Pathak 1968, Ou 1972). Because this conference deals with weeds in rice, I will discuss some interactions of rice diseases and insects with weeds. Examples are given to illustrate the types of interactions that may take place.

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## WEEDS AS ALTERNATE HOSTS

It is recognized that many weeds, in addition to directly competing with rice for light, space, nutrients, and water, also harbor insects and pathogens that can attack rice, causing even more damage to the crop. If weeds are not controlled, either in the rice crop or in a fallow field, insects can multiply on them and cause damage to the rice. Controlling weeds prevents insects from having an alternate host if rice is not available.

Several references covering the major diseases and insects of rice list or discuss host plants (Atkins 1974, IRRI 1967, Ou 1972, Pathak 1968). Other articles have discussed weeds as hosts for parasitic nematodes of rice (Babatola 1980, Hollis 1972). Israel et al (1970) brought out the importance of determining the possible hosts of the rice gall midge in formulating a method to control this pest. In this example, weed control is desirable not only to reduce competition and yield loss, but to remove the alternate host for the insect, which would provide a form of insect control. This principle can be utilized in dealing with many diseases and insects.

Entomologists and plant pathologists frequently monitor insect and pathogen populations on weeds near rice fields to predict potential outbreaks in the rice. If, in and around the rice fields, we do not control the weeds that serve as alternate hosts to insects and pathogens, we are allowing a potential source of infestation or infection to grow in our crop. Thus, by controlling the weeds we are also helping to control diseases and insects.

## INTERACTION OF CONTROL PROGRAMS

### Weed control

Control of weeds in and around rice fields results not only in increased yields due to reduced weed competition, but helps eliminate or reduce the availability of alternate hosts for insects and pathogens. For example, *Echinochloa crus-galli* has been reported to be an alternate host to many pathogens, including *Pyricularia oryzae,* the causal organism of blast, the principal disease of rice (Ou 1976). The blast organism survives on *E. crus-galli* and can infect the crop if the weed is allowed to remain in the field during the cropping season and during fallow periods. Eliminating the weed from the rice field and surrounding areas eliminates one possible source of inoculation. Pathak (1968) listed several insects, including some planthoppers and leafhoppers, that utilize *Echinochloa* spp. as alternates hosts. Elimination of *Echinochloa* spp. would remove a possible source of infestation of these insects. Therefore control of many field weeds would help in the constant battle against diseases and insects as well.

Rice producing areas that have access to irrigation water use water depth as a weed control practice. Many terrestrial weeds will grow in water but will not germinate in submerged or saturated fields. If flooded when very small, some weeds will not emerge through 10 to 15 cm of water. Flooding to control weeds may influence disease processes. Standing water, such as in flooded culture, tends to increase the seventy of sheath blight and stem rot because the fungi spread by their sclerotia floating on the water. Increasing water depth tends to decrease the severity of blast.

Herbicides used to control weeds may also have some effect on insects or pathogens, or both. Chakrabarti and Sen (1978) showed that foliar treatment of rice with propanil or 2,4-D resulted in chemical exclusion of *Helminthosporium oryzae* from the leaves, whereas MCPA-treated plants resisted the fungus after it entered the plant cells. This is an example of a herbicide exhibiting fungicidal activity or. as in the case of MCPA, inducing a response against the pathogen in the rice plant itself.

An example of weed control adversely affecting control of the root nematode can be found in the work of Prasad and Rao (1979). They demonstrated that *Eclipta prostrata* has nematicidal properties against the root nematode. Thus, control of *E. prostrata* could result in an increase in the severity of root nematode incidence in rice. But competition from *E. prostrata* may reduce rice yields. Therefore, we need to determine if the yield reduction due to the weed is greater than that due to nematodes and decide whether to control the weed.

Crop injury due to weed control methods, whether cultural or chemical, can predispose the plant to pathogen infection. This predisposition is enhanced if adverse weather such as cool temperatures and wet soil prevail. If young rice seedlings are injured by herbicides or cultivation. pathogens that otherwise would not be of much concern may infect the seedlings. causing more damage than they normally would.

**Disease control**

Sheath blight and stem rot are more of a problem under wetland culture than under dryland. Lack of floodwater, however, results in weed problems that would not have been as severe if flooding had been utilized. Hollis (1972) reported that control of the ring nematode stimulated grass and sedge competition in rice. Because the grasses and sedges served as alternate hosts for the nematode. the nematode was helping to suppress the weeds. Thus, by controlling the nematode the weeds were allowed to compete with the rice more than if the nematode had been present. The effect of the nematode on rice would have to be weighed against its effect on weeds to determine if control would be economical.

Straighthead is a physiological disease that can be a severe problem in the U.S. Draining the flooded field and allowing the ground to dry before panicle differentiation is the accepted control method (Atkins 1974, Huey 1977). If the field is drained for straighthead control, drying of the soil will allow many species of weeds to germinate and emerge and cause late-season weed problems. Also, if molinate is being used for weed control, keeping the field flooded is necessary for the success of the weed control program. To drain the field for the 2- to 3-week period required for straighthead control would almost eliminate the effectiveness of molinate and necessitate use ofanother herbicide. If a field has a history of straighthead, this must be taken into account in devising a weed control program. The time at which the rice is reflooded is critical; many herbicides should not be applied at reflooding because injury to the developing panicle may result.

**Insect control**

One of the older methods of controlling, or suppressing, the rice water weevil was to drain and dry the field (Bowling 1967). Weeds that submergence would have prevented from germinating then germinated and emerged. This method of rice water weevil control is not generally practiced today.

Fall armyworm is sometimes a problem in rice in the U.S. If the rice is tall enough when infestation occurs, flooding the field will restrict movement of the insect (Bowling 1967). Flooding will inhibit the germination and emergence of many weeds provided the field is weed free at flooding. This is a case of insect control helping weed control, but the practice is seldom used because chemical control of insects is preferred.

Carbamate insecticides such as carbaryl and carbofuran, and organophosphate insecticides such as parathion control several problem insects in rice. But the carbamate insecticides, and to a lesser extent the organophosphate insecticides, interact with propanil (the most widely used rice herbicide in the U.S.) to cause rice injury and possible death (Bowling and Flinchum 1968, Bowling and Hudgins 1964, Bowling and Hudgins 1966, Smith 1968, Smith et al 1977, Smith and Tugwell 1975). Propanil is used for weed control early in the growing season. Carbofuran insecticide applied several days after a propanil herbicide application does not harm the rice, but propanil applied with or after carbofuran will damage the rice (Smith and Tugwell 1975). Rice has the enzyme aryl acylamidase that rapidly detoxifies the propanil (Frear and Still 1968). Matsunaka (1968) demonstrated that the carbamate insecticides and, to a lesser extent, the organophosphate insecticides inhibit the propanil detoxifying activity of aryl acylamidase in the rice plant. Thus propanil can injure or kill the rice. The mechanism of interaction is such that propanil cannot follow a carbamate insecticide application, but the carbamate insecticide can follow a propanil application. This illustrates how chemicals to control weeds and insects can interact to damage the crop they were designed to protect.

The principal insecticide for water weevil control is carbofuran applied after the field is flooded. Propanil normally is not used after flooding; therefore, there is no danger of the rice being damaged by a carbofuran-propanil interaction.

Other types of insecticides such as chlorinated hydrocarbons do not inhibit aryl acylamidase activity and thus do not interact with propanil.

We have seen how weeds, diseases, and insects interact, but more important how weed and insect control programs, particularly chemical-based ones, can interact to the benefit or detriment of the crop we want to protect. The rice grower must work with all management aspects and integrate all phases of rice production into a plan that results in the best crop possible under these circumstances.

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## DISCUSSION

SMITH (comment): One approach for controlling the cyst nematode in soybean is to alternate rice, which is a nonhost crop, with soybean. Two leguminous weeds in rice are both hosts of the cyst nematode. These are *Aeschynomene virginica* and *Sesbania* hemp. If these two weeds are controlled in rice then this would make the alternate nonhost crop more beneficial and improve the cyst nematode-weed control program and cause less problems in the year that soybean was grown.

MATTHEWS: Have you any data of diseases, insects, or weeds causing losses after harvest?

*EASTIN:* Nothing on the interaction of diseases or insects. You are referring to stored grains?

MATTHEWS: Yes. For example if you have more weed seeds you will have more insects.

*EASTIN:* The only problem would be if the insects were in the weed seed. I can't see any of our weeds that would attract insects into the rice.

MOODY (comment): This is not specifically for rice, but in certain parts of West Africa they put plants in with their stored grain to reduce the level of insect attack.

*EASTIN* (comment): We put bay leaves in with flour to keep the weevils out.

MUKHOPADHYAY: (1) It has been found that a fortnight after application of propanil together with carbamate insecticide, the rice crop injury starts disappearing. What is your observation on this? (2) What is the mechanism of the action of propanil on carbamate? Does the carbamate get detoxified after a fortnight?

*EASTIN:* (1) My observation has been that, in most instances of propanil–carbamate insecticide interaction, the rice is not killed, but injured much more than from propanil alone. Therefore the rice will regrow and produce some grain; however, the yield is greatly reduced and maturity may be delayed compared to rice not treated. (2) Dr. Matsunaka and I believe the enzyme inhibition caused by the carbamate insecticide is reversible, but the carbamate persists in the rice. The length of time that the carbamate affects the enzyme is dependent upon the residual of the individual insecticide.

MATSUNAKA: In Japan, we have a serious disease called creeping sickness (Japanese encephalitis), which is spread by mosquitoes. We have two phenomena — I am not certain if they are related. In 1966, our use of diphenyl ether herbicide — nitrofen and chlornitrofen — increased and sleeping sickness decreased. In 1977, we had no deaths from this disease. I believe that the herbicides had a very strong insecticidal effect on the mosquito larvae.

*EASTIN* (comment): That is a good example of a herbicide in rice not necessarily interacting with a rice insect but one that is of human concern.

O'BRIEN (comment): Two other interactions that are perhaps important in Asia are (1) effect of chemicals on shrimp and frogs and other food sources that may be living in the paddy, and (2) the effect of weeds on rat populations, particularly if you have high levels of weeds on the farm.

DROST (comment): We have done some work on the interaction between rats and weeds. We found that rat damage was much higher in weedy plots than in weed-free plots that were located in the same paddy. The rats preferentially attacked the weedy plots, destroyed the crop there first, and then radiated out from there into the adjacent weeded area. Therefore good weed control would minimize rat damage.

BAKER (comment): We had a similar experience to that given by Dr. Matsunaka with molinate. Our entomologists were studying rice field mosquitoes and when molinate was applied it ended their experiment.

# INTEGRATING BIOLOGICAL CONTROL OF WEEDS IN RICE INTO A WEED CONTROL PROGRAM

G. E. Templeton

The concept of biological control has been expanded to include use of indigenous natural enemies for control of native pest species. These biological agents are logically termed biopesticides when they are increased in artificial culture and applied as an inundative inoculum to pest populations just as chemical pesticides are applied. Biopesticides generally are slower acting and more specific than chemicals. Their use in complex, integrated control systems that rely on several methods for remedying a spectrum of successive pest problems has been demonstrated in rice.

Biological scientists in public agencies and foundations will have primary responsibility for discovery and evaluation of this type of pesticide. Multidisciplinary efforts among scientists are essential for the discovery, evaluation, large-scale fermentation or rearing, and ultimate integration of biopesticides into effective pest control systems.

The concept of biological control has expanded during the past decade to include control of *native pests* by their *native natural enemies* (Baker and Cook 1974, Huffaker and Messenger 1976, Templeton and Smith 1977). Tactics have been

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devised to suppress indigenous pests either by conservation — manipulation of growth conditions to favor natural enemies — or by biopesticides — massive, timely augmentation of natural enemies with ones produced in artificial culture (Templeton 1981). For weed control in intensively cultivated crops such as rice, bioherbicides developed from indigenous natural enemies have greater potential than classical biological control agents — organisms imported and released to suppress weed populations, and sustain them below problem levels (Templeton et al 1979). Classical biological control operates too slowly for annual weeds in rice (Emge and Templeton 1981). However, it may have some utility for control of perennial weeds of rice, particularly if populations of the weed are abundant near the rice fields. Insects have been used in that manner for control of perennial weeds of rice (Sakamoto and Eto 1973, cited by Noda 1977).

Biological control tactics are not expected to replace chemical pesticides but to supplement their judicious use or possibly to allow increased use of more selective ones (Smith 1981b). Thus a pest control strategy that is emerging recognizes that integration of various control tactics can make up for the deficiency of any single method (Noda 1977, Smith 1981a, Smith and Moody 1981).

Successful development and implementation of an integrated pest control strategy require intimate understanding of the life cycles of pests, their natural enemies, and available crop management alternatives, as well as disciplinary collaboration among scientists. We cannot expect to understand all the intricacies of the balanced network of interacting organisms and the abiotic environment before we commence integrated control tests, but chances for success are greater if the principal biotic and abiotic constraints on both the natural enemies and the pests are known and can be used to guide use of biological agents. The ultimate test of whether or not a biological control will be effective in a given crop or geographic region is to try it there. Thus the research responsibility for discovery, primary screening, and field evaluation lies with biological scientists in publicly supported institutions, in contrast to chemical pesticide development where the responsibility for discovery and primary screening lies with organic chemists in private industry (Templeton et al 1980).

Nevertheless, private industry can also have a significant role in the development of biological pesticides even if such pesticides may be specific to only one pest and frequently are more labile than chemicals. Industry can provide quantities of biological agents suitable for commercial scale evaluation, and can eventually market the living agent in a stable formulation. Microbial agents such as bacteria and fungi are most attractive from a commercial standpoint because many of them can be produced as viable dry preparations with existing fermentation facilities and technology in both the developing and developed countries (Bower 1981). The potential of viruses, nematodes, insects, tadpole shrimp, and fastidious or extremely fragile microorganisms should not be overlooked, however. Technology can be developed for these agents if the pest problems and profit potential are great enough to warrant large research and development expenditures.

## BIOLOGICAL WEED CONTROL IN RICE

The utility of tadpole shrimp for biological control of weeds in transplanted rice has been investigated by Matsunaka (1976, 1979) in Japan. The small crustaceans *Triopus longicaudatus, T. granaris,* and *T. cancriformis* feed on seedlings and disturb their roots by mechanical agitation of the soil. They are not selective and are considered pests in California where rice is seeded directly into water, as they damage the roots of rice seedlings. This problem is avoided in transplanted rice because the plants are larger and their roots are adequately covered with soil.

Populations of 20 to 30 tadpole shrimps/$m^2$ have significantly reduced weed populations in farmers' fields. Both immature forms and adults are sensitive to insecticides and certain herbicides; thus the timing of chemical applications is critical to the successful use of the crustacean.

Eggs of the shrimp are tolerant of environmental extremes and are the preferred form for augmenting natural populations. Eggs applied at the time of flooding have yielded greater populations than those applied 3 to 9 days before flooding or than adults applied to the flood water. Effective integration of this biological control into weed control systems in transplanted rice appears very promising and will be enhanced when procedures for mass rearing and conservation of eggs are achieved. Hand labor for weeding in farmers' fields has been reduced by 70 to 80% in initial field trials with tadpole shrimp.

Fungal plant pathogens may be developed as biological herbicides in both direct-seeded and transplanted rice. Most plants including weeds are affected by one or more fungal pathogens, and many of the fungi readily grow and sporulate in artificial culture. Specificity for their host, ability to grow and produce durable spores in artificial culture, and sufficient virulence to kill their host when they are applied as an inundative inoculum are the three criteria suggested for selection of mycoherbicides (Daniel et al 1973). It is important to consider pathogens that normally induce disease at endemic levels, being more or less constantly present from year to year in a moderate to severe form. They are endemic because the pathogen is well established and persistent due to its ability to survive from one season to the next in soil, seeds, or plant refuse. Endemicity also implies that the environment is usually favorable for initial infection and subsequent disease development. Often weeds in intensively cultivated crops such as rice are not diseased because cultivation has interrupted the disease cycle of an endemic pathogen. Thus searches for potential mycoherbicides may be most productive in areas not cultivated, where the pathogen and its host have co-existed for many years with only natural constraints. An alternative is to search for diseased seedlings among plants grown from seeds collected from large geographic regions. H. L. Walker (pers. comm.) used this method to find an *Alternaria* species for control of *Cassia.*

Practical feasibility of the bioherbicide tactic has been demonstrated for several crop-weed-pathogen combinations. They include *Colletotrichum gloeosporioides* f. sp. *aeschynomene* for control of *Aeschynomene virginica* in rice and soybean fields (Daniel et al 1973), *C. gloeosporioides* f. sp. *jussiaea* for control of *Ludwigia decurrens* in rice (Boyette et al 1979), and *Cercospora rodmanii* for suppression of *Eichhornia crassipes* in waterways (Conway and Freeman 1976). The Upjohn Company is expected to register dry conidia of *C. gloeosporioides* f. sp. *aeschynomene* under the trade name "Collego" in 1982 for use in rice and soybean fields.

It is important to remember that pathogens are only one facet of the tripartite biological interaction of host, pathogen, and environment that is essential to disease development. Considerable research on a weed disease must be conducted to understand its potential as a bioherbicide before integration with other pest control and crop management systems is attempted.

## INTEGRATION OF BIOPESTICIDES AND CHEMICAL PESTICIDES

Biological agents may be sensitive to chemical pesticides necessary for control of multiple pest problems in intensively cultivated crops. In most cases, timely sequential applications of both can effectively control specific pests without mutual interference (Smith 1981b). Generally, biological agents work more slowly than chemicals, and this must be taken into account when formulating integrated control systems. Also, it is possible to combine more than one biopesticide and thus to overcome the problem of high specificity of fungi (Boyette et al 1979).

Less interference will probably occur in the future as more selective, more active chemicals are developed. Also, we can reemphasize control of certain weeds in alternate crops in a rotation with reliance on chemicals in one crop and biologicals in the other. Furthermore, we must not assume that all chemical and biological pesticides are mutually detrimental, particularly in the case of herbicides. Preliminary results indicate that Collego can be tank mixed with low levels of acifluorfen to control *Sesbania exaltata* and *A. virginica* in rice with one application (R. Klerk, pers. comm.).

Fungal pathogens can develop tolerance for specific chemical fungicides. Many fungal pathogens of economic crops have developed tolerance for benomyl, for example. Pathogens of weeds might well be deliberately adapted for tolerance for specific fungicides, herbicides, or insecticides to be used in pest management programs in rice, thereby increasing their potential for use.

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## DISCUSSION

MOODY: (1) What is the cost of the fungal preparation for *Aeschynornene* control? (2) How can the fungus be applied in sequence with herbicides?

*TEMPLETON:* (1) The price has not been established yet, but we have been assured by the company that it will be competitive with chemical herbicides available for the same purpose. (2) The preferable manner is to apply the fungus first and delay other chemical pesticides for 2 weeks. The one chemical that can be tank mixed with the fungus spores is acifluorfen, which is used to control *Sesbania.*

PLUCKNETT: Would you expect most weeds to have some pathogens related to them that could be used in this way if we really looked for them?

*TEMPLETON:* I think that all plants have pathogens, and that most weeds have many. It depends on where you look for them. If you look in your plots you probably will not find them because you have interrupted the disease cycle with various tillage practices. You are helping the weed escape from its natural enemies with fertility and management practices. If you go into a natural area where the population is diverse and there is a balance between the pathogen and the weed, I believe that you will find some. They will not all be virulent enough, they will not all be specific enough, and they will not all be culturable; but I think it is certainly worthy of exploration.

PLUCKNETT: (1) How much spray volume do you have to use? (2) What is the mode of action of the fungus? Is it the fungus itself which kills the weed or is it a chemical which is produced by the fungus? Does this compound have to be registered in the United States? (3) Your report showed success of pathogens for the control of weeds. The pathogen that you are using is specific only against broadleaf weeds. However, the most important weed species in all the rice-producing areas throughout the world are the grasses and the sedges. a) Do you have a plan to look for pathogens for these weeds? b) Do you foresee the problem of the development of biological races that would eventually be pathogens for rice?

TEMPLETON: (1) 94 liters/ha. This is what is recommended for aerial applications of propanil in rice. (2) The entire physiology of the mode of action is not known. There is the possibility that a toxin is produced during the growth of fungus. We know that if the fungus is dead the weeds will not be controlled, so there must be fungal growth to get infection, penetration, and development of the fungus. We are not relying upon secondary spread. We are compensating for the inability of the fungus to spread.

The Upjohn Company has sent application material to the Environmental Protection Agency for registration, having been encouraged by the EPA to submit this material to get the registration process underway. In the beginning they told us we had to go through the same procedures that we would have to use for a chemical, so we tested its effect on rats, mice, etc. We did all of that knowing fairly well in advance that plant pathogens do not affect humans, maybe only in an allergenic way.

The company is ultra conservative. They have also done tests to ensure that the product is safe. I keep coming back to the point with them that we are not introducing something new in the fields. We are augmenting something that is already there. The EPA has notified us verbally that a conditional registration for "Collego" and exemption from the requirement of a tolerance will be issued in late May 1982.

(3a) Yes. A group of southern U. S. states has formed a regional project on the use of fungal plant pathogens for biological control. We have set as our goal the discovery and study of pathogens that will be used to control the nine most important weeds in the southern region. The grasses, e.g., *sorghum* halepense, and the sedges are on the list along with Cassia.

(3b) No.

COX: We hear much about successful biological control measures, but there are cases of unsuccessful biological control such as the introduction of the cane toad into Australian cane fields to control a beetle. Therefore, biological control is not without its problems. There is a pathogen of *Echinochloa crus-galli* in Australia called *Ustilago trichophora,* known as common smut. Do you foresee that it may be possible through mutation by radiation or selection to make this fungus more virulent such that it would be possible to achieve some form of control?

*TEMPLETON:* The first question is where to start, and I would start with something that is not as specialized as a smut or a rust. They have had good success with the control of skeleton weed in Australia with the introduction of a rust that can spread easily; the additional stress that they have created by the addition of an obligate parasite in the use of the classical approach is effective. But for a bioherbicide I would not use something like that in the beginning. You need to get lower in the scale of parasitism. You are going to lose some specificity perhaps, but you will then pick up a little virulence. You can get so virulent at the bottom end that you have no specificity, such as with the *Pythium* and the *Phytophthera.*

I should point out that there is already a bioherbicide produced as a liquid formulation by the Abbott Company being used in the citrus orchards of Florida. It is *Phytophthera* species. which is quite a variable fungus.

There are many pathogens that affect *Echinochloa crus-galli* in addition to *Ustilago.* There is a *Helminthosporium,* and there is *Colletotrichum graminicola.* If I were going to attack *Echinochloa crus-galli,* I would start with these and try to increase the virulence or the specificity as required.

# BIOLOGY OF PADDY WEEDS AND THEIR CONTROL IN WETLAND RICE

Y. Yamasue and K. Ueki

The biology of paddy weeds, particularly their adaptation, basic survival mechanisms, and control is discussed. Most paddy weeds spend the winter in a dormant state. Periodic seed germination is synchronized mostly with the influx of water for transplanting. The extended period of emergence of weeds such as *Monochoria vaginalis* var. *plantaginea* and *Echinochloa oryzicola* can be explained by the cardinal temperature concept, and noninherent and inherent differences of individual seeds in physiological age and dormancy period. Seed weight appears to correlate highly with the depth of emergence in soil. Through hundreds of years of rice cultivation, perennial weeds have adapted largely to the working schedule for the formation of their overwintering propagules. Hand weeding and other mechanical practices can minimize weed competition, but appear to be a temporary relief. Herbicides largely minimize the competition, but they are mostly ineffective on perennial propagules with high regenerative capability and on dormant seeds. Repeated herbicide application with minimum tillage has caused a species shift of weeds and increased the perennial weed population.

Weeds are a group of pioneer species excellently adapted to colonizing disturbed lands. Their specialized survival mechanisms make them inevitable in arable lands.

The principal aim of weed control is to reduce the population to an economical threshold by hand, mechanical, or chemical means. In this paper we review the

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literature and discuss the nature of weeds of rice from the standpoint of their biology, particularly their adaptation and basic survival mechanisms, changes effected by weed control practices, and the status of the rice-weed community. The discussion will be limited to transplanted rice in Japan.

## NATURE OF WEED COMMUNITY IN RICE

### Environment in waterlogged paddy fields

Rice seedlings in wetlands are transplanted and grown in waterlogged soil. Daily temperature fluctuation is far less than in air because of the unique thermal properties of water such as high specific heat and latent heat for evaporation. The oxygen supply in water is limited and comes to the rice plants chiefly from two sources, by extremely low diffusion from atmospheric air and from photosynthesis of algae and aquatic plants. Thus, the soil rapidly changes from an oxidized to a reduced condition owing to oxygen consumption by microorganisms. Under limited oxygen supply, the accumulation of reduced materials results from the decomposition of soil organic matter (Takai 1978). Figure 1 shows the vertical oxygen distribution and a gradient of the oxidation-reduction potential as well as changes in nitrogen compounds that occur readily upon the flooding of rice fields. In reduced soil, phosphorus compounds become soluble, but iron is present in the reduced ferrous form and hydrosulfide synthesis takes place. Soil pH also increases. The iron and phosphorus compounds are often toxic and retard seed germination and plant growth.

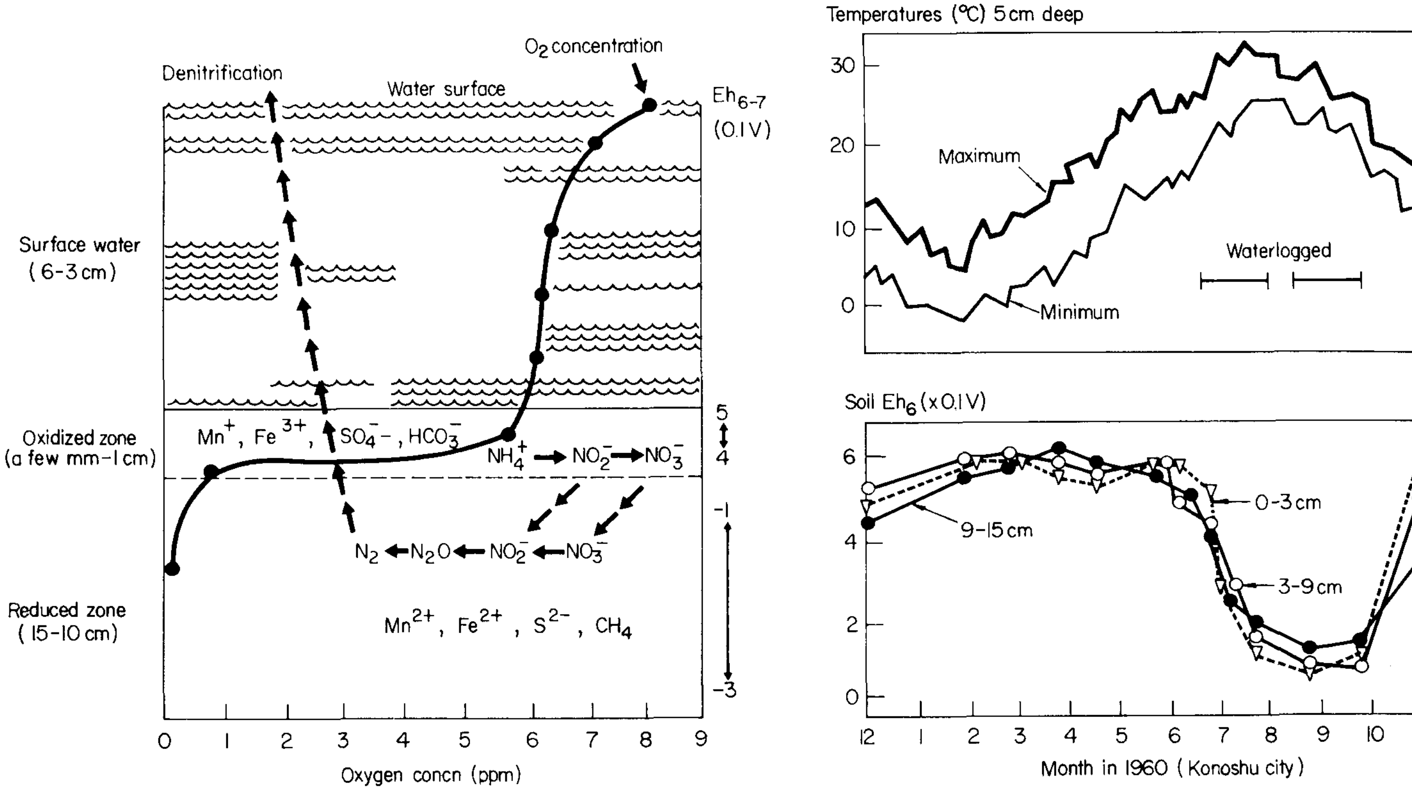
The above situation in rice fields is considered undesirable for weeds. It is, however, an extremely stable habitat for weeds resistant to excess water stress. Selected weed species display their real adaptability and establish themselves only under such a waterlogged condition.

### Species competition

Thirty years ago Kasahara (1959) estimated that in Japan there were 191 weed species representing 43 families. That estimate remains essentially unchanged notwithstanding the introduction of alien weeds such as *Heteranthera limosa* (Okatake et al 1979). Only 16 of the 191 species are important enough to warrant control (Table 1).

Maekawa (1943) reported that many weed species were introduced with rice from Southeast Asia. The midsummer environment of Japanese rice paddies differs little from that in tropical countries, but the winter environment is hostile, and only species with specialized overwintering mechanisms can survive. The most important overwintering or survival mechanism appears to be dormancy.

*Monochoria vaginalis* var. *plantaginea* and *Echinochloa oryzicola* are representative weeds that exhibit dormancy and other survival mechanisms. Arai and Yokomori (1951b) conducted a field survey of the arable habitats of 128 weed species. Arai et al (1955) studied the resistance of these species to water stress and waterlogging in a pot experiment, and classified them into three major groups: hydrophytic, hygrophytic, and mesophytic. The hydrophytic weeds, represented by *M. vaginalis* var.




**1.** Oxygen concentration in a waterlogged paddy soil (Takai 1978) and the seasonal changes in soil temperature and oxidation-reduction potential (Miyahara 1972).

**Table 1. Major weeds of rice fields in Japan.**[a]

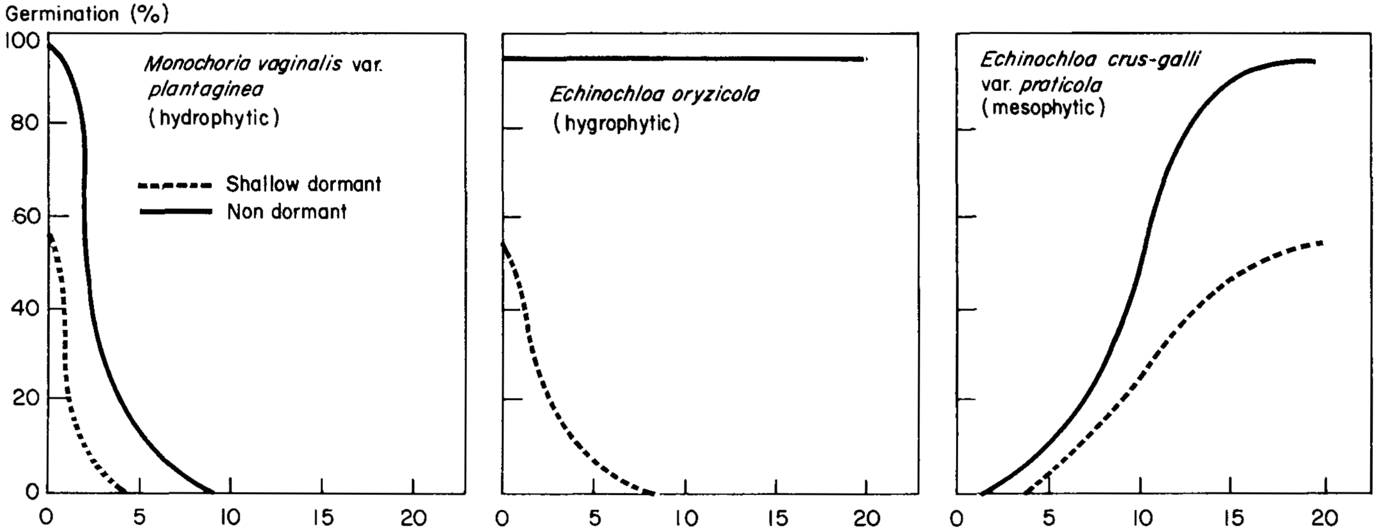
| |
|---|
| Annual weeds |
| *Cyperus difformis* |
| *C. iria* |
| *Dopatrium junceum* |
| *Echinochloa crus-galli* var. *crus-galli* |
| *E. oryzicola* |
| *Lindernia pyxidaria* |
| *Monochoria vaginalis* var. *plantaginea* |
| *Rotala indica* var. *ulginosa* |
| Perennial weeds |
| *Alisma canaliculatum* |
| *Cyperus serotinus* |
| *Eleochris acicularis* var. *longiseta* |
| *E. kuroguwai* |
| *Potamogeton distinctus* |
| *Sagittaria pygmaea* |
| *S. trifolia* |
| *Scirpus juncoides* ssp. *juncoides* |

[a]Those weeds in the winter fallow fields are not included.

*plantaginea,* are found only in waterlogged fields. The hygrophytic weeds, such as *E. oryzicola,* are found in rice fields and boundary lands, mostly in waterlogged and saturated soil. *Echinochloa crus-galli* var. *praticola* and *Digitaria ciliaris* are mesophytic weeds germinating and growing mostly in dryland fields. The determining factor of weed habitation is soil moisture. To germinate, rice weeds have either specialized requirements or resistance to waterlogged soil.

## Seed dormancy and germination

The seeds or perennial propagules of most weeds have a dormant period through whicn they survive hostile environments and cultivation. They also have special requirements for germination: light, temperature (chilling temperature, fluctuating temperature), moisture, gases, and mechanical abrasion (Harper 1957). In general, wetland rice weeds have lower requirements for light, fluctuating temperatures, and oxygen than dryland weeds (Watanabe 1978, Koda et al, unpubl.). For example, *M. vaginalis* var. *plantaginea* can germinate and grow only under an oxygen-deficient condition (Chisaka and Kataoka 1977, Kataoka and Kim 1978, Furuya et al 1978, Koizumi 1978). Except for light and fluctuating temperatures, germination requirements vary depending on physiological age or degree of seed dormancy. Seed samples taken early in the season from a well-drained winter rice field show weak dormancy and require light and fluctuating temperatures for germination. Most seeds sampled around the month of rice transplanting show high germination percentages, even in the dark and under constant temperature, although they still require an oxygen-deficient environment (Chisaka and Kataoka 1977). The mechanism of seed dormancy and germination is highly complex, and must be synchronized with the periodic changes of the seasons. At the very least, anaerobiosis appears to be an important key to unlock the dormancy mechanism. Anaerobic germination of the weed is a product of selection pressures for wetland rice weeds.



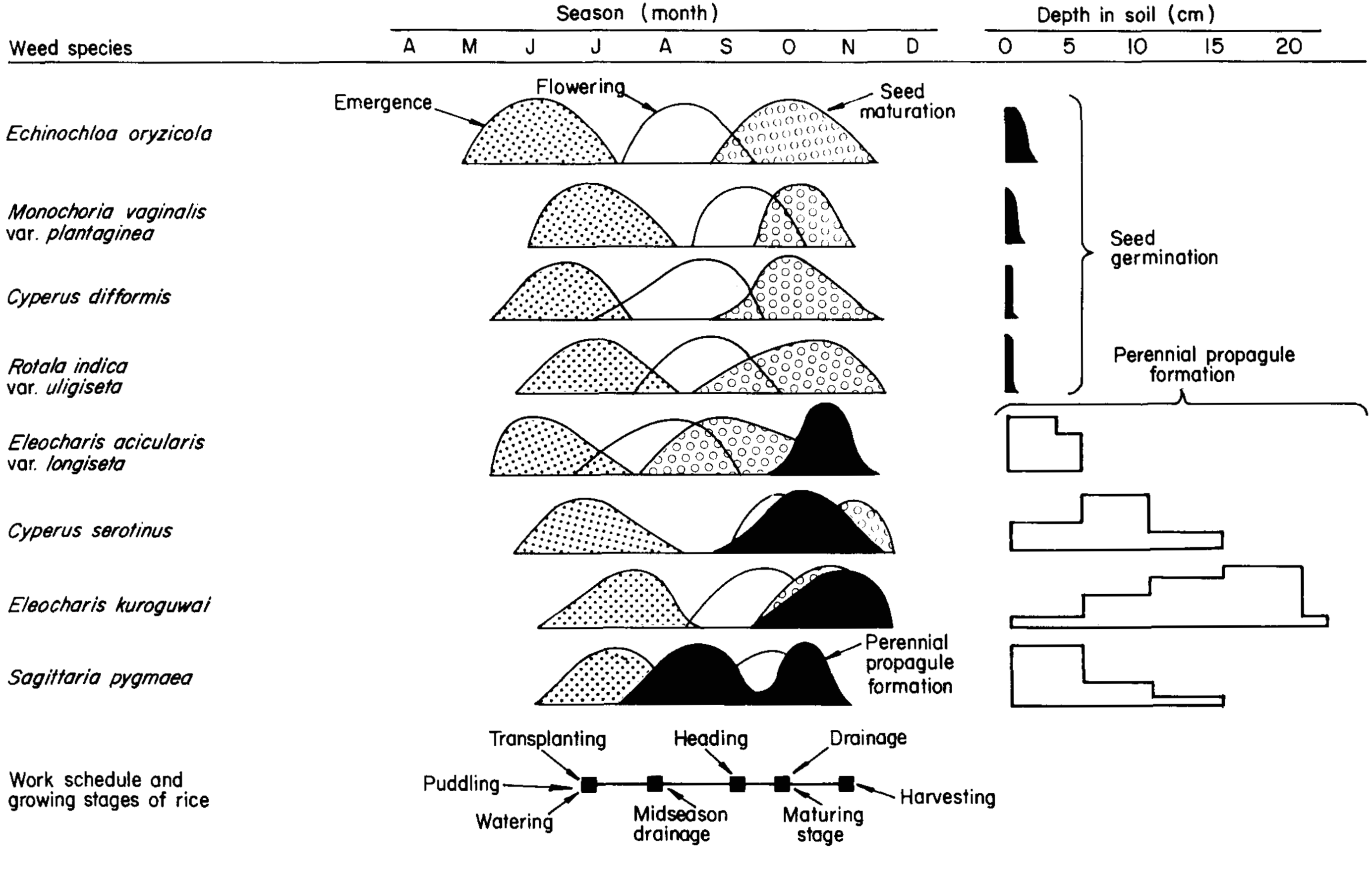

**2.** Generalized germination responses of hydrophytic, hygrophytic, and mesophytic weed seeds to a gradient of ambient oxygen pressures under light, at 30 °C, and moisture (Chisaka and Kataoka 1977; Kataoka and Kim 1978; Yamasue and Ueki 1979; and Koda et al, unpubl.).

*E. oryzicola* also germinates anaerobically (Miyahara 1972, Kataoka and Kim 1978, Yamasue and Ueki 1979), as do other major wetland weeds. Characteristics of *E. oryzicola* seed dormancy and germination were reported by Miyahara (1972). The weed differs from *M. vaginalis* var. *plantaginea* in its resistance to water stress. It is a hygrophyte and can germinate and grow in waterlogged fields and water-saturated uplands (Arai et al 1955). Figure 2 shows the germination response to ambient oxygen of weakly dormant and nondormant seeds. Our preliminary experiments show that even nondormant seeds appear to respire through an anaerobic path and produce ethanol under an oxygen-rich condition at the same rate as those incubated under oxygen-free conditions. This, together with evidence from rice (Sugawara 1960, Kawano et al 1975), suggests that the biochemical mechanism of plants that germinate in a waterlogged environment is a tolerance for or avoidance by rather primitive anaerobic respiration of whatever triggers germination. This assumption is quite interesting when we consider the strategies of biochemical adaptation of paddy weeds.

**Variation in weed emergence**

Most weeds show emergence periodicity as a result of their phenologies and selection pressures of crop cultivation. These periodic patterns are extremely important for determining the timing, frequency, and the intensity of application of any control measure. Weed emergence and community establishment come mostly from the germination of seeds in soil (King 1966). Figure 3 illustrates the seasonal field emergence of major paddy weeds at Saitama Prefecture (Arai and Yokomori 1951a). Seeds of *M. vaginalis* var. *plantaginea* have weak primary dormancy when first shed from the capsules. Early in the next year the seeds are ready to germinate whenever temperature is sufficient and water is available (Kataoka and Kim 1978). When the field is flooded and puddled for transplanting rice in mid-June to late June, the water temperature is higher than the minimum of 19°C required for germination. The weed seeds begin germinating and emerge soon after rice transplanting. Emergence continues for about 2 months. Extended emergence is explained partly by the temperature responses of individual seeds. Any batch or soil-buried population of seeds, even a genetically pure one, has cardinal temperatures that ate minimum, optimum, and maximum for germination. The rate and percentage of germination are linear over a considerable range above the minimum temperature. Some seeds experience stress at a temperature above the optimum and the germination percentage decreases (Heydecker 1977). The cardinal temperature concept explains the experimental results obtained by Suzuki and Suto (1975). They sowed seeds and perennial propagules of various wetland weeds at about 10-day intervals from late April to early August. The number of days until emergence and the duration of emergence decreased with later sowing dates as temperatures increased. These results coupled with their rice-weed competition work led them to conclude that yield losses would be small if weeding was done during the first 40 days after transplanting (DT) for early and ordinary transplanted rice, and within the first 20 days for late transplanted rice.

Compared with *M. vaginalis* var. *plantaginea*, which emerges soon after the introduction of water, *E. oryzicola* emerges before transplanting. Primary dor-




**3.** Seasonal patterns of several wetland rice weeds in field emergence, flowering, seed maturation, depth of seed germination, and perennial propagule formation in soil (Arai and Yokomori 1951a, Noda and Eguchi 1969, Kusanagi 1976).

mancy is broken by the cold temperatures from late autumn to winter and by the fluctuating temperatures of early spring (Miyahara 1972). Minimum cardinal seed germination temperatures are 10-15° C. The temperature range for germination is wider than that for many wetland weeds including *M. vaginalis* var. *plantaginea. E. oryzicola* can thus emerge for an extended period from the end of April to late August.

In addition to the cardinal temperature, other factors that govern germination and emergence are inherent and noninherent differences in the dormancy period and the soil microsites occupied by individual seeds. Miyahara (1972) demonstrated that dormancy breaking of *E. oryzicola* seeds depends on soil moisture and winter temperatures — dormant seeds incubated in soil with high moisture content and long-lasting cold temperature break dormancy earlier than those incubated in a soil with low moisture content and relatively mild temperature. High soil moisture and low temperatures in winter are characteristic of northern districts and districts along the Sea of Japan. Low soil moisture and mild winter temperatures describe southern districts and districts along the Pacific coast. Accessions of *E. oryzicola* seeds from northern Japan were larger and had weaker dormancy than those originating from the southern districts (Yamasue et a1 1981). This implies agrogeographic or geographical variation. Each seed adapts to the periodicity of rice cultivation and local edaphic conditions. *E. oryzicola* shows an agrogeographic cline in heading date and the mature seeds are shed before rice harvest (Morinaga and Nagamatsu 1942, Yabuno 1975, Yamasue et a1 1981). These variations are probably genetically controlled. In addition to local variations, there also seems to be a genotypic variation between individual plants within a field (Harper 1956, Harper et a1 1970).

Dormancy periods of individual seeds from the parent plant vary as well. Our pure strain of *E. oryzicola* produces 150 to 200 seeds, panicle and seed weight varies from 1.0 to 4.4 mg. Individual weights were linked to both the position of a seed on the panicle and flowering date (Yoshioka et a1 1981). The heavier seeds had shorter dormant periods than the lighter ones. The lighter seeds should be less competitive with rice plants because of their small food reserves and late emergence in the field. Genotypic and nongenotypic variations in dormancy and seed weight of weeds have important implications for their control in a given field, especially when we consider the seasonal patterns of weeds.

Seed weight often determines the depth at which weeds can emerge from the soil. Mean weights of 1,000 seeds for most annual wetland weeds range from 2.3 mg (*Dopatrium junceum*) to 128 mg (*M. vaginalis* var. *plantaginea*) with a few exceptions, such as *E. oryzicola,* which has a 1,000-seed weight of 3,910 mg (Kasahara 1962). Figure 3 shows that annual weeds emerge mostly from the upper surface zone at a depth of less than 5 mm in wetland rice fields (Kusanagi 1976). *M. vaginalis* var. *plantaginea,* however, can emerge from 10 to 15 mm depths (Chisaka and Kataoka 1977). *E. oryzicola* emerges mostly from less than 1 to 2 cm in waterlogged fields, but from more than 8 cm in drylands (Arai 1962). The depth from which weeds emerge in soil depends on edaphic conditions and physiological conditions of seeds. It also appears to correlate significantly with seed weight, particularly in waterlogged fields where uniform soil conditions are created by thorough plowing and puddling before transplanting. Few weed seeds, even seeds of *E. oryzicola,* are observed germinating deep in waterlogged soil, although there is anaerobiosis and sufficient temperature. We speculate it is because of a direct or indirect effect of the low oxidation-reduction potential. Arai and Miyahara (1963) reported that the germination percentage of nondormant *E. oryzicola* seeds decreased with the decrease of the oxidation-reduction potential, and there was no germination below $Eh_6$ at 100 mV. It must be noted that under strict anaerobic conditions the radicle and plumule of the paddy weed protrudes, but the radicle is unable to elongate and no chlorophyll forms in the plumule.

Perennial wetland weeds reproduce by overwintering buds, tubers, rhizomes, bulbs, other vegetative organs, and seeds. *Eleocharis acicularis* var. *longiseta* propagates mainly by its overwintering buds formed on nodes of the rhizomes and runners, and to some extent by the seeds. The vertical distribution of the rhizomatous buds is up to 3 cm deep in soil and correlates with the emergence depth upon water inflow (Shimojima 1967). The minimum sprouting temperature is 5° C, the lowest minimum temperature among major wetland weeds. *E. acicularis* var. *longiseta* emerges early, but rapidly decreases as a result of intraspecific competition. The formation of the overwintering rhizomes is remarkably synchronized with harvesting. The earlier the crop is harvested, the earlier rhizomes are formed because of removal of the shading effect.

*Cyperus serotinus* differs from most other wetland weeds. It reproduces by tubers with no dormancy period (Kusanagi 1976). The tubers require a higher ambient oxygen concentration to sprout. Thus, most stands in waterlogged fields are those originating from tubers that either floated to the surface upon puddling or whose leaves had elongated before water was introduced. Most tubers buried deep in the soil die, but some survive and emerge during midseason drainage. Tuber formation is controlled by short day length, and most tubers form at a soil depth of 5 to 7 cm. Nakagawa (1977) reported intraspecific variations in morphology, heading date, and tuber-forming stage.

Another important perennial weed in wetland rice is *Eleocharis kuroguwai,* which propagates by large tubers seated deep in the soil. The tubers are vertically distributed from 10 to 20 cm deep and easily emerge from those depths (Kusanagi 1976). Emergence starts when the air temperature is around 12-13°C, and lasts for a long time probably because of differences in dormancy (Tominaga et al 1980) and depth of individual tubers. Tuberization is promoted by drought (Yamagishi and Takeuchi 1978). Kobayashi and Ueki (1979) pointed out that the main selection pressures determining the tuberization period of *E. kuroguwai* were man's hand weeding. In the fields studied, the weed formed tubers from the last hand weeding at the end of August until rice harvest in mid-October. But in comparison, *E. kuroguwai* growing in irrigation ponds produced tubers during the period when the soil was drained as water was supplied to the fields. *E. kuroguwai* in wetland fields formed more tubers than those in irrigation ponds. The tubers were also smaller and their dormancy period was more varied.

## CONTROL PRACTICES EFFECT ON WEED COMMUNITY

Weed control is the main reason for rice cropping by transplanting. When a field is flooded to 10-15 cm depth, the emergence and growth of some hygrophytic and most mesophytic weeds decrease. But the crop's plant height and tillering may be adversely affected (Arai and Miyahara 1956). Before the development of the rotary weeder in 1892, weed control was done by hand or with trimming rakes, hoes, and plows.

Wetland weeds produce extremely large numbers of small seeds (Kasahara 1962); this common adaptation ensures a high probability of dispersal and reestablishment.

Large populations of weed seeds and propagules survive in the soil for long periods. Many weed seeds with inherent dormancy can spend many years in soil in a state of imbibition (Heydecker 1977). Seeds of *E. oryzicola* can survive more than 8 years in a wet soil, longer than in a dry soil (Miyahara 1972). Heydecker (1977) suggested that dry seeds survive because their metabolic processes are greatly slowed. But imbibed dormant seeds, although not germinating, are nevertheless highly active in other respects and continually repair any cytological damage they experience. In this way they remain at the peak of their performance capacity much longer than if they were dry.

Many perennial weeds produce propagules during periods in which they escape weeding or after the removal of crop shading by harvest. In addition, perennial weeds easily regenerate after weeding. In the following we discuss how weed community changes in response to hand weeding, tillage, plowing, and herbicide application.

## Hand weeding and other physical control practices

Hand weeding can be very effective against annual and biennial weeds on small farms, provided the root system is extracted (NAS 1961). Repeated hand weeding minimizes the competitive effects of weed infestation on the crop and prevents soil compaction in waterlogged fields, thus helping the crop grow vigorously (Terasawa 1943). But this method often is ineffective on a weed species with specific survival mechanisms, such as *E. oryzicola* and deep-rooted, perennial species. Because many wetland weeds, *E. oryzicola* for example, emerge over an extended period, some always emerge after the last hand weeding. In general, the more a weed species resembles a crop plant in ecological requirements and morphology, the more difficult it is to control by hand weeding. *E. oryzicola* is a complete mimic of rice (Yabuno 1961) and even a well-trained grower may find it difficult to distinguish between them at their early growth stage. Weed identification is easy, however, at heading, which corresponds to flowering of the crop. If weeding is postponed until after the crop flowering period, the weeds have already shed most of their mature seeds.

Repeated hand weeding can control perennial needs to some extent. Many perennial weeds have the dormancy-apical dominance relation of dormant buds on rhizomatous propagules. Repeated shoot removal at proper intervals exhausts the food reserves. If a seed is the major dispersion factor of a perennial weed, hand weeding the shoots is the most important eradication measure (NAS 1961).

Plowing and rotary tillage of fallow land affect the weed population in the next cropping season. Plowing reduces weed populations and growth more than rotary tillage because seeds are buried deep in the soil instead of being uniformly distributed to the tillage depth (Arai 1962). Plowing decreases populations of perennial weeds such as *E. acicularis* var. *longiseta* and *C. serotinus* (Kusanagi 1976, Nakagawa 1977), but has little effect on *E. kuroguwai,* which forms tubers deep in the soil (Kusanagi 1976).

Interrow cultivation is an effective weed control practice, but its effects on rice growth and improvement of soil physicochemical properties are negligible. There is also the risk of injuring crop roots (Nojima 1960). Harper (1957) argued that plowing undoubtedly had led to an increase in the population of buried viable weed seeds that are returned to the surface in later cultivation. For efficient, long-lasting weed control, he made these recommendations:

- avoid plowing,
- reduce surface tillage to a minimum, and
- leave any weed seeds on the surface to be killed by spraying when they germinate.

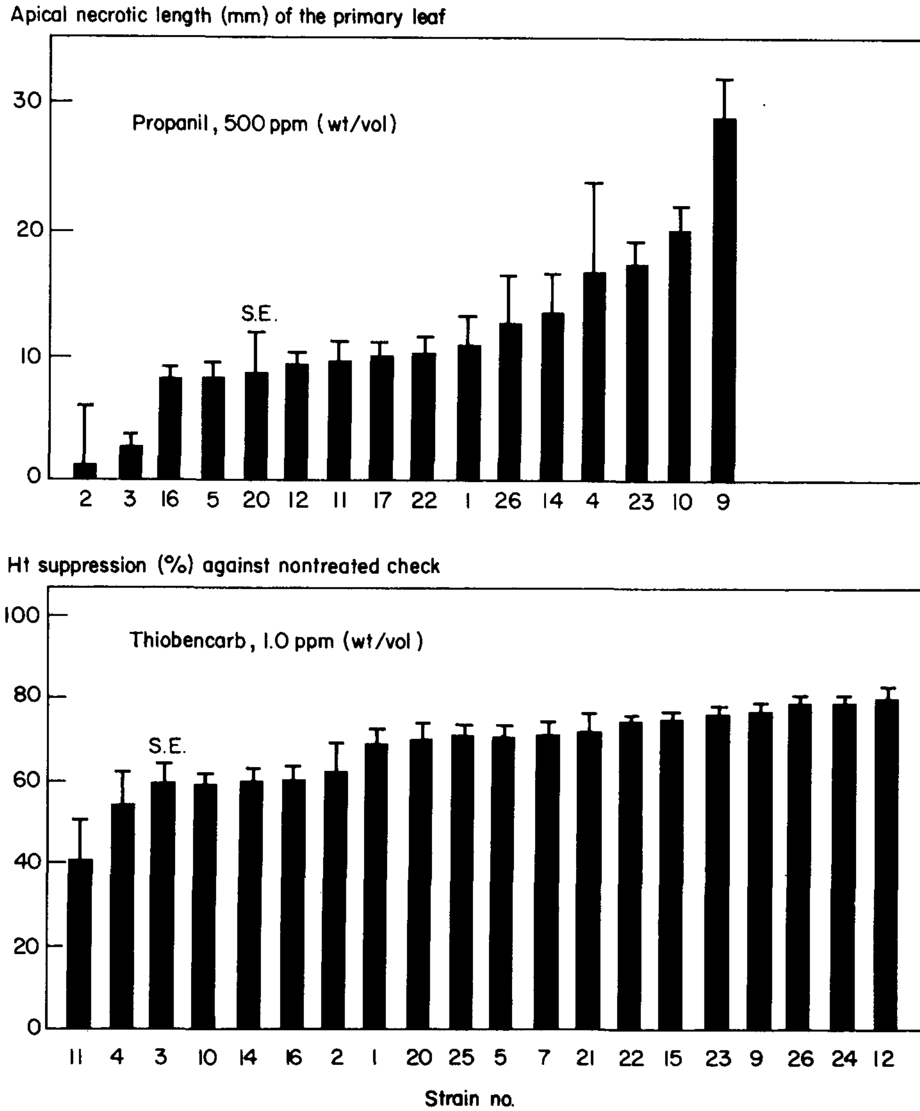
The recommendations imply that although rotary tilling and plowing minimize weed competition, they are only a temporary solution. They may be largely ineffective in dealing with the survival mechanisms of weeds. Little evidence exists for long-term population changes caused by rotary tilling and plowing.

**Chemical control**

Introduction of organic herbicides in 1950 has drastically changed the weeding schedule in wetland rice. Herbicides offer a number of advantages. They provide early season weed control and some can be applied during puddling. They can be applied to weeds within rows and to borders where cultivation would be impossible. They greatly minimize weed competition during early crop growth and increase crop yield. But herbicides are ineffective on weed seeds with dormancy, the most important survival mechanism. Weeds that survive herbicide applications flourish and produce abundant seeds. Most rice herbicides cannot kill perennial propagules below the soil surface.

In a sense, hand weeding and other physical practices are blind weeding and are nonselective. Chemicals, on the other hand, are selective, even among weed species, and create a shift of weed species. Many examples of a shift of weed species by repeated application of selective herbicides in wetland and dryland fields have been reported (Ueki 1979, 1981). Repeated application of herbicides for several years often increases the population of perennial weeds such as *Potamogeton distinctus, C. serotinus, E. kuroguwai, Sagittaria pygmaea,* and *Alisma canaliculatum* (Inano and Ishikawa 1976, Sakamoto et a1 1980, Ueki 1980). Sakamoto et a1 (1980) treated a field with herbicides for 4 years and reported remarkable increases in the populations of *Cyperus* serotinus var. *littorea, Scirpus juncoides* var. *juncoides,* and *Echinochloa* sp.

The mechanisms by which herbicides kill weeds exist in the weeds themselves. Weeds vary physiologically and biochemically regardless of their morphological resemblance. Consequently, we find intraspecific variation in herbicide susceptibility (Fig. 4). Although weeds probably are predominantly self-fertilizing, genotypic variation must exist even within a given field. If this is the case, possible changes resulting from repeated use of herbicides should include the gradual development of a resistant genotype (Harper 1956, Ueki and Yamasue 1978).

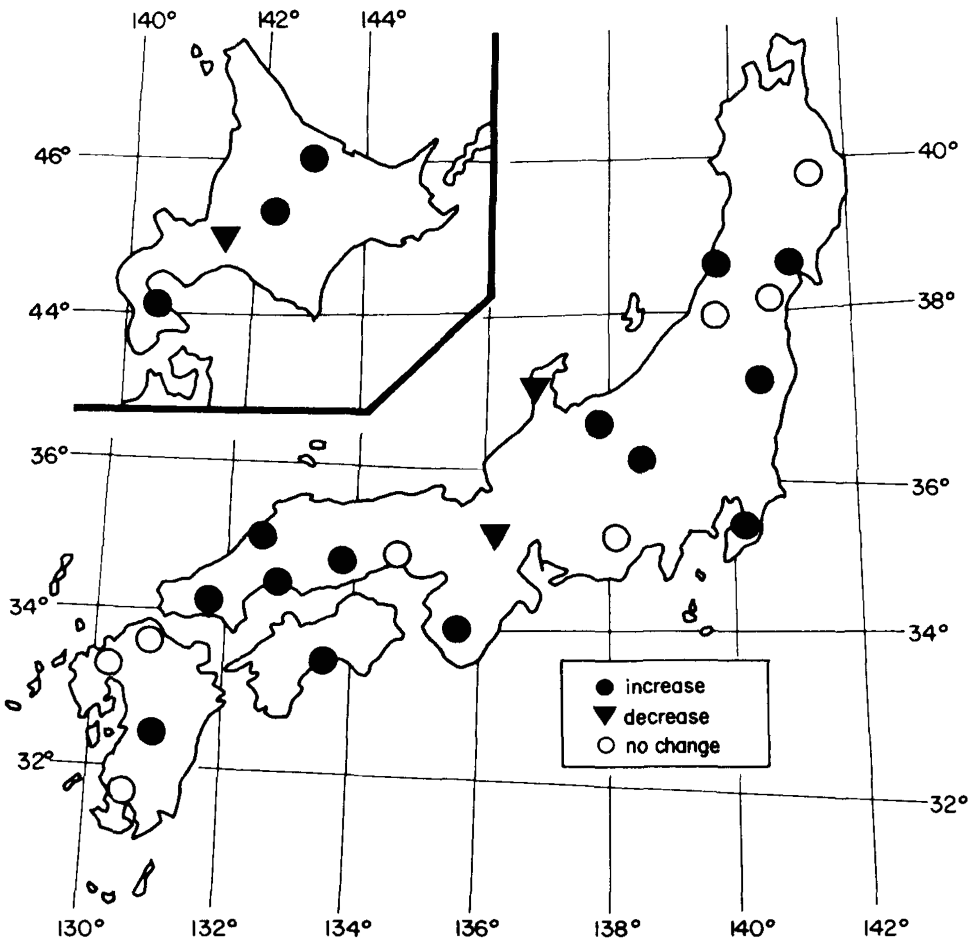



**4.** Variation in herbicide susceptibility of *Echinochloa oryzicola* strains collected in Japan (Yamasue et a1 1981).

## STATUS OF THE RICE-WEED COMMUNITY

Japanese rice growers rely on chemical weed control almost exclusively. With few exceptions, they don't till their fields after harvest. The introduction of the mechanical transplanter in 1970 has made it possible to transplant smaller seedlings at least a month earlier. Most growers treat their fields with pretransplant herbicides or posttransplant herbicides (3 or 4 DT) or both, and follow the treatment 10 to 15 days later with a postemergence herbicide. The schedule depends on area, weed population, and dominant species.

Matsunaka et al (1979) studied changes in the weed community population and dominant species in nonweeded plots of herbicide evaluation fields at 43 prefectural agricultural experiment stations. They found that mean dry weights of annual weeds per unit area for the country as a whole increased only a little, particularly for *Echinochloa* spp. Moreover, there was an increase of perennial weeds such as *C. serotinus* var. *littorea, C. juncoides* (probably var. *juncoides*), *A. canaliculatum, S. pygmaea, Sagittaria trifolia,* and exceptional reduction of *E. acicularis* var. *longiseta* (Fig. 5). Causes of weed community changes are highly complex and cannot be clearly identified. The increase in annual weed population is attributed to the weed seeds sown for the chemical evaluation tests and field preparation. The perennial




**5.** Effect of herbicide use on population shift in proportion to total weed population of perennial weeds in wetland weed communities in Japan from 1965 to 1967 (Matzunaka et al 1979).

weed increase must be related to effectiveness of the herbicides tested and even more to the lack of any other weed control measures. The effects of herbicide residues on soil physicochemical properties, algae, animals, and microorganisms have been investigated (Furusaka 1980, Kuwatsuka et al 1981). Further consequences of the use of herbicides on the rice-weed community are uncertain when we consider the aggressive adaptive differentiation of weeds and other organisms in phenology, biophysiology, and genetics. More information is needed on the basic survival mechanisms of wetland weeds — seed dormancy and tuberization — so we can develop long-lasting control.

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# CONTROL OF PERENNIAL WEEDS IN RICE IN TEMPERATE ZONES

Kil Ung Kim

*Sagittaria pygmaea, Potamogeton distinctus, Cyperus serotinus, Sagittaria trifolia,* and *Eleocharis kuroguwai* are the most important perennial weeds in temperate rice fields. Yield losses due to them range from 15% to 60%, depending upon species. Each of them can be easily controlled by a single herbicide or by a mixture of herbicides. A mixed population is more difficult to control, but can be easily managed by integrated control methods based on cultural and chemical means. An increase in perennial weeds is attributed primarily to the heavy dependence on repeated annual applications of herbicides for annual weed control. Herbicides are applied more than twice per rice crop in Japan and more than once in Korea. Weed community development in association with soil fertility gives a new insight in setting up control systems.

The rapid industrialization of Japan and Korea has led farmers to rely heavily on the use of labor-saving technology such as machines and herbicides. In Japan, most rice production operations are mechanized and make heavy use of herbicides. Herbicide consumption and machine use are much less in Korea than in Japan, but their use will probably increase sharply in the future, following the Japanese pattern.

Heavy use of herbicides, however, has resulted in weed control problems in rice

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cultivation, notably a shift to more difficult-to-control weeds such as perennials. To establish appropriate control systems, it is important to specify the problems and to quantify the factors affecting weed population shifts and dominance of some species over others.

## WEED POPULATION SHIFT

There are several reasons for a weed population shift to perennial weeds, the most important of which is the use of herbicides to control annual weeds. Ahn et al (1975) demonstrated the effect of herbicides in shifting weed populations from annuals to perennials. In Korea, perennial weed infestation was about 22% when herbicides were being applied on about 35% of the rice fields (Ryang et al 1975). In 1980, herbicide use had increased to more than 100% of the rice fields (meaning that some farmers used herbicide more than once per rice crop), and perennial weeds infested 31% of the fields (Korean Research Co. 1980). The herbicides used were effective principally against annuals.

It is rather difficult to list in order of importance the reasons for the weed shift other than herbicide use. Those which probably have an effect are the increased use of rotary cultivators, less autumn plowing, the earlier transplanting time required by machine transplanters, shallow water management, and heavy use of fertilizers.

When manual weeding was the main method of weed control, a number of weeds coexisted, with annual weeds being dominant. At that time, an invasion of perennial weeds seldom occurred because they were easily disrupted by hand weeding and prevented from producing underground reproductive organs. Once they were established, however, they easily adapted to local conditions because of such ecological characteristics as dormancy and vigorous propagation mechanisms. The intensive use of rotary tillage can promote growth of perennials by cutting chains of rhizomes into several pieces and removing apical dominance.

Autumn plowing, commonly practiced in the past, undoubtedly reduced weed emergence significantly compared with nonplowed fields. Kim and Choi (1976) reported that one autumn plowing to a depth of 20 cm reduced the dry weight of *Potamogeton distinctus* about 63% 40 days after transplanting (DT). In recent times, though, farmers have been reluctant to practice autumn plowing.

Transplanting earlier by 10 to 15 days with the use of machine transplanters has hastened weed emergence and provided a longer duration for weed-rice competition because most weeds can germinate immediately after puddling. Shallow water management of rice has been shown to favor the emergence of *Cyperus serotinus,* which needs much oxygen to germinate (Kusanagi 1981). Finally, an increased trend toward heavy use of fertilizer in rice monoculture following the introduction of the new high yielding rice varieties may also have contributed to the increase of perennial weed problems.

## WEED PROBLEMS

Of 191 weed species belonging to 43 families identified in the rice fields of Japan, one-third are perennial weeds (Kusanagi 1981). In Korea, 92 species in 27 families have been found in rice fields. Of 30 species that are considered important (Kim 1981), 13 are perennial weeds.

Table 1 gives the perennial weed species most commonly found in fields of transplanted rice in Korea and Japan. *Paspalum paspalodes* and *Oenathe javanica* are important weeds in Japan. *Leersia japonica* is considered an important perennial grass in Korea. *P. distinctus* is the most dominant weed species in Korea, occupying 14% of total rice fields, followed by *Sagittaria pygmaea* (10%), *C. serotinus* (4%). and *S. trifolia* (3%) (Korean Research Co. 1980). This information was obtained from the responses to questionnaires of 2,000 farmers throughout the Republic of Korea. None of these species was dominant; manual weeding was the main control tool.

## ECOLOGICAL CHARACTERISTICS OF PERENNIAL WEEDS

### Emergence of perennial weeds

Most perennial weeds of rice multiply vegetatively by means of tubers, bulbs, rhizomes, stolons, or overwintering buds, but some reproduce by seeds. Several factors affect emergence of the propagule — temperature is a critical factor. The optimum temperature for emergence of the propagule ranges from 25° to 35° C. with 10° C as minimum and 40° to 45° C as maximum (Kusanagi 1981). Paddy weeds require different cumulative temperatures from puddling to emergence. Annuals such as *Echinochloa oryzicola* and *Monochoria vaginalis* require 100° to 120° C and 120° to 150° C, indicating that at least 5 to 7 days are necessary for emergence of annual weeds in a temperate climate. With perennial weeds, however, the average cumulative temperature requirement varies from 100° to 120° C for *C. serotinus,* 250° C for *S. pygmaea,* 300° C for *P. distinctus* and *S. trifolia,* to a maximum of 400° C for *E. kuroguwai.* The data indicate that perennials emerge from 5 to 20 days after puddling, provided that an average daily temperature of 20° C is maintained. The longer period over which perennials emerge may account for the difficulty in controlling them.

Soil moisture is another important factor influencing emergence of perennial weeds. *P. distinctus, S. pygmaea,* and *S. trifolia* are aquatic perennials found only in submerged fields. Yamagishi and Hashizume (1972) reported that *S. pygmaea* cannot emerge or ceases to grow when soil moisture content decreases to 60% of field capacity or lower. Tubers of *C. serotinus* sprout and emerge at lower soil moisture content because they require abundant oxygen to germinate. On the other hand, the reduced conditions of soil favor propagule emergence. This is the reason most perennials, except *C. serotinus,* germinate easily from deep in the soil under submerged conditions.

### Formation of underground organs and dormancy

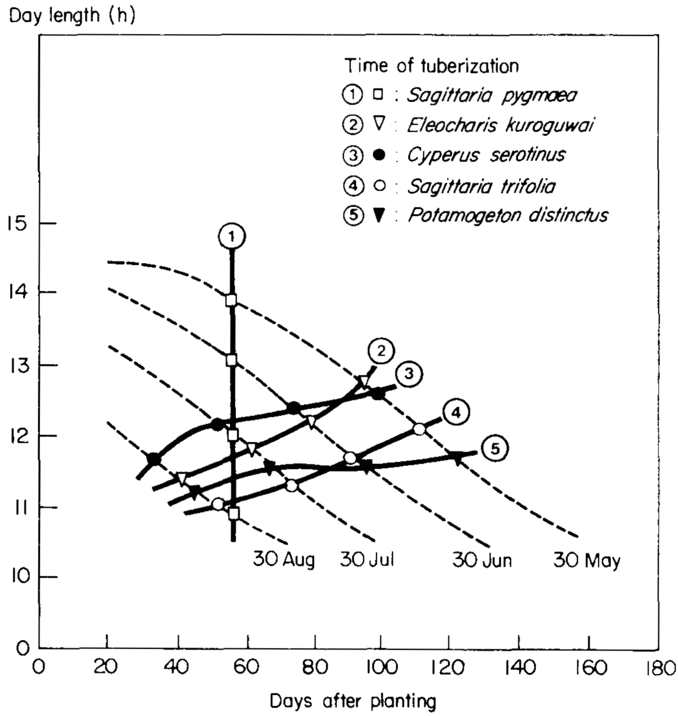
Underground organ formation is a complex phenomenon that is influenced by photoperiod, temperature, plant hormones, and soil fertility.

Photoperiod significantly affects tuberization. *E. kuroguwai, C. serotinus,* and *S. trifolia* initiated tubers at day lengths of 11 to 13 hours (Fig. 1). Early planting (30 May) required a longer duration for tuberization, about 100 to 110 days, and at that

**Table 1. Important weeds in temperate rice fields**

| Classification | Family name | Scientific name | Propagation | Growth form [a] |
|---|---|---|---|---|
| Grasses | Poaceae | *Leersia japonica* | Rhizome, seed | r |
| | Poaceae | *Paspalum distichum* | Rhizome, seed | p,b |
| Sedges | Cyperaceae | *Cyperus serotinus* | Overwintering bud, tuber, seed | e |
| | Cyperaceae | *Eleocharis kuroguwai* | Tuber | t |
| | Cyperaceae | *Eleocharis acicularis* | Rhizome, seed | t |
| | Cyperaceae | *Scirpus hotarui* | Overwintering bud, seed | t |
| | Cyperaceae | *Scirpus planiculmis* | Overwintering bud, tuber | e |
| Broadleaves | Potamogetonaceae | *Potarnogeton distinctus* | Rhizome, seed | r,b |
| | Alismataceae | *Sagittaria pygmaea* | Tuber, seed | r |
| | Alismataceae | *Sagittaria trifolia* | Tuber, seed | r |
| | Alismataceae | *Alisma canaliculatum* | Tuber, seed | r |
| | Campanulaceae | *Lobelia chinensis* | Rhizome, seed | p,b |
| | Umbelliferae | *Oenanthe javanica* | Rhizome, seed | p,b |

[a] b = branched form, e = erect form, p = procumbent form, r = rosette form, t = tussock form.




**1.** Effect of day length and planting times on tuberization (adapted from Kusanagi 1975).

time day lengths were from 12 to 13 hours. But when planting was delayed to 30 August, tuberization was initiated within 30 to 60 days at day lengths of 11 to 12 hours. One hundred to 110 days from 30 May reaches into the middle of September, during which the average daily temperature is around 20° C, and after that the temperature declines daily. Short photoperiod with somewhat low temperature is the main cause of tuberization for *E. kuroguwai. C. serotinus,* and *S. trifolia,* but *S. pygmaea* tuberization was not affected by photoperiod or the temperature. Further, Kim and Kang (1978) confirmed that perennials such as *C. serotinus* and *E. kuroguwai* did not produce tubers under a photoperiod of 14 hours or longer.

Growth regulators seem to play an important role in tuberization. Cytokinin may be a specific stimulus responsible for tuberization. Sattelmacher and Marschner (1978) showed that an interruption of nitrogen supply, which may regulate cytokinin activity, induced potato tuberization. But not many studies along this line have been made on perennial weeds in rice fields. Harada et al (1978) reported that foliar application of 5 ppm of gibberellic acid, applied before tuberimtion began, stimulated tuberization of *S. pygmaea* and *C. serotinus,* but inhibited tuberization in *S. trifolia* and *E. kuroguwai.* Hormonal regulation of tuberization deserves much attention in the establishment of integrated control measures.

Kusanagi (1975) and Kim and Choi (1976) reported similar results regarding the depth of tuberization of perennial weeds at different sites. Tubers of *Sagittaria* spp. and *C. serotinus* were produced mostly in shallow soil of less than 10-cm depth, but *P. distinctus* and *E. kuroguwai* produced tubers in relatively deeper soil, mostly between 11 and 20 cm. These differences in tuberization depth can partly explain the difficulty in controlling perennial weeds.

*E. kuroguwai* and *S. trifolia* have deep dormancy, but *C. serotinus* and *S. pygmaea* have no dormancy. It is understood that the dormancy of these species may be regulated by the levels of endogenous growth regulators such as cytokinin. The exogenous application of cytokinin is able to break dormancy as well as apical dominance. Dormancy of weed seeds and tubers produced in temperate zones can be naturally broken by the chilling effect of low winter temperature, which may regulate the level of inhibitor.

Viability of perennial tubers varied, depending upon species, from 1 to 6 years. It was 1 ½ years for *C. serotinus,* 2 to 3 years for *Sagittaria* spp. and *P. distinctus,* and 5 to 6 years for *E. kuroguwai* (Kusanagi 1981).

## YIELD LOSS

Yield decreases of 15-45% were reported in rice fields infested mainly with annual weeds compared with weeded plots (Arai and Kawashima 1956). Yield loss caused by perennial weeds, however, varied from 15 to 60%, depending upon species. When yields of weeded and weedy plots were compared, it was observed that *S. pygmaea* reduced rice yield by 15 to 25%, *Scirpus hotarui* by 20 to 40%. *C. serotinus* by 25 to 50%, *P. distinctus* by 20 to 45%, and *E. kuroguwai* by 30 to 60% (Kusanagi 1976).

## PERENNIAL WEED CONTROL IN TEMPERATE RICE

### Cultural control

Deep autumn plowing is considered an effective method against perennial weeds in temperate zones because of the drying and freezing of underground organs exposed to winter cold. Hirano (1975) reported that autumn plowing reduced emergence of *S. pygmaea* by 50% compared with nonweeded plots. Cultivation of winter crops in rice fields reduced emergence of *S. pygmaea* as much as 40 to 50% (Hori 1980). Double-cropping of rice with barley or wheat is an effective means against perennial weeds compared with continuous monocropping of rice.

A 1-year rotation of paddy fields to dryland conditions reduced *S. pygmaea* emergence as much as 80 to 90%, but rotation is not commonly practiced.

### Biological control

The biological control method seems attractive when compared to herbicide contamination or pollution. However, its use is restricted because of its limited effectiveness. A grasscarp, *Ctenopharyngodon tdellus.* can be useful for aquatic weed control in waterways (Tsuchiya 1977). In the future, this method is expected to be part of integrated control systems.

**Chemical control**

Herbicide has been the main method for controlling weeds in rice fields since 1960 in Japan and since 1970 in Korea. In Japan, there were more than 90 registered herbicides in 1980. and there were about 30 herbicides in Korea. In 1979, herbicides were applied on about 202% of the paddy fields in Japan, meaning that a farmer used herbicides more than twice per rice crop (Table 2). Some applied herbicide once. others twice, and some even three or four times. Herbicide usage in Korea is much less than that of Japan. About 104% of Korean paddy fields were treated with herbicides in 1979 (Table 2). More than 94% of the herbicides consumed — butachlor and thiobencarb — were those that controlled annual weeds. Recently. mixtures or combinations of herbicides have been tested on annuals and perennials in Korea.

In Japan. however, most herbicides are available in the form of mixtures, as shown in Table 2. The mixtures are based mostly on thiobencarb, molinate. and phenoxy herbicides. These are combined with s-triazine herbicides such as simetryn. These types, particularly piperophos - dimethametryn, are generally effective against perennial broadleaf weeds such as *P. distinctus.* Bentazon is effective against perennial sedges. and its use is increasing as weeds such as *C. serotinus* increase. One of the more difficult to control weeds in rice fields is *S. pygmaea,* but herbicides such as naproanilide and pyrazolate are effective (Takasawa 1981).

**Table 2. Estimated area of rice fields treated with herbicides in Korea and Japan in 1979.**

| Herbicide | Area treated[a] (thousand ha) | |
|---|---|---|
| | Korea | Japan |
| Bentazon | 4.8 ( 0.4) | 46.1 ( 1.8) |
| Bifenox | 7.9 ( 0.6) | – |
| Butachlor | 922.2 ( 75.0) | 352.6 ( 14.1) |
| Chlomethoxynil | – | 605.6 ( 24.2) |
| 2,4-D and its mixtures | 42.6 ( 3.5) | 240.9 ( 9.6) |
| MCPA and its derivatives | – | 245.0 ( 9.8) |
| Molinate | 14.9 ( 1.2) | 895.2 ( 35.8) |
| Molinate - simetryn | – | 97.0 ( 3.9) |
| Molinate - simetryn - MCPB | – | 395.3 ( 15.8) |
| Nitrofen and its derivatives | 149.5 ( 12.2) | – |
| Oxadiazon | 18.9 ( 1.5) | 463.1 ( 18.5) |
| Perfluidone | 2.1 ( 0.2) | – |
| Piperophos - dimethametryn | 25.0 ( 2.0) | 266.1 ( 10.6) |
| Simetryn - MCPB | – | 68.4 ( 2.7) |
| Swep - MCPA | – | 31.4 ( 1.3) |
| Thiobencarb | 86.8 ( 7.1) | 18.2 ( 0.7) |
| Thiobencarb - chlornitrofen | – | 271.5 ( 10.9) |
| Thiobencarb - simetryn - MCPB | – | 348.7 ( 13.9) |
| Mamet | 4.0 ( 0.3) | – |
| Total | 1279.3 (104.0) | 5045.2 (201.6) |
| Total area of rice fields (ha) | 1230.0 | 2500.0 |

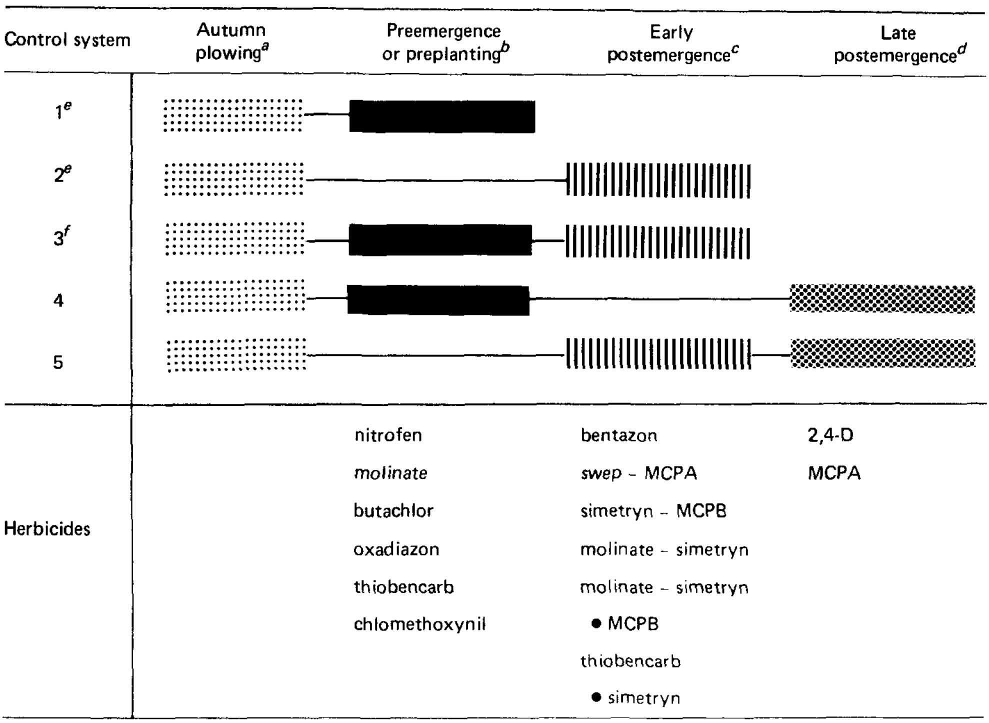
[a] Percentages of total area treated are in parentheses.

These herbicides are applied at different times:

- preplanting or preemergence treatment from just before transplanting to 6 to 8 days after transplanting (butachlor, thiobencarb, molinate, nitrofen, and oxadiazon),
- treatment soon after emergence (single application of combined herbicides 6-8 to 20 days after transplanting), and
- an optional late postemergence treatment from the end of effective tillering to the young panicle initiation stage (phenoxy herbicides such as 2,4-D) for eliminating surviving weeds after the preemergence or the early postemergence control.

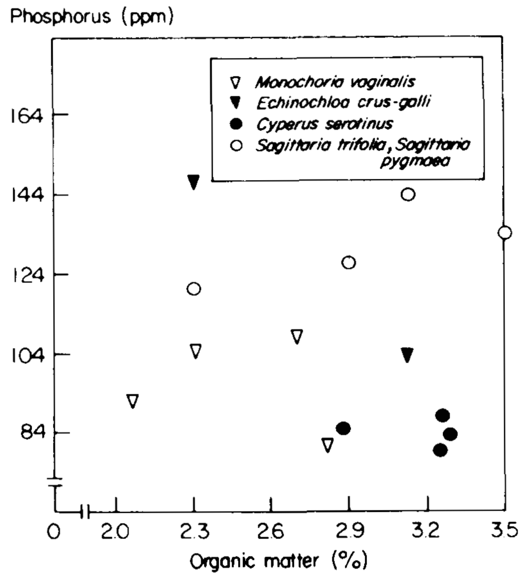
### Weed control system

Figure 2 gives examples of integrated control systems applicable to perennial weeds in monoculture rice in temperate zones. The integrated systems proposed are based on the chemical methods previously mentioned along with autumn plowing. Control system 1 or 2, along with autumn plowing, will give satisfactory control depending, of course, upon weed species. System 1 will be better under predominantly annual infestation, and system 2 will work better under perennial infestation.




[a]Plowed in autumn with 20 cm of soil depth after rice harvest. [b]From preplanting to 8 days after transplanting (barnyardgrass is 1.0-leaf age). [c]Single application 8 to 20 days after transplanting (barnyardgrass is 1.0- to 3.5-leaf age). Combined application 15 to 30 days after transplanting. [d]From the end of effective tillering to young panicle initiation stage of rice. [e]In paddy fields where weed infestation is relatively low, system 1 for annual and system 2 for perennial weed control. [f]Paddy fields where weeds are annuals and perennials.

2. Integrated control systems for controlling perennial weeds in rice fields.




**3.** Interrelationship of organic matter and phosphorus content of soil with weed community types (adapted from Kim et al 1980).

A mixture of two or three herbicides applied soon after emergence will cover a broad range of weeds. Under heavy infestation of annuals together with perennials. however, system 3 is recommended. System 4 is supplementary to system 1, and system 5 to system 2. Nevertheless, selection of appropriate herbicides for weeding rice fields is often more critical than the system chosen.

## WEED COMMUNITY TYPES

The weed vegetation of a given area is influenced by climatic, biotic, and edaphic factors. In a given environment, the biotic factors, particularly cultural practices, are the main ones affecting weed vegetation. The effects of cultural practices on population shift from annuals to perennials in rice fields have been discussed. Figure 3 gives an example of weed community types affected by organic matter and phosphorus content in soils. *M. vaginalis* was dominant under relatively low organic matter (2.1-2.8%) and low phosphorus content (80-110 ppm), *S. pygmaea* and *S. trifolia* were dominant under high phosphorus content (120-140 ppm), and *C. serotinus* was dominant under high organic matter (2.9-3.3%). Thus, herbicide use and soil fertility play a significant role in the establishment of weed community types in rice fields.

Diagnosis of diversity and succession in a given community is helpful in determining an appropriate control system. In nature, a selective advantage is always given to larger organisms that have greater storage capacities and more complex life cycles, Furthermore, there is rapid shift from short-lived annuals to long-lived vegetatively. spreading perennials.

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## DISCUSSION

SUSDARU: You mention that *Paspalum paspalodes* is a problem in the temperate zone. This weed may replace *Echinochloa crus-galli.* which is easy to control with thiobencarb or 2,4-D/MCPA. Have you any experience on how to chemically control *P. paspalodes* in transplanted rice?

*KIM:* It is not easy to control *Paspalum paspalodes* once it has become established, but the weed is much less of a problem in the temperate zone because its life cycle can be broken by winter cold. It is listed as an important weed, but its effect is not as great as other perennials. The use of a nonselective herbicide such as glyphosate or paraquat before rice planting, and thorough land preparation can be helpful in managing *P. paspalodes.*

DE DATTA: Do you know anything about the weed problem in North Korea? Do they have similar perennial weeds? Are they using herbicides as intensively as in South Korea?

*KIM:* NO.

LI (comment): The weed species are somewhat similar and they often use herbicides.

COX (comment): The Australian approach to *Paspalum* control once the *Paspalum* has begun to flower is to go into the crop with glyphosate using small rope wick applicators and applying it to the surface. We have obtained reasonable control. It is a fairly manual method. but it gives some measure of control. If we can start control measures just as the outbreak occurs. we can restrict it to small areas. In cases when it has become a more extensive problem, then the approach is often to go out with a controlled droplet applicator and spray that patch. forsaking that amount of rice.

SEAMAN: Do you believe the herbicide-caused weed shifts from annuals to perennials could be reversed back to annuals by new herbicides?

*KIM:* The continuous use of new herbicides that are effective against perennials may cause the reverse shift, but wise use of herbicides, rotation of herbicides, or the use of mixtures of herbicides can minimize these problems.

# PERENNIAL WEEDS AND THEIR CONTROL IN RICE IN THE TROPICS

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In the tropics, the major perennial weeds in wetland rice fields are *Scirpus maritimus* and *Paspalum paspalodes.* Tubers of *S. maritimus,* which are numerous, remain dormant in the soil, making the weed difficult to control completely with herbicides alone. Among the herbicides tested, 2,4-D applied about 26 days after transplanting effectively controlled *S. maritimus.* Against *P. paspalodes,* glyphosate followed by paraquat appeared most effective.

For dryland rice, *Cyperus rotundus* is the most serious weed in the tropics. Among the herbicides tested against it, methyldymrone and 2,4-D amine looked promising. There are a number of other nonselective herbicides that can provide effective control of *C. rotundus* prior to planting dryland rice.

For both wetland and dryland rice, tillage in combination with appropriate herbicides, together with other cultural practices including hand and mechanical weeding, can reduce perennial weeds to manageable levels.

As we develop technology to increase rice production, it is equally important to develop technology to minimize the potential threat of enemies of the rice plant that would compete for resources that the rice plant requires. With modernization of agricultural technology and, more importantly, with increased use of fertilizers and herbicides, perennial weeds in wetland and dryland rice fields are already causing

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serious problems in temperate rice-growing countries.

In the tropics, the major perennial weeds of both wetland and dryland rice fields have been identified (De Datta 1978, 1981). The threat from such weeds is not as serious in wetland rice as in dryland rice.

This paper summarizes recent information on the control of perennial weeds in both wetland and dryland rice.

## WETLAND RICE

*Scirpus maritimus,* a sedge, is perhaps the most important and most investigated perennial weed found in wetland rice. It can adapt to a wide variety of conditions, including salinity (Mercado et al 1971). It is also highly competitive, causing from 64% (De Datta and Lacsina 1974) to 79% (Lubigan and Mercado 1977a) yield reductions. In fact, it is more competitive in wetland rice than other weeds such as *Monochoria vaginalis* and *S. supinus* var. *lateriflorus* (Vega et al 1971). *S. maritimus* becomes established and spreads rapidly because of the adaptability of its vegetative parts (flowers are rarely produced) (Ghosh et al 1973). Tubers of *S. maritimus* remain dormant in the soil. Furthermore, apical buds inhibit sprouting of other buds on the same tuber. The capability of its tubers to remain dormant in the soil and bud dormancy make eradication of this weed particularly difficult (Kim and De Datta 1974). Furthermore, the number of tubers is generally high. A single plant normally produces 60 to 70 tubers in 40 days (De Datta and Lacsina 1974). Cao and Mercado (1975) reported that as many as 67 nondormant tubers and 73 dormant tubers may be formed from a single tuber. Subsequently, Visperas and Vergara (1976) observed 265 tubers produced from 1 tuber in 180 days. The superior competitive ability of *S. maritimus* is attributed to its rapid elongation and greater and faster nutrient uptake during its early growth stages when the production of shoots. leaves, and tubers is extremely rapid and the penetration of roots is deep (Chosh et al 1973, Visperas and Vergara 1976).

*Paspalum paspalodes* is also found on wetland rice fields. It is a creeping perennial grass with roots growing at the nodes and the branches are stout and somewhat compressed. The underground system consists of adventitious roots and rhizomes (Manuel et a1 1979). During the early stages of rice growth *P. paspalodes* competes with the rice plant, reducing its tiller and leaf numbers. Like *S. maritimus,* this weed is sensitive to shade (Manuel and Mercado 1977). It tends to resist conventional control measures; Noda (1969) explained its resistance to herbicides by its stem’s remarkably thick cell walls. It has been reported in Laguna, Bulacan, and Nueva Ecija Provinces in the Philippines (Lubigan and Mercado 1977b). A subsequent report by Manuel et al (1979) suggested that it is also present in Cagayan, Isabela, Nueva Vizcaya, Tarlac, Pangasinan, and the Bicol region of the Philippines as well. It has been reported to infest rice fields in Cuba (Labrada 1975). Japan (Noda 1969), and Guyana (Poonai 1960).

### Chemical control

Despite some difficulties caused by unavailability of labor, hand weeding and use of the rotary weeder are perhaps the most effective methods of controlling all weeds, including perennial weeds. De Datta and Lacsina (1974) and De Datta (1978) reported that bentazone and fenoprop can control *S. maritimus* in wetland rice. Lubigan and Mercado (1977a) reported that the combination of bentazone and 2,4-D IPE at 1.0 and 0.5 kg/ha, respectively, was more effective in controlling *S. maritimus* than applying bentazone alone at 2.0 kg/ha (Table 1).

Vega et al (1971) reported that *S. maritimus* is susceptible to propanil. Paller et al (1971) reported better control with a concentration of 1-2 kg/ha propanil or 0.5 kg, ha of 2,4-D or MCPA.

Most studies on *S. maritimus* control with foliar herbicides have dealt with applications based on the growth stage of the rice crop rather than that of the weed (De Datta and Lacsina 1974, Lubigan and Mercado 1977a). Although success has been achieved with such herbicides as the phenoxyacetics, the phenoxypropionics, and bentazone (De Datta 1980), the growth stage at which the applications were effective has not yet been carefully determined.

An experiment at IRRI during the 1980 dry season identified the stages in the growth and development of *S. maritimus* in which it is susceptible to 2,4-D. The dimethylamine salt and isopropyl ester of 2,4-D were used at 0.5 and 1.0 kg/ha. These were applied at six different stages of *S. maritimus* growth. The first application (at shoot emergence) was made 1 week after transplanting and the last (at the 10-leaf stage) 7 weeks after.

*S. maritimus* was effectively controlled by both rates and both formulations of 2,4-D in all treatments. By and large, differences in weed control and yield among the treated plots were not significant (Table 2). When 2,4-D was applied at the 6-leaf stage of *S. maritimus,* yield was significantly higher than the untreated check. Results also showed that *S. maritimus* at all postemergence stages is susceptible to 2,4-D. However, time of herbicide application in relation to the crop's growth stages. is apparently critical. For example, early application of 2,4-D enabled *S. maritimus* to regrow freely due to the absence of sufficient crop cover to suppress it.

For *P. paspalodes* control, chemicals such as paraquat and glyphosate have been evaluated. Glyphosate alone at 2 kg/ha controlled *P. paspalodes* but was not effective against *Fimbristylis littoralis.* Paraquat alone at 2 kg/ha effectively controlled annual grasses, sedges, broadleaf weeds, and. initially, *P. paspalodes,* but these weeds regrew faster than with the glyphosate treatment (De Datta et al 1979). The best results were obtained when a combination of glyphosate followed by paraquat was applied. It was also demonstrated that a single application of either chemical did not give complete control of *P. paspalodes* (Table 3).

## Tillage and chemical control

Many studies have evaluated various levels of tillage as a means to shorten turnaround time between crops and to save considerable time, labor, capital, and energy without loss in yield. But where perennial weeds were present, continued practice of reduced tillage of the land resulted in increased weed incidence (Seth et al 1971).

For *S. maritimus,* tubers germinate about 5 days after the first plowing and harrowing of a field, and tuber formation starts from 13 to 20 days after initial tillage.

During the 1980 dry season, a study was conducted at IRRI to find out if a

**Table 1. Control of mixed population of *Echinochloa crus-galli* and *Scirpus maritimus* in wetland rice fields with different herbicides. IRRI, 1974 dry season (adapted from Lubigan and Mercado 1977).**

| Treatment [a] | Application | | Grain yield [c] (t/ha) | Weed count/25 x 50 cm (33 DT) [b] | |
|---|---|---|---|---|---|
| | Rate (kg/ha) | Time (DT) [b] | | *Scirpus maritimus* | *Echinochloa crus-galli* |
| 2,4-D IPE fb bentazone | 0.8 fb 2.0 | 15 | 3.5 abcd | 5.0 | 0.3 |
| 2,4-D IPE fb bentazone | 0.8 fb 2.0 | 25 | 4.8 ab | 0.3 | 2.3 |
| Butachlor fb bentazone | 1.5 fb 2.0 | 15 | 5.7 a | 0.6 | 0.3 |
| Butachlor fb bentazone | 1.5 fb 2.0 | 25 | 3.9 abc | 0 | 1.0 |
| Piperophos - dimethametryn fb bentazone | 0.75 fb 2.0 | 15 | 2.9 abcd | 8.0 | 0 |
| Piperophos - dimethametryn fb bentazone | 0.75 fb 2.0 | 25 | 4.0 abc | 0.6 | 0 |
| Piperophos + 2,4-D IPE fb bentazone | 0.75 + 0.5 fb 2.0 | 15 | 3.8 abc | 2.0 | 0 |
| Piperophos + 2,4-D IPE fb bentazone | 0.75 + 0.5 fb 2.0 | 25 | 4.5 abc | 0.5 | 16 |
| Bentazone + 2,4-D IPE | 1.0 + 0.5 | 15 | 2.5 bcd | 2.0 | 6.6 |
| Bentazone + 2,4-D IPE | 1.0 + 0.5 | 25 | 3.1 abcd | 0 | 14.3 |
| Bentazone | 2.0 | 15 | 1.7 cd | 7.0 | 7.3 |
| Bentazone | 2.0 | 25 | 3.7 abc | 0 | 3.3 |
| Hand weeded | – | – | 4.1 abc | 0 | 0 |
| Unweeded | – | – | 0.5 d | 22.0 | 11.0 |

[a] fb = followed by, IPE = isopropyl ester. [b] DT = days after transplanting. [c] Numbers followed by a common letter are not significantly different at the 5% level.

**Table 2. Effects of 2,4-D applied at various stages of *Scirpus maritimus* to control this weed, and yield of transplanted IR36 rice. IRRI, 1980 dry season.**

| Leaf stage treatment[a] | *S. maritimus* dry weight[b] (g/m$^2$) | | Yield[b] (t/ha) |
|---|---|---|---|
| | Maximum tillering | Crop maturity | |
| Hand-weeded check | 21 a | 10 a | 5.5 a |
| Shoot emergence | 100 b | 237 cd | 3.4 bc |
| 2-leaf stage | 90 b | 206 bcd | 3.4 bc |
| 4-leaf stage | 104 bc | 202 bcd | 3.5 bc |
| 6-leaf stage | 86 b | 160 bc | 3.9 b |
| 8-leaf stage | 138 cd | 127 b | 3.8 bc |
| 10-leaf stage | 166 d | 157 bc | 3.6 bc |
| Untreated check | 173 d | 312 d | 2.7 c |

[a]Butachlor was applied at preemergence in all treatments. [b]Av of 3 replications, 2 formulations, and 2 rates of 2,4-D. In a column, means followed by a common letter are not significantly different at the 5% level.

**Table 3. Effect of chemical treatment alone and in combination with tillage on the grain yield of transplanted IR26 rice and dry weights of weeds.[a] IRRI. 1976 dry season (adapted from De Datta et al 1979).**

| Treatment | Application | | Weed dry weight (g/m$^2$) | | | Grain yield (t/ha) |
|---|---|---|---|---|---|---|
| | Rate (kg/ha) | Time (days before planting) | Grasses | Sedges | *Paspalum paspalodes* | |
| Glyphosate fb paraquat | 1.5 fb 1.0 | 7 fb 6 | 91 a | 450 b | 166 b | 5.6 ab |
| Glyphosate fb paraquat | 1.0 fb 1.5 | 7 fb 6 | 66 a | 114 b | 144 b | 5.6 ab |
| Glyphosate | 2.0 | 7 | 106 a | 2052 a | 106 b | 2.6 c |
| Paraquat | 2.0 | 7 | 78 a | 56 b | 444 a | 4.3 b |
| Glyphosate fb plowing | 2.0 | 7 fb 2 | 24 a | 356 b | 11 b | 5.7 a |
| Conventional tillage | - | 2 | 8 a | 81 b | 157 b | 5.7 a |
| Untreated check | - | - | 23 a | 1872 a | 469 a | 0.9 d |
| CV (%) | | | 26 | 23 | 23 | 12 |

[a]fb = followed by. In a column, means followed by a common letter are not significantly different at the 5% level.

properly timed final harrowing would reduce the stand of *S. maritimus.* Reharrowing was done 5, 10, and 15 days after the first tillage operations of one plowing and one harrowing done in 1 day. Tillage treatments were synchronized to permit planting on the same date. IR50 was transplanted the day after the field was reharrowed. Treatments with 2,4-D at 0.5 and 1.0 kg/ha, applied either singly or sequentially as a preemergence and postemergence spray, were superimposed on each tillage plot.

Significant reductions in the *S. maritimus* stand resulted mainly from postemergence application of 2,4-D. The differences in control between plots reharrowed at 5 days and those at 10 and 15 days were negligible, indicating that the interval of harrowing time did not make any difference (Table 4). Generally, plots treated at postemergence with 2,4-D gave yields significantly higher than those of the untreated check. When applied at preemergence and postemergence in sequence, 2,4-D controlled both *S. maritimus* and the annual weeds and gave yields comparable to the yield of the hand-weeded check (Table 5). Applied at preemergence, 2,4-D controlled the annual weeds as effectively as butachlor did, but had no effect on *S. maritimus.* However, when applied at postemergence, 2,4-D controlled *S. maritimus* and *M. vaginalis.* but not the grassy weeds.

Repeated tillage within a span of 30 days has been reported to control *P. paspalodes* effectively. When land was prepared thoroughly, an additional advantage in *P. paspalodes* control was recorded with further application of herbicides such as paraquat, dalapon, and glyphosate in various combinations (Manuel et al 1979).

A long-term experiment for 14 successive croppings recorded weed shifts being affected by various degrees of tillage. The conventional tillage treatment consisted of 1 plowing and 2 harrowings completed in 10 days during the first 4 crops. Minimum tillage for most crops was cutting the rice straw of the previous crop followed by three passes of a harrow. The zero tillage treatment also involved cutting near ground level and removal of rice straw and weeds of the previous crop, followed by a 0.5 kg paraquat spray/ ha the following day, or as needed. All tillage treatments were adjusted to permit planting on the same date.

The predominant weed species were *Echinochloa glabrescens, E. crus-galli* ssp. *hispidula, M. vaginalis. P. paspalodes,* and *S. maritimus.*

Generally, as conventional tillage was changed to zero tillage, weeds shifted toward the perennials *P. paspalodes* and *S. maritimus* (Fig. 1). Through the fifth crop, *P. paspalodes* was the predominant perennial weed in the minimum- and zero-tillage plots. But in the 6th, 7th, 12th, and 13th crops, *S. maritimus* became the dominant weed. Generally *S. maritimus* appeared to increase with a decrease in *P. paspalodes,* rather than to be affected by tillage level. For example, a decline in the *P. paspalodes* and annual weed components in conventional tillage plots was accompanied by a shift toward *S. maritimus* (Fig. 1). This confirms earlier findings that not all perennials are controlled by tillage (De Datta and Lacsina 1974, De Datta 1978). The virtual absence of weeds in the 4th, 8th, and 11th crops was due mainly to recultivation, which completely controlled the perennial weeds, and to the effective control of the annual weeds by preemergence herbicides (De Datta and Bernasor 1981).

**Table 4. Effects of herbicide and tillage treatments (reharrowing after 5, 10, and 15 days) on control of *S. muritimus*[a] IRRI, 1980 dry season.**

| Treatment | Application | | *S. maritimus* dry weight[c] (g/m$^2$) | | | Herbicide mean (g/m$^2$) |
|---|---|---|---|---|---|---|
| | Rate (kg/ha) | Time (DT)[b] | 5 d | 10 d | 15 d | |
| 2,4-D | 0.5 | 4 | 173 a | 170 abc | 129 ab | 157 ab |
| 2,4-D | 0.5 | 26 | 91 abc | 90 abc | 59 abc | 80 bc |
| 2,4-D | 1.0 | 4 | 58 abc | 131 abc | 132 ab | 107 ab |
| 2,4-D | 1.0 | 26 | 26 cd | 81 cd | 40 bcde | 49 cd |
| 2,4-D fb 2,4-D | 0.5 fb 0.5 | 4 fb 26 | 67 abc | 74 abc | 64 abcd | 68 bc |
| 2,4-D fb 2,4-D | 0.5 fb 1.0 | 4 fb 26 | 18 d | 29 cd | 26 cdef | 24 de |
| 2,4-D fb 2,4-D | 1.0 fb 0.5 | 4 fb 26 | 22 d | 97 bcd | 12 ef | 44 de |
| Butachlor fb 2,4-D | 1.0 fb 0.5 | 4 fb 26 | 40 bcd | 63 abc | 91 ab | 65 bc |
| Butachlor fb 2,4-D | 1.0 fb11.0 | 4 fb 26 | 8 d | 9 d | 17 dcf | 12 c |
| Butachlor | 1.0 | 4 | 140 ab | 198 a | 222 a | 187 a |
| Hand-weeded check | – | 20 fb 35 | 1 c | l e | 2 f | 1 f |
| Untreated check | – | – | 262 a | 177 ab | 149 ab | 196 a |

[a] fb = followed by. In a column, means followed by a common letter arc not significantly different at the 5% level. [b] DT = days after transplanting. [c] Av of 3 replications.

**Table 5. Effects of herbicides on control of *Scirpus maritimus* and annual weeds and on yield of transplanted IR50 rice.[a] IRRI, 1980 dry season.**

| Treatment | Application | | Weed weight[c] (g/m$^2$) | | Grain yield (t/ha) |
|---|---|---|---|---|---|
| | Rate (kg/ha) | Time (DT)[b] | *Scirpus maritimus* | Annual weeds | |
| Hand-weeded check | | 20 fb 35 | 1 a | 17 a | 4.6 a |
| Butachlor fb 2,4-D | 1.0 fb 0.5 | 4 fb 26 | 65 de | 58 ab | 4.3 ab |
| Butachlor fb 2,4-D | 1.0 fb 1.0 | 4 fb 26 | 12 b | 53 ab | 4.1 ab |
| 2,4-D fb 2,4-D | 1.0 fb 0.5 | 4 fb 26 | 44 bc | 74 bc | 4.0 ab |
| 2,4-D fb 2,4-D | 0.5 fb 1.0 | 4 fb 26 | 24 bc | 61 bc | 3.8 bcd |
| 2,4-D fb 2,4-D | 0.5 fb 0.5 | 4 fb 26 | 68 de | 75 bc | 3.8 bcd |
| 2,4-D | 1.0 | 26 | 49 cd | 135 c | 3.6 bcde |
| 2,4-D | 1.0 | 4 | 107 ef | 50 ab | 3.3 cdef |
| Butachlor | 1.0 | 4 | 187 f | 47 ab | 3.2 cdef |
| 2,4-D | 0.5 | 26 | 80 de | 102 bc | 3.1 def |
| 2,4-D | 0.5 | 4 | 157 ef | 65 bc | 2.9 ef |
| Untreated check | – | – | 196 f | 103 bc | 2.5 f |

[a]fb = followed by. In a column, means followed by a common letter are not significantly different at the 5% level. [b]DT = days after transplanting. [c]Av of 3 replications and 3 tillage treatments.

Other long-term studies have been conducted to determine the effects of weeding methods on the population density of *S. maritimus* and other weeds in different cropping patterns. Details of the experimental procedure and results obtained during the 1974-75 crop seasons were reported by De Datta and Jereza (1976). Results summarized here are from 1975-80 crop seasons.

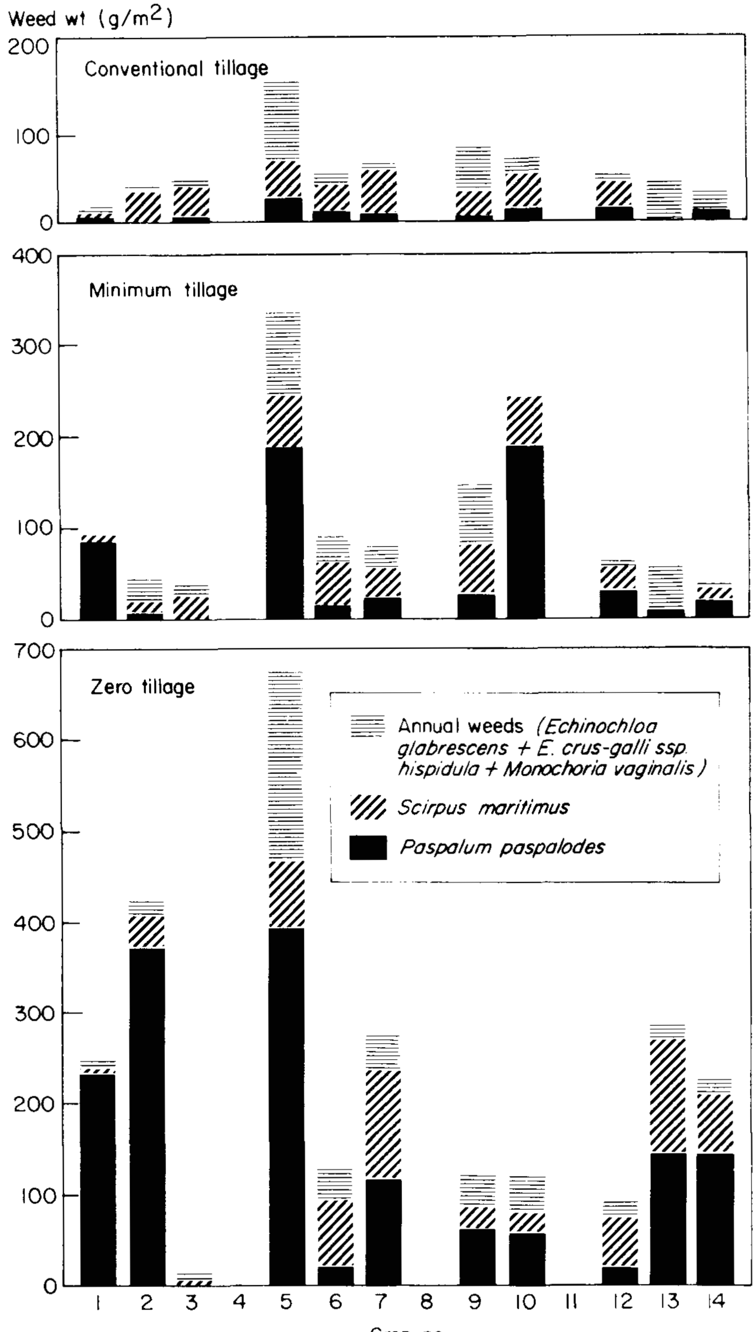
In the untreated check plots (Table 6), *S. maritimus* persisted over the years in the continuous transplanted rice pattern. In situations where irrigated transplanted rice was rotated to a dryland crop, *S. maritimus* disappeared and its density dropped to half when the land was returned back to an irrigated condition. This reduction in the population of *S. maritimus* due to proper land and water management resulted in a rice yield of 1.2 t/ha, compared with only 0.3 t/ha in the continuous transplanted rice pattern. *Cyperus rotundus* appeared in the dryland condition only. It persisted in the dryland crop and in the dry-seeded rainfed bunded rice pattern, but *S. maritimus* was minimized.

These results demonstrated the use of crop, soil, and water management systems to shift weed species from one which is difficult to control to one which is less difficult to control. In situations where the perennial *S. maritimus* is present, proper management of crop, land, and water minimizes yield loss.

The foregoing results show the need to develop careful integration of weed control practices such as tillage, use of herbicides, and crop rotation in controlling weeds such as *S. maritimus* and *P. papalodes* in wetland rice.

## DRYLAND RICE

*C. rotundus* is the most serious perennial weed in all dryland crops. It has been reported in tropical areas of Asia, Africa, and Latin America (Okafor 1973, Mercado 1979), and is believed to be native to the tropics (Small 1933). Bhardwaj and




**1.** Weed dry weights at harvest as indices of weed control by 3 tillage levels (av of 3 cultivars/tillage level per crop).

**Table 6. Weed shifts in untreated check plots as affected by cropping pattern (av of 6 years). IRRI, 1975-80 dry and wet seasons.**

| Season | Crop | Weed populations (no./$m^2$) | | | Yield |
|---|---|---|---|---|---|
| | | Annuals | Perennials | | |
| | | | *Scirpus maritimus* | *Cyperus rotundus* | |
| | | *Cropping pattern I - continuous transplanted rice* | | | |
| Dry | Transplanted rice | 638 | 297 | 0 | 0.3 t/ha |
| Wet | Transplanted rice | 752 | 310 | 0 | 0.4 t/ha |
| | | *Cropping pattern II - dryland crop - transplanted rice* | | | |
| Dry | Maize + dryland crop[a] | 742 | 40 | 14 | 17,083 marketable ears/ha + 139 kg/ha |
| Wet | Transplanted rice | 503 | 153 | 0 | 1.2 t/ha |
| | | *Cropping pattern III - dryland crop - dry-seeded rainfed bunded rice* | | | |
| Dry | Maize alone | 1,290 | 16 | 39 | 20,083 marketable ears/ha |
| Wet | Dry-seeded rainfed bunded rice (1st) | 1,586 | 24 | 32 | 0 |
| Wet | Dry-seeded rainfed bunded rice (2d)[b] | 1,063 | 18 | 37 | 0 |

[a] Planted to mungbean and soybean during 1975-76 and 1977-80 dry seasons, respectively. [b] Av of 1975 and 1979 wet seasons only.

Verma (1968) reported that *C. rotundus* removed about 95 kg N, 5 kg P, and 80 kg K/ha, and that more than 50% of these nutrients were contained in the tubers. Okafor and De Datta (1974) subsequently reported that *C. rotundus* competes with dryland rice for both moisture and nitrogen.

Mercado (1979) suggested that *C. rotundus* is considered the world's worst weed because it is extremely difficult to control. Many factors have contributed to this problem, among which are:

- decreased use of hand hoeing, deep plowing, and cultivation,
- continuous use of herbicides that control only annual weeds, and
- intensive monoculture cropping.

Hand weeding is the most common control method used in dryland rice, but it is laborious. It also has to be done at the correct time to prevent substantial yield losses. A shortage of labor during the peak weeding period, continuous rain, and moist unworkable soil conditions hamper both manual and mechanical weeding (Patro and Tosh 1973). Furthermore, for control of weeds such as *C. rotundus,* hand weeding is extremely difficult and uneconomical.

**Chemical control**

Del Rosario and Vega (1967) reported inhibited germination of weed tubers in the Philippines at 50 ppm WL 9385 with no effect on rice. In Colombia, Cruz and Cardenas (1971) found R4574 to be effective in rice.

Bentazone has been suggested to control *C. rotundus* at early stages of weed growth, and complete control has been reported with 1.1 kg/ha (Boswell 1971). Ghosh et a1 (1974) reported that bentazone at 6 kg/ha applied 35 days after seeding with rice was able to control *C. rotundus.* Okafor and De Datta (1976) reported that dymrone, methyldymrone, perfluidone, and fenoprop were fairly successful in controlling *C. rotundus.*

In 1977, an experiment at IRRI compared perfluidone, dymrone, methyldymrone, and 2,4-D amine for control of *C. rotundus* and for selectivity to IR9575 rice. The weeds present at the experimental site were *C. rotundus, Amaranthus spinosus, Commelina benghalensis, Ipomoea triloba, Portulaca oleracea,* and *Eleusine indica.* Weed infestation was so heavy that the untreated plots yielded nothing (Table 7). All plots treated with herbicides that control *C. rotundus* yielded significantly more than the untreated plots or the plots treated with dinitramine alone. Most promising for control of *C. rotundus* appeared to be 2,4-D amine, which did not damage the crop; plots treated with it performed as well as the hand-weeded control (Table 7). Methyldymrone controlled *C. rotundus* adequately but was moderately toxic to the rice crop. Likewise, perfluidone was toxic to rice and gave only fair control of *C. rotundus.* On the other hand, dymrone at 6.0 kg/ha was selective to the crop but gave the poorest weed control. For adequate weed control, 8 kg/ ha or higher of dymrone may be necessary.

*C. rotundus* infestation directly and indirectly contributed to the zero yields in plots treated with dinitramine alone. Besides reducing crop tiller production. *C. rotundus,* upon senescence, permitted later growth of *C. benghalensis* and *I. triloba,* which took over the entire plots.

During the 1979 wet season, some preemergence and postemergence herbicides

**Table 7. Effects of herbicides on control of *Cyperus rotundus* and on yield of dryland IR9575 rice.[a] IRRI, 1977 wet season.**

| Treatment | Application | | Weeds[c] (g/m²) | | Grain yield (t/ha) |
|---|---|---|---|---|---|
| | Rate (kg/ha) | Time[b] | *Cyperus rotundus* | Annual weeds | |
| Hand-weeded twice | – | 15 fb 30 DE | 1 a | 1 a | 2.4 a |
| Dinitramine fb 2,4-D amine | 1.5 fb 1.0 | 2 DS fb 15 DE | 15 bc | 7 bc | 2.2 a |
| Dinitramine fb 2,4-D amine | 1.5 fb 1.0 | 2 DS fb 20 DE | 33 cd | 16 bc | 1.8 a |
| Methyldymrone fb dinitramine | 3.0 fb 1.5 | PPI fb 2 DS | 55 cd | 22 c | 1.0 b |
| Perfluidone + dinitramine | 2.0 + 1.5 | 2 DS | 112 de | 10 bc | 0.6 b |
| Dymrone fb dinitramine | 6.0 fb 1.5 | PPI fb 2 DS | 132 de | 23 c | 0.4 b |
| Dinitramine | 1.5 | 2 DS | 141 e | 11 bc | 0.0 c |
| Untreated check | – | – | 6 ab | 487 d | 0.0 c |

[a]fb = followed by; + means that the chemicals were applied separately at about the same time. In each column, means followed by a common letter are not significantly different at the 5% level. [b]DE = days after rice emergence, DS = days after seeding, PPI = preplant incorporated. [c]Sampled at flowering of *C. rotundus.*

**Table 8. Effects of preemergence and postemergence herbicides on control of *Cyperus rotundus*, crop tolerance, and yield of IR9575 grown under dryland conditions.[a] IRRI, 1979 wet season.**

| Treatment[b] | Application | | Weed weight (g/m²) | | | | Toxicity rating[c] | Yield[d] (t/ha) |
|---|---|---|---|---|---|---|---|---|
| | | | *C. rotundus* | | Annual weeds | | | |
| | Rate (kg/ha) | Time | 6 WE | At harvest | 6 WE | At harvest | | |
| Hand-weeded check | – | 2 fb 5 WE | 0 | 12 | 0 | 129 | 0 | 1.5 a |
| 2,4-D | 0.5 | 3 WE | 56 | 13 | 5 | 54 | 0 | 1.4 a |
| Bentazone fb 2,4-D | 1.0 fb 0.5 | 2 fb 4 WE | 43 | 23 | 2 | 14 | 0 | 1.3 ab |
| 2,4-D | 1.0 | 2 WE | 39 | 22 | 1 | 45 | 5 | 1.1 b |
| 2,4-D fb bentazone | 0.5 fb 1.0 | 2 fb 4 WE | 30 | 52 | 1 | 68 | 0 | 1.1 b |
| 2,4-D fb 2,4-D | 0.5 fb 0.5 | 2 fb 4 WE | 30 | 23 | 17 | 57 | 0 | 1.0 b |
| 2,4-D | 0.5 | 2 WE | 29 | 9 | 2 | 71 | 0 | 1.0 b |
| 2,4-D | 1.0 | 3 WE | 60 | 71 | 5 | 120 | 3 | 1.0 b |
| Bentazone | 2.0 | 3 WE | 16 | 1 | 12 | 266 | 0 | 0.7 c |
| Bentazone | 1.0 | 3 WE | 81 | 7 | 17 | 435 | 0 | 0 d |
| Methyldymrone | 3.0 | PPI | 71 | 1 | 147 | 367 | 6 | 0 d |
| K-3185 | 3.0 | PPI | 26 | 4 | 81 | 263 | 8 | 0 d |
| K-3185 | 1.5 | PPI | 74 | 2 | 90 | 362 | 5 | 0 d |
| Methyldymrone | 1.5 | PPI | 86 | 11 | 41 | 230 | 4 | 0 d |
| Pendimethalin | 2.0 | 2 DS | 99 | 3 | 34 | 317 | 0 | 0 d |
| Untreated check | – | – | 85 | 1 | 210 | 475 | 0 | 0 d |

[a]fb = followed by, WE = weeks after crop emergence, PPI = preplanting incorporation, DS = days after seeding. [b]Pendimethalin at 2.0 kg/ha was applied at the preemergence stage to all plots, except the check, to control annual weeds. [c]Taken at 1 WE and 1 wk after application of postemergence herbicides. Scale 0-10: 1 = no toxicity, 10 = complete kill. [d]Av of 3 replications. Means followed by a common letter are not significantly different at the 5% level.

were screened at IRRI for the control of *C. rotundus* in dryland rice. Two preplant herbicides — methyldymrone and methoxydymrone — were incorporated into the topsoil during final tillage and two postemergence herbicides — bentazone and 2,4-D — were sprayed on the foliage. Sequential application of bentazone and 2,4-D was by spraying on the foliage. Pendimethalin was used to control the other weeds, mainly *Rottboellia exaltata, Calopogonium mucunoides,* and *C. benghalensis.* Grain yields of 1.0 to 1.4 t/ ha were obtained from plots treated with 2,4-D applied both alone and sequentially, which controlled *C. rotundus* between 24 and 70% (Table 8).

Recently, Lopez et al (1980) reported that dinitramine, propanil, and 2,4-D amine were not able to control *C. rotundus* effectively in dryland rice.

The foregoing results suggest that *C. rotundus* is difficult to control with one herbicide or a herbicide combination alone. This is due to its complex network of underground rhizomes and dormant tubers, which are not affected by herbicide treatments. The apical dominance system makes the inactive buds and tubers inaccessible to most chemicals. Therefore, Mercado (1979) suggested identification of those chemicals for *C. rotundus* control that can effectively move from the absorption site to the rhizomes and tubers. It might be more difficult to identify herbicides that are selective than those that are nonselective in dryland rice.

**Tillage and chemical control**

Combinations of tillage and chemical methods have been reported to be more effective in controlling *C. rotundus* than either tillage or chemicals alone. For example, Verhoeven and Cowdry (1961) observed substantial reduction in tuber population in the top 30 cm of soil when plowing to 25 cm deep was followed by disking and 2,4-D applications at 4.4 kg/ ha.

During the 1976 wet season, an experiment at IRRI evaluated the degree of tillage combined with herbicide in controlling *C. rotundus* and other weeds in dryland rice (Vargas 1978). One plowing followed by one rototilling resulted in significantly greater weed weight at the maximum tillering stage of rice than plowing followed by

**Table 9. Total dry weed weight at maximum tillering stage (55 DE[a]) as affected by tillage degree and weed control treatments in drill-seeded dryland rice.[b] IRRI, 1976 wet season (adapted from Vargas).**

| Weed control treatment[c] | Dry weed weight[d] ($g/m^2$) | | | Weed control mean[d] ($g/m^2$) |
|---|---|---|---|---|
| | Plowing fb 1 rototilling | Plowing fb 2 rototillings | Plowing fb 3 rototillings | |
| Dymrone fb terbuchlor | 181 | 119 | 109 | 136 b |
| Hand weeded twice | 35 | 22 | 25 | 28 a |
| Untreated control | 251 | 232 | 203 | 229 c |
| Tillage mean | 155 b | 124 a | 113 a | |

[a]DE = days after rice emergence. [b]Av of 4 replications and 3 cultivars. [c]Dymrone was preplant soil incorporated at 6.0 kg/ha to control *C. rotundus.* fb = followed by. Terbuchlor was applied preemergence at 1.0 kg/ha to control annual weeds. [d]Any 2 means followed by a common letter are not significantly different at the 5% level.

two rototillings or plowing followed by three rototillings. Plowing followed by three rototillings resulted in the lowest dry weed weight but was not significantly different from one plowing followed by two rototillings (Table 9).

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## DISCUSSION

SUNDARU: I have found that 2,4-D causes inhibition of physiological activity in rice plants by inhibiting root development and forming of callus at the bottom of the rice plant. Do you have any information on the effect of 2,4-D applied twice on either the growth or the yield of rice?

*DE DATTA:* When you spray with either 2,4-D or MCPA when the temperature is somewhat low, you will occasionally see some onion-leaf symptoms, but these vanish as quickly as they appear. Within 10 days or at the most 2 weeks, these symptoms are no longer a serious problem. Our experience has been that 2,4-D does not control weeds completely, but the problem is minimized and becomes acceptable. You may find cultivar differences in sensitivity to all herbicides, particularly 2,4-D, therefore, before a cultivar is released make sure that the standard herbicides are evaluated against it so that you do not release a cultivar that is supersensitive to herbicides.

I have not observed 2,4-D to cause a significant reduction in yield under most situations.

COX (comment): We have also found phenoxy damage in rice, but we are fairly convinced that it is rather short-term, and we have found most damage under conditions of cool temperature stress. We have temperatures as low as 8° quite frequently, and damage is definitely more pronounced under cooler conditions and conditions of stress. If MCPA or 2,4-D is applied during the middle of summer during warm conditions, then the effect seems to be quite minimal in terms of actual yield loss.

SETH: Do you know if there is any difference in response between japonica and indica cultivars?

*DE DATTA:* In some of our earlier work we observed the indicas to be a little more sensitive than the japonicas. Dr. Seaman, correct me if I am wrong.

SEAMAN (comment): It was the other way around; the japonicas were more sensitive than the indicas.

CHEN (comment): In Taiwan, the indicas are more sensitive.

*DE DATTA:* In the tropics, we grow very little japonica. Rice, in general, means indica. So this is not a priority area of research. I have not updated the information.

YEH (comment): We found japonica cultivars to be more sensitive to 2,4-D. We applied 2,4-D sodium salt at 400 g/ha. If we applied it before the maximum tillering stage, we observed spreading of the hills and the leaves became shorter, darker, and curly. The panicles had difficulty emerging out of the sheath and the spikelet fertility was very poor. When 2,4-D was applied after maximum tillering it was safer. The disadvantage of this application is that most of the surface of the field has been covered with rice so it is difficult for the herbicide to reach most of the weeds.

*DE DATTA:* In Taiwan, japonicas have been selected out much more critically over the years. In the Philippines, indicas are more at home. So by growing japonicas you have already placed the rice cultivar under some kind of stress. If on top of that you apply phenoxy herbicides, it becomes more sensitive. Even within indica or japonica cultivars there should be a spread of sensitivity that we should watch out for. If we have a supersensitive cultivar we should warn the grower that this cultivar is highly susceptible to MCPA or 2,4-D.

SUNDARU (comment): Indica cultivars are more susceptible due to the forming of ethylene in the leaves caused by the 2,4-D application. Ethylene causes some toxicity in small amounts, but by applying 2,4-D the amount of ethylene forming in the leaves will be increased. Among the indica cultivars there is a variation in susceptibility to 2,4-D. For example the new cultivars in Indonesia are not as susceptible as the short (dwarf) cultivars.

MATTHEWS: In dryland rice, what are the chances of using deep litter, say 6 t/ha, jab planting the rice through that, and a bit of follow-up direct application of glyphosate at some stage to control *Cyperus rotundus?* If you have enough litter on the ground surface, *C. rotundus* does not come through.

*DE DATTA:* We tried straw mulch to minimize weed infestation. I do not remember any specific data we collected on *C. rotundus.* Dr. Mercado, isn't *C. rotundus* shade sensitive?

MERCADO (comment): Yes.

*DE DATTA:* If you cover the soil surface with mulch because *C. rotundus* is shade sensitive, you should minimize the infestation but not eliminate it.

SYARIFUDDIN (comment): In Indonesia we had less *C. rotundus* in the mulched plots.

MUKHOPADHYAY: Why did you use paraquat, which gives only top kill without any effect on the underground parts?

*DE DATTA:* If you use equal rates of paraquat and glyphosate, then you know which is more expensive. When we use the herbicides by themselves we use that which is the least expensive. When we use combinations, one will have top kill and the other will have more sustained control but is used at a considerably lower rate than the maximum rate. We would be able to minimize the rate used. We are doing research on both. We are not recommending any one of the herbicides.

VONGSAROJ: I am interested in hand weeding for *C. rotundus* control. How do you do this effectively?

*DE DATTA:* We do not. It takes many hours to complete the job of hand weeding. It can be done, but this is not the most pleasant job.

MATTHEWS: How many man-hours are required per hectare?

*DE DATTA:* It depends on the degree of infestation. I would say 600 man-hours/ha would be minimal.

# PANEL DISCUSSION: NEW HERBICIDES AND APPLICATION TECHNIQUES

## PERFORMANCE OF PENDIMETHALIN HERBICIDE IN RICE CULTURE

F. B. Calora and R. R. Fine

Pendimethalin is registered for use in rice in 14 countries. Applications for registration have been submitted in the Philippines, Japan, and the United States.

Application may be either preemergence in drill-seeded irrigated or dryland rice or soon after emergence in combination with propanil in drill-seeded cultures and also in pregerminated, broadcast rice sown in flooded soil or disked after seeding. In transplanted rice, pendimethalin may be applied before transplanting at the last puddling, or 3-5 days after transplanting.

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Cyanamid Agricultural Research Foundation, Inc., P. O. Box 147, College, Laguna, Philippines, and American Cyanamid Company, P. O. Box 400, Princeton, New Jersey 08540, USA.

# PANEL DISCUSSION: NEW HERBICIDES AND APPLICATION TECHNIQUES

# THIOBENCARB: A RICE HERBICIDE

I. Kimura

In the past 10 years since thiobencarb was first introduced for rice weed control, a number of formulations including various mixtures and their application techniques were widely tested throughout the world.

Remarkable characteristics of thiobencarb are its:

- high selectivity between rice and grasses,
- wide application period,
- broad herbicidal spectrum,
- compatibility with other pesticides,
- low toxicity and low residue, and
- easy application.

Because of these characteristics, thiobencarb can be effectively applied in almost every rice field in the world under various climates and cultural systems, either alone or mixed with other suitable rice herbicides.

Thiobencarb and its mixtures can cover a wide range of weeds at application times varying from preemergence to soon after emergence, under flooded and dryland conditions, and in the form of an emulsifiable concentrate or granule. The emulsifiable concentrate itself, without dilution, can be directly applied to the wetland rice field or in the irrigation water, or can be mixed with soil to be broadcast by hand.

Kumiai Chemical Industry Co., Ltd., 4-26 Ikenohata, 1-Chome, Taitoh-ku, Tokyo 110, Japan.

# PANEL DISCUSSION: NEW HERBICIDES AND APPLICATION TECHNIQUES

## OXADIAZON: SHAKER BOTTLE FORMULATION

L. Lepetit

The application technique is one of the important considerations in applying rice herbicides.

The oxadiazon shaker bottle formulation is one of the most convenient and fastest methods of applying herbicides in transplanted rice.

**The shaker bottle**

Depending on the country in which the product is marketed, the shape and materials used for the shaker bottle differ. However, the common feature of the bottle is the perforated cap with three calibrated holes that control the application rate. The capacity of the bottle is normally 500 cc.

**The formulation**

The formulation is self-spreading and contains 120 g oxadiazon/liter. It is not necessary to mix it with water or sand, or to apply it with a knapsack sprayer.

Rhone-Poulenc Agrochimie, 14-20 Rue Pierre Baizet, 69009 Lyon. Cedex, France.

## Application method

The product is applied by swinging the bottle left and right every 3-4 m while walking at a normal pace in the paddy to a treat a swath about 10 m wide. Normally 30-40 minutes is required to treat 1 ha.

## Application time

During application of oxadiazon, the paddy field must be fully submerged to a depth of about 5 cm.

*Before transplanting.* Oxadiazon can be applied just before or immediately after leveling. When the product is applied just before final leveling, the active material will be slightly incorporated into the soil at final leveling. When the product is applied in the muddy water right after final leveling, the active material will be adsorbed quickly by the soil particles. Rice seedlings should be transplanted 1-2 days after application.

*After transplanting.* The product can be applied 4-8 days after transplanting but before weed emergence.

## Rate

The recommended rate is 480 to 600 g a.i./ha (8-10 bottles) depending on factors such as soil type, temperature, and time of application.

# PANEL DISCUSSION: NEW HERBICIDES AND APPLICATION TECHNIQUES

## BENTAZONE ALONE OR IN COMBINATION WITH OTHER HERBICIDES FOR RICE WEED CONTROL

B. H. Menck

The ideal herbicide for weeds in rice combines high selectivity and efficacy with safe application methods. In rice bentazon is metabolized to nonphytotoxic compounds. With 2 kg a.i. bentazon/ha, most important rice weeds such as *Alisma* spp., *Commelina* spp., *Fimbristylis* spp., *Monochoria vaginalis, Sagittaria* spp., and *Scirpus* spp. can be controlled. To reduce herbicide rate and to broaden the weed spectrum, bentazon was combined with MCPA to control *Cyperus difformis* and *S. maritimus* with one application. For additional control of *Echinochloa crus-galli,* bentazon was formulated with propanil. In areas where rice is rotated with soybean or cotton, many dryland weeds such as *Cassia* spp., *Ludwigia* spp., *Sesbania* spp., and *Ipomoea* spp. are problems in rice. These weeds can be controlled by bentazon mixed with low rates of dicamba.

Bentazon as granules can be applied in drained fields and distributed with small application equipment, or it can be mixed with sand and applied by hand.

But bentazon is applied mainly as a liquid with ground or aerial sprayers. Ground application and air application have been compared. The most consistent results have been obtained with ground sprayers. Double application with a fixed wing aircraft showed lower standard deviation compared with a single treatment. The addition of adjuvants improved the efficacy mainly against *C. difformis.* The velocity should be 144-160 kmh with a spray pressure of 2.1 kg/cm$^2$ and 20-30 droplets/cm$^2$. Recommended flight altitude is 1.5-3.0 m with 50-100 liters water/ha and a swath overlap of at least 1.5 m. The propeller angle of the nozzles should be 45-55°. Best results are obtained with relative humidity of 60-90% and temperatures between 20° and 30° C.

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BASF Aktiengesellschaft, Agricultural Research Station, D-6703 Limburgerhof/Pfalz, Federal Republic of Germany.

# PANEL DISCUSSION. NEW HERBICIDES AND APPLICATION TECHNIQUES

# USE OF WIPING TECHNOLOGY TO EXPAND WEED CONTROL OPPORTUNITIES WITH GLYPHOSATE

R. W. Schumacher

Glyphosate, a postemergence translocated herbicide, effectively controls a wide spectrum of annual and perennial grasses and broadleaf weeds. Until recently, glyphosate has been used primarily for preplant, spot, and postharvest weed control in many cropping systems. With wiping technology, glyphosate can be used to selectively control weeds growing above the crop canopy or between crop rows.

Wiping technology is the use of an inert absorbent medium to transfer glyphosate solution from the applicator reservoir directly to the target weed without injuring susceptible crops growing below or beside the treated weeds. The absorbent media used in these applicators include ropes made of synthetic fibers (primarily nylon or polyester), fabrics, sponges, and other substances that permit the capillary flow of the herbicide solution from the reservoir to the target plant. Because the wipers are made from relatively simple materials, designs can be varied to fit the crop or use situation. Above-crop wipers can be mounted on a variety of mechanized equipment, or hand-held units can be designed. For between-row weed control, shields should be used to prevent contact between the adsorbent medium and the crop plants. For preplant or postharvest weed control, high-recharge media should be used.

In field trials, 0.50 to 0.125 vol% solutions provided effective control of numerous annual and perennial weed species. Because glyphosate translocates, contact with the upper one-quarter to one-half of actively growing plants is normally sufficient for optimum control. Glyphosphate's lack of soil activity permits it to be used safely before planting labeled crops.

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Monsanto Singapore Co. (Pte) Ltd., 2601-2606, 26th Floor, Clifford Centre, Raffles Place, Singapore 0104.

# PANEL DISCUSSION: NEW HERBICIDES AND APPLICATION TECHNIQUES

## AN ELECTRODYNAMIC SPRAYING SYSTEM FOR PESTICIDE APPLICATION

A. K. Seth

It has long been recognized that most of the currently available spraying systems have many inherent deficiencies. Conventional spray equipment produces droplets in a wide range of sizes. In practice this means that some droplets — the very small ones — drift away from the target and others — the larger ones — simply bounce off the leaf surfaces. In between the extremes are the droplets in the useful size range. These are the droplets that hit the target and produce biological results. Other deficiencies of conventional systems include high volume rates, inaccurate application rate of the pesticide on the target, environmental contamination, and inadequate penetration of plant canopy.

Within the past few years, new machines fitted with spinning disc atomizers have permitted more accurate and convenient pesticide application. The size of droplets produced by these machines is controlled within narrow limits, enabling more even and less wasteful distribution of a pesticide, and making substantial reductions in the volume of applications possible.

A new revolutionary sprayer based on the discovery of electrodynamic spraying has been developed. This sprayer uses electrical energy directly to atomize the spray and control the population of charged droplets directed toward the target plant.

The pesticide formulation is supplied in a special disposable unit called the *Bozzle* container. The spray solution is fed by gravity from the reservoir to a special nozzle. There the droplets atomize and are propelled by the electrical force set up between a high voltage positively charged nozzle, the droplets themselves, and the neutral target crop.

Imperial Chemical Industries Ltd. Fernhurst, Haslemere, Surrey, England GU27 3JE.

First a number of uniform ligaments are formed. They in turn break up into positively charged, mutually repellant droplets of even sue. The droplets move along the flux lines of the electric field and are deposited in a uniform coating over the plant. Because the electrical field envelops the plant, complete wrap-around coverage is achieved, including the undersides of leaves and stems.

The benefits offered by the electrodynamic spraying system are summarized as follows:

- Droplets produced are of a controlled size within a narrow spectrum. Droplet size is determined by product formulation, nozzle design, and applied voltage.
- The high velocity of droplets and their electrical charge, which makes them mutually repellent, help eliminate drift and make spraying practicable under a wide range of wind and temperature.
- Droplet distribution on the plant is excellent with both leaf surfaces and stems getting even coverage.
- Virtually all of the spray reaches and stays on the target plant. Practically none falls on the soil or escapes into the general environment.
- Little energy is used. Although operating voltages are high — around 25,000 V — currents are so low (2-3μA) that there is no operator hazard. Four standard U2 batteries will power the sprayer for 60 hours.
- There are no moving parts so mechanical maintenance is eliminated.
- The ultralow volume application can be as low as 0.5 liter/ha. Because a special oil-base formulation is used, the droplets evaporate much more slowly than those from a water-base spray.
- Because the product is supplied ready for use, measuring and mixing are unnecessary.

The system is capable of being applied to hand-held, tractor-mounted, and aerial sprayers. So far we have concentrated on hand-held equipment. The first commercial application will be applying insecticides to cotton. Research work on the use of herbicides is in progress.

# PANEL DISCUSSION: NEW HERBICIDES AND APPLICATION TECHNIQUES

## NEW USES OF MOLINATE COMBINATIONS AND APPLICATION TECHNIQUES

S. Y. C. Soong

In addition to control of grasses by molinate alone, uses of combinations have been successfully developed for broader spectrum weed control.

*Molinate/propanil: premixed or tank mixed.* Molinate promotes the penetration of propanil, giving more complete contact control. If the rice field is reflooded within 48 h, molinate residue will control germinating grasses.

*Molinate/thiobencarb: premixed granular or emulsifiable concentrate at 2 + 2 kg ai/ ha for water-seeded rice.* A lower rate of thiobencarb is safer for rice and the weed spectrum is widened, especially on *Leptochloa* spp., *Scirpus mucronatus,* and *S. maritimus.*

Application techniques for molinate include premixing emulsifiable concentrate with dry soil or sand and application via water.

Stauffer Chemical Company, Mountain View Research Center, 1195 West Fremont Avenue, Sunnyvale, California 94087, USA.

## DISCUSSION

OBIEN: Dr. Seth, because the particles are positively charged, what do you think is the hazard involved in the application process?

*SETH:* If the operator directs the spray toward his body, then obviously he will be sprayed, but thedesign of the machine prevents the spray droplets from moving toward him. With very early models, when spraying was not done carefully, we did observe operator contamination, but this was taken into account in design modifications and we can almost completely eliminate operator contamination. But clearly, how you hold the machine is important.

OBIEN: You didn't show that the droplets are attracted to the soil. All the slides showed them attracted to the plant. From this, we have the impression that the sprayer can't be used for preemergence herbicides.

*SETH:* We have done work on preemergence compounds. It can be used. The droplets go to the first target. If you are using it to treat at preemergence where there is no vegetation, then all the droplets go to the ground.

OBIEN: Will the carrier be cheaper or more expensive than the chemical?

*SETH:* The carrier can't be water so it can't be as cheap as water. It will cost money. This machine avoids the need to have 500 liters water. You will spray with 0.5 or 0.75 liter. The cost of the formulation will depend on the purpose for which it is used. The carriers are largely different kinds of oil. They are not as cheap as water, but the volume required is so small that the cost difference might not be dramatic.

OBIEN: Because the product is formulated by your company, then we cannot use any other compound except those formulated by your company.

*SETH:* The company is giving very serious consideration to that matter. Clearly, my company cannot supply the full range of products that the farmer needs. In that situation we will have to think very hard how we develop this machine.

MUKHOPADHYAY: Dr. Menck, you said that bentazon + MCPA can control *Cyperus rotundus* effectively. Do you mean that you can prevent the reappearance or regeneration of *C. rotundus?*

*MENCK:* These are our first results. I mentioned we have to do split applications. With one application we do not get good results. We are now looking at the tubers to see if they regrow or not. So far we know that there is some influence on the tubers if there is connection between the different tubers in the soil. If there is no connection or a poor connection, you will not kill all the tubers.

COX: Dr. Seth, you are considering the use of MCPA in rice with the electrodyne sprayer. This is fine if the broadleaf weeds are above the crop, but if the rice is above the broadleaf weeds then surely the electrostatic charges fall upon the first plant that interferes between the point of release and the ground. Then you are going to get more MCPA on the rice than on the broadleaf weeds.

*SETH:* The current method of using MCPA or 2,4-D is to apply it fairly early, 4 or 6 days after transplanting. We did compare 4, 9, and 24 days and there are differences. With early application you do get control of *Echinochloa* species so we are not just talking about control of broadleaf weeds and sedges. Most of the work we have done so far has been with insecticides — the pyrethroids in cotton. We have over the last 1 ½ years become interested in herbicides. There is still quite a lot to learn. In trials that we have done we did no coverage work. There is the need to develop formulations. There is the need to do coverage work. There is the need to do work on timing. There is the need to see what sort of charge one needs to carry for rice application. There is a long way to go. What I wanted to show you today is the direction in which application technology is moving as far as both the small and the big grower are concerned. I think we are making a leap forward in application technology. We have reached that stage now. We are going to be jumping ahead rather than walking forward.

WIRJAHARDJA: I want to know if you have data on the degree of degradation of various compounds. There is a problem with pesticides. The Institute of Ecology in Bandung made a study taking samples from the whole of Indonesia to determine the content of pesticides in water. The content of pesticide in rice is low, but in cooked rice the pesticide content is high. That means that in the water the pesticide is high. Mostly with taro in Indonesia this is high. After *Imperata cylindrica* has beeneradicated with glyphosate, the perennial broadleaf weeds. which are more difficult to control, will dominate the area. This is the case in the southern part of West Java.

MATSUNAKA: The selectivity mechanism of bentazon comes from the hydroxylation at the 6 position, and after that combination occurs with glucose. This property of the grasses and some cultivars of soybean is fundamental for selectivity.

The mode of action of oxadiazon is similar to the diphenyl ethers. The herbicide is absorbed by the weed seeds and they are killed in the presence of light. In the absence of light, the weed seeds are not killed — there is no activity. With the shaker bottle, the activity of oxadiazon is unstable when the field is not leveled — when there is soil above the water level. The soil should be leveled before oxadiazon is applied.

SCHREIBER: It seems to me that there has been a lot of discussion about the time of germination and the length of control desired. I would like to ask the panel, as a group. if there is any effort being made to extend the activity of some of these or other materials for a longer period — for full season weed control?

*SOONG:* With molinate we have tried several experimental granular formulations. One gives good protection upon the release of the active ingredients. Dr. Seaman applied this granular formulation to dry soil on top of the soil surface without incorporation. The field was flooded 9 days later. Excellent control was achieved. If a conventional granular formulation had been used, maybe 70% of the molinate would have volatilized. We have tried linseed oil coating. which also gives a longer period for release. Unfortunately, these formulations are expensive.

SMITH: We have been working cooperatively with one of our USDA labs in using an alginate formulation of molinate. These are small wet granules that can be sprayed through a conventional spray system or broadcast. We have looked at these in relation to molinate. oxadiazon, and some other herbicides and it appears that we can increase the persistence or longevity of some of these herbicides and perhaps reduce the rates that are required in the initial application. This technology is early and it will be some time before it is developed far enough to really see if it has a practical application.

*MENCK:* We tried to have a two-phase granular formulation for bentazon — fast release and slow release — but it is too expensive to develop.

SCHREIBER: What was the basis of the formulation? Was it starch encapsulated?

*MENCK:* No. I do not know exactly.

SCHREIBER: We found that starch encapsulation completely eliminated volatilization and photodecomposition. Another interesting aspect is that there seem to be a lot more combination treatments. It is possible to formulate some of these materials with two or possibly three chemicals combined in the same granule. You can mix the various granules for fast release, moderate release, and slow release. You can extend the period of release as you desire. This, again, is in the developmental stage. This may have some application, particularly in some of the rice cultures that we have been talking about.

SETH: Does encapsulation help with selectivity?

*SCHREIBER:* Yes. We have been able to reduce the concentration used in some cases. but we have also been able to change the selectivity of some of the compounds mainly because we don't have to start at extremely high concentrations. We can start at a lower concentration rate and have it extended fora longer period. We all know that selectivity is based on a rate or a concentration and if you can start at a lower concentration you have fewer problems. It doesn't take much herbicide to kill a weed. It is a matter of getting it at the right time at the right place.

MOODY: Dr. Schumacher, you indicated the possibility of using glyphosate interrow with a shield. Do you have to have direct contact of the weed with the herbicide through the wick?

*SCHUMACHER:* Yes.

MOODY: The problem that I foresee is how you keep the wick off the soil. How do you get direct contact when you use the shield?

*SCHUMACHER:* You have to use gauge wheels or some kind of mechanism to keep the shield and the rope above the soil. It is a matter of spacing. They have been using this successfully in the US for the control of *Cynodon dactylon* and *Agropyron repens* in soybean by using space or gauge wheels to keep the shield and the wick above the ground, but still in contact with the weeds. The shield keeps the herbicide off the crop.

MOODY: We have heard a lot about preemergence herbicides, but is there any thought about moving in the direction of early postemergence treatments? Frequently, when I travel around Asia, the farmers ask how you know a preemergence herbicide works. There are no weeds present. They want to see weeds. They want to see a rapid kill. Is there any thought among the companies of moving in this direction?

*SOONG:* In the past decade in the US, industry has been influenced by weed scientists who have said that the injury caused by the early infestation of weeds is irreversible, so we have concentrated on preemergence treatments. Now, industry has the chance to develop early postemergence treatments, especially after several grass postemergence herbicides hit the market.

*SETH:* This is a perennial issue. I think the problem from a company's point of view is that the established market — Europe and the US — is geared to using preemergence herbicides and it is only in special situations people are willing to look at postemergence herbicides. Over the last 4 or 5 years, an interesting group of herbicides has appeared in the market. All are early postemergence grass killers that are highly selective in broadleaf crops. If these herbicides are successful, and there is no reason why they should not be, there will be a move away from preemergence herbicides to early postemergence treatments, and this is what is going to benefit farmers in Asia and Africa because they do not have sophisticated equipment to spray preemergence herbicides and incorporate them at the right depth at the right rate at the right time. They want something that they can spray when the weeds are there and they can see the effects quickly. I see change coming in the emphasis in 10 or 15 years when we are going to be looking more and more at postemergence herbicides, particularly for this part of the world.

SMITH: With respect to the evolution of herbicides in the southern US, initially the farmers were reluctant to use the preemergence or preplant incorporated treatments we had available because they wanted to see the weed situation. We developed propanil and the farmers could actually see the weed situation before they had to spend their money. Now, farmers want herbicides that they can apply preplant incorporated. We are having tremendous pressure from the farmer groups to provide herbicides that they can apply preplant. A lot of this has evolved from the fact that they have had this development in other crops, e.g., soybean and cotton, where they use preplant incorporated treatments. I think that they are pretty well resigned to the fact that they are going to have weed problems regardless of how long they use herbicides. We may see that situation turning the other way over time.

SCHREIBER: Do we need the degree of control that we are looking for all the time? If we could reduce the vigor of a plant, if we could reduce the potential to reseed, do we actually have to kill the plant completely? Do we have to have an absolutely clean field if we know what the degree of competition is going to be with a specific species? If we can keep it from going to seed, if we can stunt it enough so that the crop grows and yields well, can we come in with a nonselective material after harvest?

*MENCK:* I think it depends on the weed species. It is not necessary to kill all the weeds because 2 or 3 weeds/$m^2$ will not give any yield reduction, but if you have some special weeds that prevent harvesting or you get poor quality of the harvested product, then you need to look at the special weed problem. Maybe then you have to control every weed per square meter.

We are looking for herbicides that can be used postemergence, but some of them have no soil activity and, because weeds germinate at different times, you have to apply the herbicide two, maybe three, times. We are looking for herbicides that can be applied postemergence, but have soil activity, or to combine different herbicides, one with leaf activity and the other with soil activity, for one application.

*SOONG:* Dr. Matsunaka mentioned that in Japan they don't want any weeds in their rice because they can afford a clean rice field. The farmer does not want to be known as a lazy farmer.

MATSUNAKA: 1 mentioned three types of farmers: a) the best farmer does weeding before he finds out what the weeds are, b) the ordinary farmers weed just after they find out what the weeds are, and c) the lazy farmers do nothing after finding what the weeds are. The usual farmer in Japan is the ordinary farmer. He wants to use herbicide after finding out if there are weeds. If there are no weeds, he needs no herbicide. This results in a saving of material and reduces the environmental problem. I think we are going to need postemergence herbicides. This should be the tendency for the new technology. I want to appeal to industry to make a second propanil or a second bentazon.

*SETH:* Dr. Matsunaka has introduced to us the fourth type of farmer — the clever farmer. I think we are going to see this more and more in the future. Weed technology is increasingly becoming weed science and a farmer will need to be much more sophisticated in what he chooses for a given job. We will have to work very closely together to bring the farmer along with us so that he appreciates the value and need for using these specialized products for a specialized job.

MATTHEWS: The discussion so far has been leveled more at the advanced nations than the developing nations and yet, when we look at the developing nations, at this moment less than 10% of the world's herbicides are used there. The discussion this morning centers largely on where we have water control and only about 30% of the world's rice. I would like the panel to give me some indication how they are going to conquer this world market or increase the use of herbicides in the least developed countries, particularly for rice. What herbicide are we going to use when the rice is broadcast? I think this is one area where industry should direct more of its efforts.

*MENCK:* I mentioned one combination of bentazon that we are developing for upland rice this year. We are using low rates of bentazon. That means that the price will not be so high, even with the small addition of dicamba.

*SOONG:* As everybody knows, developing a new compound costs at least $25 million and takes about 10-12 years if you are lucky. With the market in the developing countries, frankly I don't think any chemical company will aim to develop a new compound for that market, but we do try our best with whatever we develop for other uses. We adjust the technology or use whatever combinations will be suitable for the prevailing conditions.

*SETH:* My personal view is that it would be naive of the companies to think that they can change the situation single-handedly. What is needed is a joint effort between international organizations, the national governments with their resources, and industry. Given the present situation, it is not profitable for the companies to develop a new product primarily for the developing countries, but with the electrodyne sprayer we have given priority to the hand-held machine because we believe this is an invention that meets the needs of the small farmer immediately. Dr. Menck mentioned low rate combinations. The ideas are there. We don't have to invent new technology to benefit the farmer that Dr. Matthews is thinking about. The biggest problem is of extending the knowledge to him, doing it so that there is a little bit of profit for the industry. After all, industry is not a philanthropic organization. Industry operates on profit motives. You show us the profit in a job and we will be after you.

DE DATTA: If you have a good product it will move just as fast in the developing countries. I think that the sale of butachlor and thiobencarb is quite substantial in the developing countries and it will only grow over time. What is needed is a product to increase rice yields in rainfed conditions. We do not have appropriate herbicides or herbicide combinations to handle the possibility of increased rice production by dry seeding. The market will not grow unless we have a product. If the product is good, whether it is in developing or developed countries, it will move.

*KIMURA:* Thiobencarb has a moderate nature between butachlor and molinate. It is absorbed from the root or partly by the leaf. In combination with other products it is effective in rainfed cultivation. We are now making efforts to decrease the production cost and to make new combination products.

*SCHUMACHER:* We do have a rice screening program, but we have not been as fortunate in the rice area as some of our competitors or as we have been in other areas, but we are actively looking for new products.

DE DATTA: We are not telling you to develop herbicides specifically for developing countries but only that there is a large rice area. If you have a good product you will be surprised what the market possibilities are. Butachlor and thiobencarb are examples of what has happened. I think these have moved faster in the developing countries than in the developed countries.

# TAXONOMY AND DISTRIBUTION OF *ECHINOCHLOA* SPECIES WITH SPECIAL REFERENCE TO THEIR OCCURRENCE AS WEEDS OF RICE

P. W. Michael

About 50 species (including subspecies and varieties) of *Echinochloa* are listed according to their region of origin. Three varieties, namely *E. crus-galli* (L.) Beauv. var. *bealananensis* A. Camus, *E. crus-pavonis* (H. B. K.) Schult. var. *rostrata* Stapf, and *E. zelayensis* (H. B. K.) Schult. var. *macra* Wieg., have been raised to specific status. Separate tentative keys for the identification of the annual and perennial species are given followed by notes on the species most widespread and of greatest significance in rice fields throughout the world. Some taxonomic problems are discussed and lectotypes have been designated for *E. glabrescens* Munro ex Hook.f., *Panicum crus-galli* L., and *P. phyllopogon* Stapf.

The genus *Echinochloa* includes a number of the most important weeds occurring in rice throughout the world. There are about 50 species, a few of which have not yet been described. The genus embraces plants that are well adapted to wet conditions and often grow in water throughout their life cycle. I believe that any of the species, even those not already documented as weeds of rice, surely occur in rainfed rice if not in irrigated rice in various parts of the world.

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Therefore, it is appropriate to present a complete list of species (including subspecies and varieties) grouped by region of origin and followed by tentative keys to their identification. Keys have been prepared for annual and perennial species. I have given attention to well-known synonyms, the misapplication of names, and other taxonomic problems in this preliminary treatment.

Previous treatments of the genus *Echinochloa* and of Panicum sp., now transferred to *Echinochloa,* that have been most helpful in the preparation of this paper are those of Bor (1960, 1970), Bosser (1969), Gould et al (1972), Harker and Napper (1960), Hitchcock (1920), Hutchinson and Dalziel (1936), Kossenko (1947), Martinez Crovetto (1942), Napper (1965), Ohwi (1942, 1962), Pirola (1965), Stapf (1899, 1934), Vasconcellos (1954), Vickery (1975), Wiegand (1921), and Yabuno (1966, 1975). I have also freely used information available in my previous papers — Michael and Vickery (1975, 1980) and Michael (1973, 1978, 1980).

## *ECHINOCHLOA* SPECIES, SUBSPECIES, AND VARIETIES LISTED BY REGION OF ORIGIN

### *World Tropics*

†*E. colona* (L.) Link

### *Eurasia*

†*E. crus-galli* (L.) Beauv. ssp. *crus-galli* var. *crus-galli*

### *Asia (including Malesia[1])*

*E. caudata* Roshev.
†*E. crus-galli* (L.) Beauv. ssp. *crus-galli* var. *praticola* Ohwi
†*E. crus-galli* (L.) Beauv. ssp. *hispidula* (Retz.) Honda var. *hispidula*
†*E. crus-galli* (L.) Beauv. ssp. *hispidula* (Retz.) Honda var. *austro-japonensis* Ohwi
†*E. frumentacea* Link
†*E. glabrescens* Munro ex Hook. f.
†*E. oryzoides* (Ard.) Fritsch
†*E. phyllopogon* (Stapf) Koss.
†*E. picta* (Koen.) Michael
†*E. praestans* Michael
†*E. utilis* Ohwi et Yabuno

### *Australia*

*E. elliptica* Michael et Vickery
*E. inundata* Michael et Vickery
*E. kimberleyensis* Michael et Vickery
*E. lacunaria* (F. Muell.) Michael et Vickery

[1] Embraces Southeast Asia, Indonesia. and New Guinea and adjacent islands.
†The species marked with a dagger have spread outside their regions of origin and all of these except *E. praestans,* recently recorded from Northern Australia, occur as weeds in rice.

*E. macrandra* Michael et Vickery
*E. telmatophila* Michael et Vickery
*E. turneriana* (Domin) J. M. Black

*Africa (including Madagascar)*

*E. bealananensis* (A. Camus) Michael stat. nov., originally published as *E. crus-galli* var. *bealananensis* by Camus in *Bull. Soc. Bot. France,* 107, 1960, p. 208.
*E. brevipedicellata* (Peter) Clayton
*E. callopus* (Pilger) Clayton
*E. haploclada* (Stapf) Stapf
*E. holubii* (Stapf) Stapf
*E. jubata* Stapf
*E. lelievrei* (A. Chev.) Berhaut
*E. madagascariensis* Mez
*E. obtusiflora* Stapf
† *E. pyramidalis* (Lam.) Hitchc. et Chase
*E. rostrata* (Stapf) Michael stat. nov., originally published as *E. crus-pavonis* var. *rostrata* by Stapf in *Flora Capensis* (ed. W. T. Thistleton-Dyer), Vol. 7, 1899, pp. 396-7.
*E. rotundiflora* Clayton
*E. senegalensis* Mez
*E. subverticillata* Pilger
† *E. stagnina* (Retz.) Beauv.
*E. ugandensis* Snowden et C. E. Hubbard
*E. verticillata* Berhaut

*North America*

*E. holcijormis* (H. B. K.) Chase
*E. macra* (Wieg.) Michael stat. nov., originally published as *E. zelayensis* var. *macra* (spelt *macera)* by Wiegand in *Rhodora 23,* 1921, p. 54.
† *E. microstachya* (Wieg.) Rydb.
*E. muricata* (Beauv.) Fern.
*E. oplismenoides* (Fourn.) Hitchc.
*E. paludigena* Wieg.
*E. walteri* (Pursh) Heller
*E. zelayensis* (H. B. K.) Schult.

*South America*

† *E. crus-pavonis* (H. B. K.) Schult
*E. helodes* (Hack.) Parodi
*E. polystachya* (H. B. K.) Hitchc. var. *polystachya*
*E. polystachya* (H. B. K.) Hitchc. var. *spectabilis* (Nees) Martinez Crovetto

*E. elliptica* in Australia, *E. bealananensis* in Madagascar, *E. holubii* in Southern

Africa (including Madagascar), and *E. helodes* and *E. polystachya* in South America have been recorded as rice weeds in their regions of origin. Little information is available on the occurrence of many of the native African species. I have not been able to establish the identity of the plant recorded as Baronet grass in Louisiana (Williams 1956).

TENTATIVE KEY TO THE ANNUAL SPECIES OF *ECHINOCHLOA*

N.B. Spikelet length measurements do not include awns.

| | | |
|---|---|---|
| 1. | Spikelets with small globular callus below glumes. | *E. callopus* |
| 1. | Spikelets without small globular callus below glumes | 2. |
| 2. | Spikelets obtuse. | 3. |
| 2. | Spikelets acute. | 4. |
| 3. | Spikelets 2.2-3.5 mm long. | *E. obtusiflora* |
| 3. | Spikelets 3.8-4.8 mm long. | *E. rotundiflora* |
| 4. | Whole plant pubescent-villous. | *E. verticillata* |
| 4. | Vegetative parts essentially glabrous except for occasional hairy leaf sheath, base of leaf blade, and ligular region. | 5. |
| 5. | Spikelets 3-5 mm long. | 6. |
| 5. | Spikelets less than 3 mm or greater than 5 mm long. | 24. |
| 6. | Ligule a line of bristles or fine short cilia. | 7. |
| 6. | Ligule absent, or the ligular region bears a few cilia or fine pubescence. | 9. |
| 7. | Leaf blades narrow. no more than 5 mm wide. Panicle erect, linear. | *E. ugandensis* |
| 7. | Leaf blades broad, up to 10 mm or more wide. | 8. |
| 8. | Numerous long bristles at nodes of inflorescence. Panicle spindle-shaped, up to 15 cm long. Spikelets narrowly elliptical. Awns of lower lemma up to 30 mm long, of second glume up to 10 mm long. | *E. elliptica* |
| 8. | No long bristles along main axis or branches of inflorescence. Panicle narrow, linear. Spikelets broadly ovate or ovate-elliptical. | *E. turneriana* |
| 9. | Spikelets broadly ovate, crowded along the often incurved branches of the inflorescence. Fertile florets and caryopses markedly humped. | 10. |
| 9. | Fertile florets and caryopses not markedly humped. | 11. |
| 10. | Spikelets brownish at maturity. Commonly awnless, sometimes awned. Caryopses brownish. | *E. utilis* |
| 10. | Spikelets pale green at maturity, awnless. Caryopses whitish. | *E. frumentacea* |
| 11. | Essentially obligate weeds of rice. Close tufted erect habit. Greatly resembles rice before flowering. | 12. |
| 11. | Not obligate weeds of rice, but all growing in wet places and often occurring in rice. Plants more or less | |

spreading at base. 14.
12. Spikelets 3.5-5 mm long. 13.
12. Spikelets 3-3.5 mm long. Lower lemma convex, hard, and shiny. Awnless or less frequently awned. Occasionally found on banks and fallow land where it assumes a spreading habit. *E. glabrescens*
13. Spikelets broadly ovate to ovate. Inflorescence hanging almost horizontal at maturity. Spikelets nearly always awned. Awns sometimes as long as 50 mm. Caryopses ovate, embryo about 0.7 the length of the caryopsis. *E. oryzoides*
13. Spikelets ovate-elliptical. Inflorescence more or less erect at maturity. Spikelets awned or awnless. Lower lemma often convex. hard, and shiny. Collar region of leaves often with tufts of hairs. Caryopses oblong, embryo often 0.9- or more the length of the caryopsis. *E. phyllopogon*
14. Lemma and palea of fertile floret acute or acuminate with stiff tip. Panicle spreading, erect. Caryopses yellowish. 15.
14. Lemma of fertile floret with withering tip sharply differentiated from the body of the lemma. Panicle erect or nodding. 16.
15. Spikelets 3-3.5 mm long. *E. microstachya*
15. Spikelets 3.5-4 mm long. *E. muricata*
16. Spikelets always awnless. *17.*
16. Spikelets short- or long-awned. Sometimes mostly awnless, but if so, there are always a few awned spikelets at the ends of the branches. *18.*
17. Long bristles absent from main axis and branches of the inflorescence. Spikelets finely pubescent. Palea of lower floret absent or poorly developed. *E. zelayensis*
17. Spikelets with short bristles. Bristles present at base of branches of inflorescence which are more or less whorled. Lower floret staminate. *E. subverticillata*
18. Inflorescence strongly drooping at maturity. sometimes bending over as much as 180°. Spikelets crowded with short, curved awns, mostly 3-10 mm long, but can be up to 15 mm long. *E. crus-pavonis*
18. Inflorescence often nodding but not strongly drooping at maturity. *19.*
19. Spikelets narrowly elliptical, awns of lower lemma almost always up to 40 mm long. Awn on the second glume up to 7 mm long or longer. *20.*
19. Spikelets broadly ovate to elliptical, never narrowly elliptical. Almost awnless, short-awned or long-awned. *21.*

| | | |
|---|---|---|
| 20. | Spikelets up to 5 mm long. Bristles on spikelets prominent and spreading. Leaf sheaths with prominent bristles and pubescence. | *E. walteri* |
| 20. | Spikelets up to 4.2 mm long. Bristles on spikelets not spreading. Leaf sheaths glabrous. | *E. telmatophila* |
| 21. | Spikelets ovate-elliptical up to 5 mm long. Bristles on main axis and/or branches of inflorescence few or absent. Inflorescence rarely pyramidal. Anthers 1 mm long or longer. | *22.* |
| 21. | Spikelets broadly ovate, ovate, or ovate-elliptical, 34 mm long. Long bristles abundant along main axis and branches of inflorescence. Inflorescence pyramidal or not. Anthers generally less than 1 mm long. | *23.* |
| 22. | Spikelets 3.5-5 mm long. Panicle almost linear, up to 30 cm long with close branches rarely more than 6 cm long. Lower floret neuter or sometimes staminate. | *E. inundata* |
| 22. | Spikelets 34 mm long. Panicle up to 40 cm long spreading at base with more or less erect, often widely spaced branches up to 14 cm long. Lower floret staminate. | *E. paludigena* |
| 23. | Spikelets broadly ovate or ovate, awnless except at the ends of branches, short-awned or long awned. Caryopses ovate. Panicles of variable length, more or less erect, often pyramidal, sometimes nodding, branches never obviously whorled. Long panicles, often with secondary branches on lower primary ones. | *E. crus-galli* ssp. *crus-galli* var. *crus-galli* |
| 23. | Spikelets ovateelliptical, short or long awns. Caryopses more or less oblong. Panicles rarely pyramidal, erect or nodding, branches often whorled, more or less erect except for the lowermost ones. | *E. crus-galli* ssp. *crus-galli* var. *hispidula* |
| 24. | Spikelets 5 mm long or longer. | *25.* |
| 24. | Spikelets 3 mm long or shorter. | *30.* |
| 25. | Spikelets long-awned. Ligule a line of bristles or cilia. | *26.* |
| 25. | Spikelets awnless or awned. Ligule absent, rarely a line of short cilia. | *28.* |
| 26. | Awns up to 25 mm long. Anthers about 1 mm long. Possibly a perennial. | *E. bealananensis* |
| 26. | Awns up to 90 mm long. Anthers more than 1.5 mm long. | *27.* |
| 27. | Anthers 1.5-2 mm long. Palea of lower floret about | |

| | | |
|---|---|---|
| | half the length of the lemma, sometimes absent. Lower floret neuter. | *E. kimberleyensis* |
| 27. | Anthers 2-2.8 mm long. Palea of lower floret about length of lemma. Lower floret staminate. | *E. macrandra* |
| 28. | Spikelets awnless, ovate, very finely pubescent. Main axis and short branches of inflorescence without bristles. | *E. lacunaria* |
| 28. | Spikelets awned. | *29.* |
| 29. | Spikelets elliptical with fine, often very sparse bristles on the branches of the narrow, more or less erect panicle. Awns usually about 10 mm long. Palea of lower floret sometimes absent. Ligule rarely a line of short hairs. | *E. oplismenoides* |
| 29. | Spikelets ovate, inflorescence hanging more or less horizontally at maturity. Awns up to 50 mm long. Obligate weed of rice. | *E. oryzoides* |
| 30. | Palea of lower floret absent or poorly developed. | *31.* |
| 30. | Palea of lower floret fully developed. | *32.* |
| 31. | Spikelets dense with awns up to 45 mm long. Panicle up to 20 cm long. | *E. caudata* |
| 31. | Spikelets awnless or with very short awns. Panicle short and narrow. | *E. macra* |
| 32. | Ligule a line of short cilia. | *33.* |
| 32. | Ligule absent. | *35.* |
| 33. | Spikelets elliptical with awns 10-15 mm long. Panicle dense with short branches about 25 mm long. | *E. jubata* |
| 33. | Spikelets awnless. | *34.* |
| 34. | Spikelets crowded in regular rows. Panicle branches erect, up to 40 mm long, closely appressed to main axis. Possibly perennial. | *E. senegalensis* |
| 34. | Spikelets irregularly grouped along the branches. Panicle branches somewhat spreading, up to 30 mm long. | *E. brevipedicel-lata* |
| 35. | Spikelets broadly ovate to ovate. | *36.* |
| 35. | Spikelets ovate-elliptical to elliptical, usually with short awns. Inflorescence close, short with more or less erect branches, but rarely very long, up to 28 cm with secondary branches on lower primary ones. | *E. crus-galli* ssp. *hispidula* var. *austro-japonensis* |
| 36. | Spikelets with short curved awns, crowded in clusters along the primary branches, frequent secondary branches. Inflorescence with stout main axis, often about 40 cm long. | *E. rostrata* |
| 36. | Spikelets awnless. Inflorescence with thin main axis, | |

never more than about 15 cm long. *37.*

37. Spikelets regularly arranged in rows. First glume regularly half the length of the spikelet. Caryopses whitish. Long bristles mostly absent from main axis and branches of inflorescence, occasionally a few scattered along the branches and clustered at the nodes. *E. colona*

37. Spikelets irregularly arranged. First glume about one-third length of spikelet. Caryopses brownish. Long bristles along main axis and branches of inflorescence present or absent. *E. crus-galli* ssp. *crus-galli* var. *praticola*

TENTATIVE KEY TO THE PERENNIAL SPECIES OF *ECHINOCHLOA*

N.B. Spikelets length measurements do not include awns.

1. Spikelets more than 3 mm long, awned or awnless. Ligular bristles always present and obvious, especially in the lower leaves. Lower floret often staminate. Usually long creeping rhizomes or stolons. Culms often up to 4 m long. Often growing in deep water. *2.*
1. Spikelets 2-3 mm long, short-awned. Ligular bristles often absent. Tall, close-tufted. *E. haploclada*
2. Whole plant hairy with narrow leaves about 6 mm wide. Culms less than 1 m tall. *E. madagascariensis*
2. Leaf blades essentially glabrous, but sometimes with prominently hairy sheaths. *3.*
3. Spikelets awnless or with short awns or long cusps. *4.*
3. Spikelets awned, awns often long. *5.*
4. Spikelets often woolly-ciliate. Branches of inflorescence closely appressed to main axis and distant. Culms less than 1 m tall. *E. holubii*
4. Spikelets crowded, very finely pubescent or for the most part glabrous, with short bristles and short awns or long cusps. Inflorescence often more than 40 cm long. Secondary branches often closely appressed to primary branches of inflorescence. Plants often up to 4 m tall with stout culms. *E. pyramidalis*
5. Spikelets elliptical or lanceolate. *6.*
5. Spikelets obovate, broadly ovate, or ovate. *9.*
6. Spikelets 6 mm long or longer. *7.*

| | |
|---|---|
| 6. Spikelets 3-5 mm long. Floating, often with long culms. | *8.* |
| 7. Spikelets elliptical, about 2 mm wide. Second glume inserted 1 mm above the base of the first glume. Lower glume extending only slightly beyond base of lower lemma. Lower palea absent. | *E. holciformis* |
| 7. Spikelets lanceolate, 1.7-2 mm wide. Second glume inserted at the same level as first glume. Lower glume three-fourths length of spikelet. Lower palea present. | *E. helodes* |
| 8. Spikelets 3-5 mm long arranged in 3 or 4 rows along the branches of the inflorescence. Lower palea present. | *E. stagnina* |
| 8. Spikelets 4-5 mm long arranged in 1 or 2 rows along the branches of the inflorescence. Lower palea absent. | *E. lelievrei* |
| 9. Spikelets obovate, usually more than 5 mm long. Awns 3-30 mm long. Lower floret staminate. Culms up to 3 m tall. | *10.* |
| 9. Spikelets broad-ovate or ovate, less than about 4 mm long. Awns rarely frequent and never exceeding 15 mm. | *11.* |
| 10. Leaf sheaths glabrous. | *E. polystachya* var. *polystachya* |
| 10. Leaf sheaths hairy. | *E. polystachya* var. *spectabilis* |
| 11. Spikelets finely pubescent. Ligular bristles obvious in all leaves. Stout culms, up to 3.6 m tall with broad leaves, uppermost leaf blades as much as 20 mm wide. | *E. praestans* |
| 11. Spikelets with bristles up to 0.5 mm long. Ligular bristles often not apparent in uppermost leaves. Culms generally less than 1 m, uppermost leaf blades not exceeding 10 mm wide. | *E. picta* |

## WIDESPREAD ECHINOCHLOA SPECIES

The most widespread of the *Echinochloa* species are discussed in this section. The species are ordered alphabetically, not by their importance as weeds of rice or their abundance and distribution.

### Echinochloa colona

*E. colona* is the correct spelling of the specific epithet, not *colonum.* The name is derived from the nonclassical Latin adjective *colonus-a-um,* meaning “of a colony.” This species is well known as a weed of rice in subtropical and tropical regions throughout the world. It sometimes extends beyond 30° N and 30° S lat., to the rice fields of the southern U. S. and southern New South Wales, Australia. It has also been recorded from rice fields in Sicily (Pirola 1965). The different forms of *E. colona* vary in habit, length of inflorescence, and size of spikelets. Some forms show prominent transverse purplish bands on the leaf blades.

*E. colona* has been confused with the small-spikelet *E. crus-galli* var. *praticola* and *E. crus-galli* var. *austro-japonensis.*

***Echinochloa crus-galli***

I consider that *E. crus-galli* species includes two subspecies, each with two varieties —*E. crus-galli* ssp. *crus-galli* var. *crus-galli* and var. *praticola,* and *E. crus-galli* ssp. *hispidula* var. *hispidula* and var. *austro-japonensis.*

Because of confusion over the typification of *Panicum crus-galli* L. (Hitchcock 1908, Could et a1 1972) on which *E. crus-galli* (L.) Beauv. is based, I designate as lectotype specimen 1:103 in Burser's Herbarium at the University of Uppsala, Sweden. The spikelets of this specimen are 3.2-3.5 mm long with occasional awns up to 13 mm long. This is the plant Linnaeus described as *Gramen paniceum,* spica *divisa.* Bauh. pin. 8. The designation of a neotype by Could et a1 (1972) was unnecessary. A photograph of the type of *Panicum hispidulum* (Retz.) on which *E. crus-galli* ssp. *hispidula* (Retz.) Honda is based appears in Ohwi (1962).

*E. crus-galli* var. *crus-galli* is abundant in the more temperate rice-growing areas of the world, such as parts of the Indian subcontinent, China, Japan, Iraq, Iran, Soviet Union, southern Europe, North and South America, and Australia. In Africa, it appears to be confined to North Africa, Egypt, and far-southern Africa. It is doubtful that it occurs in Madagascar.

The many forms of *E. crus-galli* var. *crus-galli* differ in overall size, size and branching of inflorescence, degree of awning and bristliness of spikelets, and in the crowding of spikelets along the branches. Because the degree of awning in some forms depends on environmental conditions, it is difficult to fit the many varietal names available (vars. *aristata, breviseta, longiseta, mitis, mutica, submutica)* to these forms. In any case, the forms often merge into each other. One form known in the Soviet Union as *E. spiralis* Vasing. or *E. crus-galli* ssp. *spiralis* (Vasing.) Tzvel., and which occurs also in New South Wales, Australia, has crowded spikelets (with or without awns) that are usually pale green at maturity. Another form confined mainly to rice fields, usually with reddish awns up to 40 mm long or longer, was wrongly referred to as *E. crus-pavonis* by Pignatti (1955) and by Pirola (1965). This long-awned form occurs in southern Russia, Iraq, California (USA), New South Wales (Australia), and in other parts of more temperate Asia. It is the form drawn as *Panicum crus-galli echinatum* by Trinius (Spec. Gram. P1. 162, 1829) from a plant grown from seed collected in the rice fields of southern Russia.

A plant from rice fields in France was originally given the provisional name *Panicum crus-galli* var. *serotinum* by Tallon (1960). Gasquez et a1 (1975) later referred to it as *E. serotina* Tall. but considered it as a form of *E. crus-galli.*

*E. crus-galli* var. *praticola* is an upland or roadside weed in far east Asia probably occurring only on the banks of rice fields. It is uncommon in Australia and the US. In subtropical and tropical regions of Asia and in East Africa, *E. crus-galli* ssp. *crus-galli* is replaced by *E. crus-galli* var. *hispidula* or var. *austro-japonensis.* Both varieties are abundant in the Pacific islands. *E. crus-galli* var. *hispidula* also occurs in coastal northern Queensland, Australia, but so far has not been observed in rice there. It is the most abundant weed of rice throughout Southeast Asia, parts of the Indian subcontinent, and Sri Lanka. It has not been positively identified in the Americas. *E. crus-galli* var. *austro-japonensis* is essentially eastern Asian, extending south from Taiwan, the Ryukyu Islands, and adjacent parts of mainland Asia to the higher, cooler parts of Southeast Asia, the Philippines, Papua New Guinea, and the Pacific Islands.

In Japan *E. crus-galli* var. *crus-galli* and var. *hispidula* seem to merge and identification may sometimes be difficult. In Asia, both varieties of *E. crus-galli* ssp. *hispidula* have often been wrongly called *E. crus-pavonis.* In Japan and Korea, long-awned forms of both subspecies belonging to *E. crus-galli* var. *hispidula* and var. *crus-galli* have been misnamed *E. caudata* or *E. crus-galli* (L.) Beauv. var. *caudata* Kitagawa. *E. caudata* is a riverine nonweedy plant confined to far eastern Siberia. The type collection of immature plants, from rice fields in Italy, originally described by Pollacci (1908) as *Panicum erectum* [syn. *E. crus-galli* ssp. *erecta* (Pollacci) Cif. et Giac., *E. erecta* (Pollacci) Koss] appears to represent *E. crus-galli* ssp. *hispidula.* I suspect, however, that Italian authors apply this name to a form of *E. phyllopogon.*

### *Echinochloa crus-pavonis*

*E. crus-pavonis* often occurs in abundance in all South American countries where rice is grown, and in southern U. S. and Mexico. It has only recently been found in rice in New South Wales, Australia. It also occurs in New Zealand although rice is no longer grown there. There has been no positive identification of *E. crus-pavonis* from Asia or Europe. It appears to be remarkably uniform. In Africa, *E. rostrata* is often referred to as *E. crus-pavonis* or as a variety of it, but I consider it a distinct species.

### *Echinochloa frumentacea*

*E. frumentacea* is a cultivated derivative of *E. colona.* This name and other names based on it or on *Panicum frumentaceum* Roxb. have often been misapplied to *E. utilis* (Ohwi 1962, Yabuno 1971). As far as I know it is weedy in rice only in India where it originated, and it is occasionally weedy in unirrigated lands elsewhere, as in coastal Queensland, Australia.

### *Echinochloa glabrescens*

Bor (1960) typified *E. glabrescens* on the basis of specimens Wallich 8687 at Kew. Examination of the Wallich specimens, however, indicates that they include specimens of *E. crus-galli* ssp. *hispidula* and *E. oryzoides* as well. Wallich 8687B then is chosen as lectotype. The original and duplicate of this number are both *E. glabrescens.*

*E. glabrescens* extends from the Indian subcontinent through mainland Southeast Asia and China to Taiwan, Korea, southern Japan, and parts of the Philippines. It has also been recorded in Togo in West Africa (Scholz 1978).

In Japan, the synonyms *E. crus-galli* (L.) Beauv. var. *formosensis* Ohwi and E. *crus-galli* (L.) Beauv. var. *kasaharae* Ohwi have been commonly used for *E. glabrescens. E. micans* Koss. is another synonym.

### *Echinochloa microstachya*

Although *E. microstachya* is native to the U.S., I have not found any record of its occurrence in rice there. But I think it is highly likely that it occurs at least in California rice fields. It is locally abundant and grows vigorously in rice in southern New South Wales, Australia. It has also been collected in Europe, South Africa, and New Zealand.

### *Echinochloa oryzoides*

*E. oryzoides* occurs in rice-growing areas throughout the world and is probably the most widespread species apart from *E. crus-galli.* It occurs in the Indian subcontinent, Sri Lanka, China, Korea, Japan, Manchuria, the Soviet Union, Southeast Asia (especially the Philippines), Afghanistan, Iran, Iraq, Egypt, Argentina, Peru, Louisiana, California, Australia, and New Zealand. It probably occurs in all European rice-growing countries. (I have seen an excellent specimen in the Botanische Staatssammlung in München grown from seed collected in Italian rice fields in 1784.) Curiously, it does not seem to have been collected in rice fields in Indonesia: the only specimen I have seen is one grown in the Botanic Gardens at Bogor. *E. oryzoides* matures at about the same time as rice and may be harvested with the rice grain, especially with mechanical harvesting. *E. oryzoides* has often been overlooked, especially in Japan and the U. S. because it has been confused either with the larger-spikelet forms of *E. crus-galli* or with *E. phyllopogon.* It was collected by Urban Faurie during 1886 to 1905 in northern Honshu and Hokkaido.

Synonyms of *E. oryzoides* include *E. macrocarpa* Vasing., *E. hostii* (Bieb.) Boros ex Holub, and *E. crus-galli* (L.) Beauv. ssp. *oryzoides* de Bolós et Mascl. The invalid name *E. coarctata* has also been used. Earlier confusion over the use of the binomial *Panicum stagninum* has led to some errors. Pirola (1965) used a drawing (p. 207, Fig. 9) of *E. stagnina* (Retz.) Beauv. presented originally by Jacques-Felix (1962) for his illustration of *E. crus-galli* ssp. *oryzoides.* Incidentally, one of Pirola's two drawings of *E. crus-galli* (p. 207, Fig. 6) is actually *E. muricata* (Beauv.) Fern. taken from Hitchcock (1950).

### *Echinochloa phyllopogon*

*E. phyllopogon* is an important weed of rice in India, Burma, Nepal, China, Korea, Japan, the Soviet Union, Iran, Afghanistan, European rice-growing countries, and California, U. S. It has not been recorded from Africa, Australia, or South America. It appears to have a more temperate distribution than *E. oryzoides* with which it is often confused.

Unfortunately Stapf's type collection of *Panicum phyllopogon* at Kew, on which *E. phyllopogon* (Stapf) Koss. is based, is a mixture of *E. oryzoides* and *E. phyllopogon.* His plate (Hook f. Icon. Pl. Ser. 4,1901: tab. 2698) shows vegetative features of *E. phyllopogon* and inflorescence features of *E. oryzoides.* Stapf's brief Latin diagnosis refers only to the vegetative features, specifically to the tufts of hair in the collar region, which are quite distinctive of this annual species. Accordingly, it is appropriate to select as the lectotype the one sheet in the type collection that has vegetative material only.

Important synonyms of *E. phyllopogon* include *E. crus-galli* (L.) Beauv. var. *oryzicola* Ohwi; *E. oryzicola* (Vasing.) Vasing. and *E. oryzoides* (Ard.) Fritsch ssp. *phyllopogon* (Stapf) Tzvel. Names based on *Panicum hispidulum* Retz have been erroneously referred to as *E. phyllopogon* or its synonyms by some authors.

Yabuno, dealing with *E. phyllopogon* under the names *E. crus-galli* var. *oryzicola* (1961) and *E. oryzicola* (1966), widened our concept of it to include a range of forms. Not all the forms Yabuno describes show the distinctive vegetative features of Stapf's *Panicum phyllopogon.* He presents good evidence that an F-form (in which the lower lemma is flat and coarse) and a C-form (with convex, hard, shiny lower lemma) can be considered as belonging to the one species. The spikelets of his C-form are never awned, while the F-form has many short- or long-awned spikelets. The F-form commonly has tufts of hair at the collar region and bristly sheath margins characteristic of the form Stapf described.

### *Echinochloa picta*

*E. picta* is a variable species abundant in tropical Asia (especially in the Indian subcontinent), Sri Lanka, mainland Southeast Asia, and the Philippines. It also occurs along the east coast of Africa as far south as Zimbabwe and in some of the Pacific Islands such as in Norfolk Island, Fiji, Samoa, and Hawaii. It is uncommon in Indonesia and Papua New Guinea, but occurs on Cape York Peninsula in Australia. It has not been collected in the Americas, with the possible exception of Guadeloupe.

*E. picta* is common around the borders of rice fields. Sometimes it is the dominant weed as in the rice fields of Cagayan Province in northern Luzon, Philippines, and it is prominent in floating rice in Thailand.

*E. picta* often has transverse purplish bands on the leaf blades and has long been confused with *E. stagnina* (Retz.) Beauv. *E. picta* is not so dependent on permanent water as *E. stagnina.*

### *Echinochloa pyramidalis*

*E. pyramidalis* is abundant in the floating rice areas of tropical Africa and often occurs with *E. stagnina* as a weed in rice. It has been introduced to India and tropical America, but apparently is not a significant weed in rice outside Africa.

Yabuno (1970) pointed out that *E. pyramidalis* is unusual in the genus *Echinochloa* in that it is largely self-incompatible and thereby ensures crossbreeding. All other species examined are self-fertile.

### *Echinochloa stagnina*

*E. stagnina* is an important weed of floating rice, abundant in Madagascar and tropical Africa where, as already mentioned, it occurs with *E. pyramidalis,* It occurs in India, Vietnam, Thailand, the Philippines, and Indonesia. It occurs more frequently than *E. picta* in Indonesia, but is usually associated with deep water and is of little significance in the rice fields.

Further examination of this variable species, especially throughout Africa (including Madagascar), may lead to the identification of other taxa within it. Berhaut (1954) has already convincingly separated *E. lelievrei* from material generally known as *E. stagnina.* Yabuno (1978) has drawn attention to two strains of *E. stagnina* with different growth habits and inflorescences.

### *Echinochloa utilis*

*E. utilis,* the cultivated Japanese farmyard millet, is of only limited importance as a weed in rice, but undoubtedly it is of some significance in far-east Asia. It occurs occasionally in the rice fields of New South Wales, Australia, and the U. S. Many authors have misnamed *E. utilis,* using names based on *E. frumentacea* Link or *Panicum frumentaceum* Roxb.

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## DISCUSSION

SCHREIBER: Has any chemotaxonomy been done with the *Echinochloa* species?

*MICHAEL:* Years ago I began some work with the flavonoids in *Echinochloa* species and it proved to be very promising indeed in showing differences between species. Simple techniques can be used. Someone was telling me the other day that there is a person in the western US looking at flavonoids and coming up with the same general sorts of conclusions. My problem was that I thought it very important to find out which flavonoids and there were some difficulties. Looking ahead one might envisage that a very quick testing of seedlings could give you a very good indication as to whether it was, say, *E. phyllopogon* or *E. crus-galli.* These two species for example could be easily distinguished by a technique which takes no more than half a day.

WIRJAHARDJA: I am interested in the naming of *Echinochloa colona.* (1) Is your revision based on the law of priority or the grammatical structure of Latin. (2) Because there is a chapter in the Code of Nomenclature that says that the orthographic errors are usually retained, — is your revision of the other *Echinochloa* species based on the law of priority or on morphological, ecological and cytological studies?

*MICHAEL:* (1) Linnaeus described the plant as *Panicum colonum.* When this plant was transferred to *Echinochloa* it was called *Echinochloa colona* by Link but early this century Hitchcock, the important grass expert at the Smithsonian Institution, looking at Latin dictionaries couldn't find an adjective *colonus-a-um.* There is a Latin noun called *colonus* meaning "a farmer." Hitchcock thinking that Linnaeus was a brilliant Latin scholar decided that Linnaeus must have reduced a genitive plural. In other words he eliminated the "or" and called his species *"Panicum colonum"* meaning *Panicum* of the farmers. But it has turned out since in a study of earlier Latin dictionaries that the Latin dictionaries of the time of Linnaeus did in fact include that adjective. It was not a word used in classical Latin but a word that had been used in medieval Latin. These are other aspects to it but there seems no question at all that *colona* is correct. (2) The second question is rather complicated. For example, *E phyllopogon* takes priority over *E. oryzicola* according to the Laws of Nomenclature. Essentially, all are based on the law of priority.

# BIOLOGY OF *ECHINOCHLOA* SPECIES

T. Yabuno

Ten species of the genus *Echinochloa* were collected and investigated by the author from the biosystematic viewpoint.

Among them, *E. crus-galli* (2n = 6x = 54) and *E. colona* (2n = 6x = 54) are the most common weeds in the temperate region and in the subtropical and tropical regions, respectively.

In Japan, *E. crus-galli* var. *formosensis* and *E. oryzicola* (2n = 4x = 36) are rice mimics and companion weeds of rice. It is assumed that the annual diploid species *E. obtusiflora,* which is indigenous to West Africa, is a companion weed of *Oryza glaberrima.*

The stoloniferous perennial *E. stagnina,* distributed in the floating rice zones of Southeast Asia and tropical West Africa, and the rhizomatous perennial *E. pyramidalis,* distributed in tropical Africa, have a floating habit. The two species include various cytotypes, and their taxonomy is not yet complete. Morphological, physiological, and ecological differences among *Echinochloa* species reflect the high variability of plants of this genus and the environmental factors involved in rice culture. The East Asian cultivated species *E. utilis* — originating from *E. crus-galli* — and the Indian cultivated species *E. frumentacea* — from *E. colona* — are phylogenetically different from each other.

Many weeds show diverse and peculiar adaptations because they have long been subjected to environmental factors such as weed control and competition with crops. Basic knowledge on the classification, morphology, physiology, and ecology of specific weeds is needed for the development of superior control methods.

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Some species of the genus *Echinochloa* are known as the world's worst weeds. But plants of this genus show many variations, and the taxonomy is confused.

The 10 species of *Echinochloa,* including 2 cultivated species, collected by the author are listed in Table 1.

## *ECHINOCHLOA* SPECIES OF JAPAN

### Classification

There has been confusion in the species names of the members of the genus *Echinochloa* found in Japan (Table 2).

The Japanese species show complex variations but can be divided, by external morphology and ecology, into two annual species, one of which exists in three varieties (Table 3).

*E. oryzicola* (2n = 4x = 36) grows only in wetland rice fields throughout Japan. This species comprises two forms, the C- and F-forms, differing in the texture of the lemma of the first floret (Yabuno 1960, 1961).

*E. crus-galli* (2n = 6x = 54) has spikelets which are 2.5-4.0 mm long, and the first empty glume is 1/3-2/5 the length of the spikelet. It is remarkably variable in panicle shape and awn length, but the following three varieties can be classified in this species: var. *formosensis* occurs only in wetland rice fields in southwestern Japan and heads in mid-September. Its color is light green. The surface of the lemma of the first floret resembles that of the C-form of *E. oryzicola.* Var. *crus-galli* naturally grows in the wet areas including wetland rice fields. It is polymorphic, being variable in such characters as plant color, awn, panicle shape, spikelet size, leaf width, culm diameter, plant type, and heading time. Var. *praticola* naturally grows by the roadside or in vacant lots near dwelling houses where relative dryness usually prevails. Its leaf blades are 5-10 mm wide. Although the Japanese varieties of *Echinochloa* differ morphologically and ecologically, they have the same genome

**Table 1. *Echinochloa* species collected by the author.**

| Species | Distribution |
|---|---|
| *Echinochloa oryzicola* (Vasing.) | Japan, Korea, China, Northern India, Sri Lanka, Italy, and France |
| *E. crus-galli* (L.) Beauv. | Throughout the world, rather more plentiful in warm temperate regions than in the tropics |
| *E. colona* (L.) Link | The subtropical zone and tropics |
| *E. crus-pavonis* (H.B.K.) Schult. | Tropical South America and Africa |
| *E. obtusiflora* Stapf | West Africa |
| *E. haploclada* (Stapf) Stapf | East Africa |
| *E. stagnina* (Retz.) Beauv. | Tropical Asia and Africa |
| *E. pyramidalis* (Lam.) Hitchc. & Chase | Tropical Africa |
| *E. utilis* Ohwi & Yabuno | Cultivated in Japan, Korea, and China |
| *E. frumentacea* Link | Cultivated in India and Pakistan |

**Table 2.** ***Echinochloa*** **species of Japan.**

| Japanese name | Species name | Synonyms | Names used in error or inappropriate names |
|---|---|---|---|
| Tainubie | *E. oryzicola* Vasing. | *Panicum oryzicola* Vasing.<br>*E. crus-galli* (L.) Beauv. var. *oryzicola* (Vasing.) Ohwi<br>*E. phyllopogon* (Stapf.) Koss. ssp. *oryzicola* (Vasing.) Koss. var. *genuina* Koss. | *E. crus-galli* (L.) Beauv. var. *hispidula* (Retz.) Honda |
| Hime-inubie | *E. crus-galli* (L.) Beauv. var. *formosensis* Ohwi | *E. glabrescens* Munro ex Hook. f.<br>*E. crus-galli* (L.) Beauv. var. *kasaharae* Ohwi<br>*E. micans* Koss. | |
| Inubie | *E. crus-galli* (L.) Beauv. var. *crus-galli* | *Panicum crus-galli* L.<br>*E. crus-galli* (L.) Beauv. ssp. *genuina* (Hack) Honda var. *echinata* (Trin) Honda | *E. caudata* Roshev.<br>*E. crus-galli* (L.) Beauv. var. *caudata* (Roshev.) Kitagawa |
| Hime-inubie | *E. crus-galli* (L.) Beauv. var. *praticola* Ohwi | | *E. crus-galli* (L.) Beauv. ssp. *submutica* (Meyer) Honda |
| Hie | *E. utilis* Ohwi & Yabuno | | *Panicum frumentaceum* Roxb.<br>*P. crus-galli* L, var. *frumentaceum* (Roxb.) Trim.<br>*E. frumentacea* Link<br>*E. crus-galli* (L.) Beauv. var. *frumentacea* (Roxb.) W. F. Wight<br>*E. crus-galli* (L.) Beauv. ssp. *edulis* Hitchc.<br>*E. colona* (L.) Link var. *frumentacea* (Roxb.) Ridl. |

**Table 3. Wild *Echinochloa* species of Japan.**

| Species and variety | Characteristics | Habitat |
| --- | --- | --- |
| *Echinochloa oryzicola* Vasing. | Plant type erect. Spikelets 4-5 mm long. Lower empty glume large-3/5 the length of the spikelet. Awned or unawned. F- and C-forms are recognized. n = 18. | Paddy field |
| *E. crus-galli* (L.) Beauv. var. *formosensis* Munro ex Hook. L. | Monotypic. Plant type erect. Surface texture of lemma of the lower floret is convex, coriaceous, and shiny. Awnless. n = 27. | Paddy field |
| *E. crus-galli* (L.) Beauv. var. *crus-galli* | Variable in plant type, heading time, panicle shape, awn characteristics, and spikelet size. n = 27. | Bank, ditch, marsh, and paddy field |
| *E. crus-galli* (L.) Beauv. var. *praticola* Ohwi | Plant type procumbent, 80-100 cm high. Culms and leaves slender. Spikelets awnless, 2.5-3.0 mm long. Heading time early July. n = 27. | Dryland |

constitution and produce vigorous fertile intervarietal hybrids. This fact shows that cytogenetically they are closely related (Yabuno 1953, 1966).

In the meiosis of the $F_1$ hybrid between *E. crus-galli* and *E. oryzicola,* the chromosome pairing $1_{III}$ + $17_{II}$ + $8_I$ and $18_{II}$ + $9_1$ appeared with high frequencies (Yabuno 1966). From the cytological evidence, the geographical distribution of *E. crus-galli* and *E. oryzicola,* and their comparative morphology, I presumed that *E. crus-galli* is an allohexaploid produced by the natural hybridization of *E. oryzicola* with a not-yet-discovered diploid species of *Echinochloa* or its related genus and by subsequent chromosome doubling (Yabuno 1966). The wide geographical distribution of *E. crus-galli* and its morphological and ecological diversity may be related to the allohexaploidy of this species.

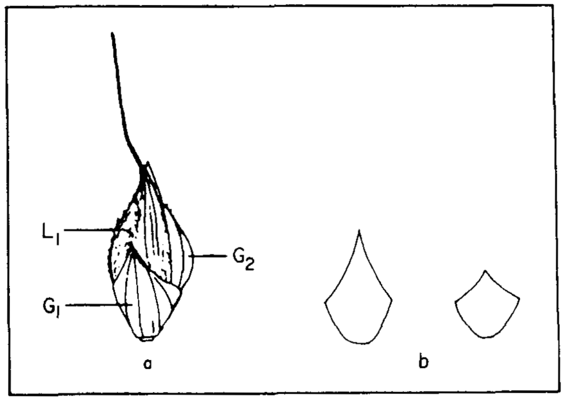
*E. oryzicola* (2n = 4x = 36) can also be distinguished from Japanese strains of *E. crus-galli* (2n = 6x = 54) by the shape of the first empty glume (Fig. 1).

The classification of the *Echinochloa* sp. of Japan presented in Table 3 reflects their genetic and evolutionary relationships. It is hoped, therefore, that the species names listed there will be used in the future.

## Ecological characteristics

Spikelets of *Echinochloa* species easily fall off. About 10–14% and 32% of seeds can germinate 8-12 days and 14 days, respectively, after flowering, and the germination rate after the 16th day is 81-99% (Ehara and Abe 1952). In paddy fields, more than 20,000 seeds/m$^2$ may be produced if the *Echinochloa* species luxuriates there (Miyahara 1965); 6,580 is given as the per-plant number of *E. oryzicola* seeds (Kasahara 1968) and about 2,670 for *E. crus-galli* var. *formosensis* seeds (Nishi 1968).

The seeds may contribute to the geographical expansion of the *Echinochloa*




**1.** a) Spikelet of *Echinochloa* species. $G_1$ : 1st (lower) empty glume, $G_2$ : 2d (upper) empty glume, $L_1$ : lemma of 1st (lower) floret. b) Shape of 1st empty glume of *E. oryzicola* (left) and of Japanese strain of *E. crus-galli* (right).

species by being carried to distant places after being mixed with rice seeds at harvest time.

According to Kasahara and Kinoshita (1952), seeds of *E. oryzicola* can germinate in a paddy field flooded to a depth of more than 5 cm, but seeds of *E. crus-galli* var. *crus-galli* and var. *praticola* germinate poorly beyond that depth. When inundated to a depth of 10 cm, elongation of seedlings was satisfactory with *E. oryzicola, E. crus-galli* var. *formosensis,* and *E. crus-galli* var. *crus-galli,* but seedlings of *E. crus-galli* var. *praticola* ceased to elongate under water (Yabuno 1960). Thus, the occurrence of *E. crus-galli* var. *praticola* under conditions of flooding is less than that of other varieties; this is presumably due to the different oxygen requirements of these weeds.

It is known that dead seeds of *E. oryzicola* are less in ill-drained paddy fields where water remains throughout the year than in well-drained paddy fields where there is water only for the period of rice culture (Arai and Miyahara 1962). When two japonica rice cultivars were planted with *E. oryzicola,* tillers of both cultivars decreased, but the tillering of *E. oryzicola* was scarcely affected (Yabuno 1960).

The presence of *E. crus-galli* var. *formosensis* with a cover degree of 20% reduced the dry weight of rice stems and leaves to 50% and the weight of rice grains to only 44% compared with a weeded plot (Nishi 1968).

Thus the predominance of *E. oryzicola* and *E. crus-galli* var. *formosensis* in their competition with rice plants is partly related to the fact that they grow only in wetland rice fields.

Nagamatsu (1951) recognized that the differentiation into early and late types of *Echinochloa* species in various places in Japan is highly parallel to that of rice cultivars. I also recognized the same tendency in the heading time of *E. oryzicola* (Yabuno 1966) — about 2 month's difference in the heading time between the early and late types.

*E. oryzicola,* a widespread species, can develop with rice plants sufficiently well so that the seeds of the weed are harvested and sown with rice seeds at planting time. *E. oryzicola* is thus a paddy rice mimic and a companion weed on rice.

*E. crus-galli* var. *formosensis,* which occurs abundantly in wetland rice fields on

Cheju Island, Korea, is also a companion weed of rice. It may be of Southeast Asian origin. Japanese paddy field weeds include many other species found in the central and southern parts of China and in Southeast Asia. Like rice, many Japanese paddy field weeds probably originated in South China or Southeast Asia and, most likely, arrived in Japan with rice from these areas via South China (Kasahara 1959). A form of *E. crus-galli* var. *crus-galli* has evolved as a mimic of dryland rice in a limited area of the Kanto district of Japan (Yabuno 1960). Presumably this is a recent evolution. Manual weeding may have played a major role in artificial selection of the rice mimic types of *Echinochloa* species of Japan.

## *ECHINOCHLOA* SPECIES AS A RICE WEED IN SUBTROPICAL AND TROPICAL REGIONS

### Annual species

*E. colona* (2n = 6x = 54) and *E. crus-galli* are similar species that occur in subtropical and tropical regions, but *E. colona* does not have the temperate zone range that *E. crus-galli* has. These two annual species can be distinguished from each other by certain morphological characteristics (Table 4. Fig. 2). At a glance, *E. colona* resembles *E. crus-galli* var. *praticola,* but its first empty glume is about 1/2 the length of the spikelet. Under conditions of inundation to 10 cm, the seedlings of almost all strains of *E. colona* cease to elongate. *E. colona* is a rather slender weed, being about 60 cm high, but if rice culture is badly managed the crop may be forced out by this weed. The young *E. colona* closely resembles the young rice plant, although it also occurs in relatively arid areas.

*E. crus-pavonis* is distributed in tropical South America and Africa and is reported as a weed chiefly in rice. I collected this species in wetland rice fields in Ibadan, Nigeria, in 1978. The plant type is erect, 1-3 m tall with stout, spongy stems. Racemes are compound, spikelets are 2.5-3 mm long, and awns are 2-5 mm long. Seedlings of the Nigerian strain (Ni-78) used in a flooding experiment (water depth 10 cm) ceased to elongate under water. The chromosome number of the Nigerian strain is n = 9.

*E. obtusiflora* has been found only in West Africa. In 1978, I collected this species freely in dryland rice fields in northern Nigeria in areas where *Oryza glaberrima* was cultivated (Fig. 3), suggesting that its distribution has been connected with *O. glaberrima* cultivation. (It is said that *O. glaberrima* originated in the region of the central delta of the Niger River about 3,500 years ago. The *O. glaberrima-E. obtusiflora* complex may be an interesting subject for study.)

**Table 4. Principal characteristics distinguishing the two wild species of *Echinochloa.***

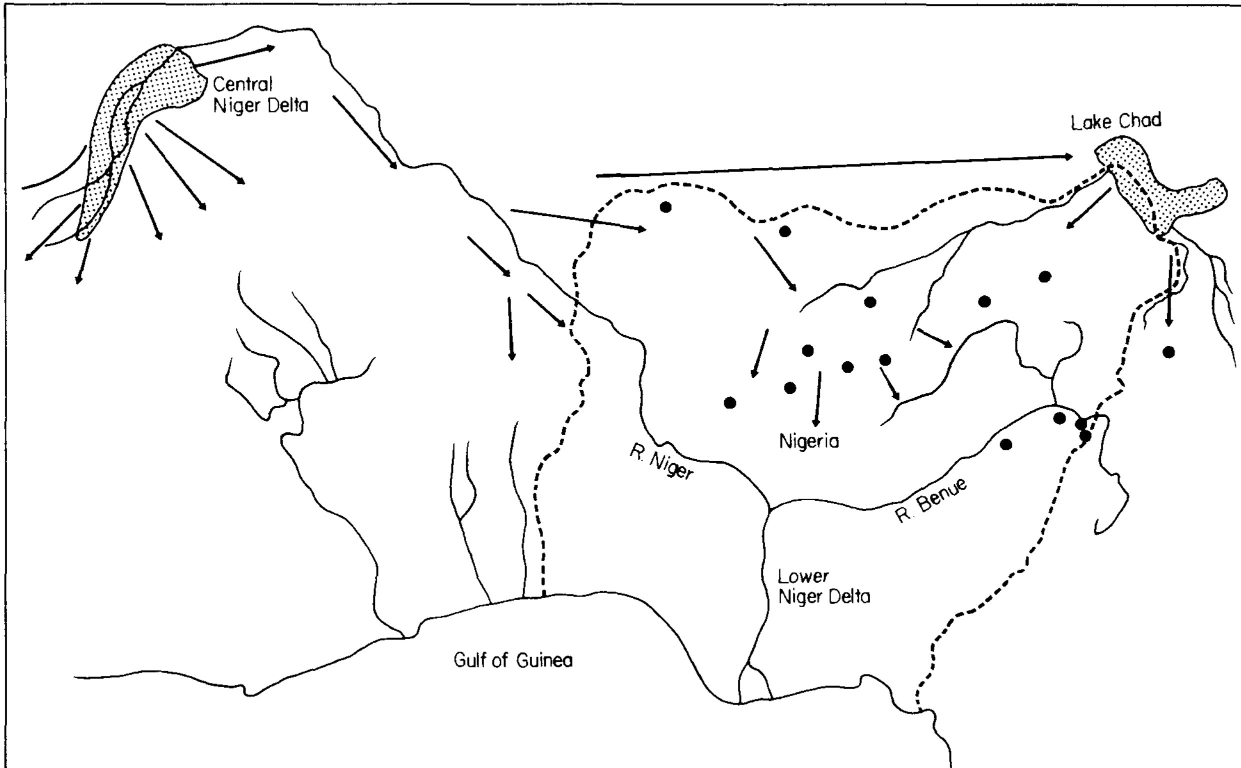
| Characteristic | *E. crus-galli* | *E. colona* |
|---|---|---|
| Panicle | Usually nodding | Erect |
| Branch of rachis | Rather close on a rachis, more or less branched | Rather distant on a rachis, simple |
| Spikelet | Often not arranged in rows | Usually arranged in 4 rows |
| Awn | Variable in length | Awnless |
| Stigma color | White or red | Blackish purple |
| Anther color | Brown or yellow | Purple |


**2.** Panicles of *Echinochloa crus-galli* (a) and of *E. colona* (b). Panicles of the cultivated species *E. frumentacea* are indicated by arrows in (b).

The plant type of *E. obtusiflora* is erect. The ligule is represented by a fringe of hairs. Spikelets are markedly blunt at the tip, 3 mm long, hairless, and often in 4 rows; the first empty glume is obtuse, about 1/3 the length of the spikelet. Leaf blades are 20-40 cm long and up to 9 mm wide. Branches of rachis are more or less erect. The lower floret is male. All the strains examined were partially self-incompatible. The chromosome number is n = 9 (Yabuno 1981). Under an experimental flooding condition (water depth 10 cm), seedlings of *E. obtusiflora* ceased to elongate under water.

**Perennial species**

Besides the annual species, I collected perennial species of *Echinochloa.* Some have a




**3.** Migration (→)) of *Oryza glaberrima* in West Africa (from Porteres 1957) and collection sites (•) of *Echinochloa obtusiflora* in Nigeria.

floating habit and are troublesome rice weeds in subtropical and tropical regions.

*E. haploclada* from Kenya is cormous and partially self-incompatible. The Kenyan strain has chromosome number n = 18 (Yabuno 1973). A diploid strain of this species was reported in Tanzania (Tateoka 1965).

*E. pyramidalis* and *E. stagnina* include various cytotypes, and taxonomy of these two species is not complete (Yabuno 1968). Type specimens of *E. stagnina* (Madras strain) and *E. pyramidalis* (Senegalese strain) are deposited at the Botaniska Museum (Lund) and the Museum National d'Histoire Naturelle (Paris), respectively. Both species have fringe, stiff-haired ligules, and staminate first florets.

*E. pyramidalis* is distributed in tropical Africa and in America (Bor 1960). It is characterized by ease of budding and by rooting from culm nodes. All samples reportedly of this species collected from different parts of Africa were awnless and spikelets about 3.5-4.0 mm long. All the strains examined were partially self-incompatible (Yabuno 1970a), and strains with rhizomes and those with corms have been discovered. Also, strains with chromosome numbers of n = 9, 18, 36, and 45 have been found among samples formerly identified as *E. pyramidalis* (Table 5) (Yabuno 1968). The diploid and tetraploid strains were collected in Kenya and Nigeria, respectively. This species is also known to grow naturally in Mopti in the floating rice zone of West Africa. Its plants attain a height of 3 m and have large and stout culms. Its panicles are relatively small for the plant body. Because it is partially self-incompatible, it probably depends more on vegetative reproduction by rhizomes or corms than on seed reproduction.

*E. stagnina* is an annual or perennial species distributed in tropical Asia and Africa (Bor 1960). Its spikelets are about 5.0 mm long and awned. A strain collected on the Ord River in Kimberley, Northwest Australia, was annual, and the chromosome number was n = 54 (Yabuno 1966, 1970b). Perennial strains have been collected in Assam, Burma, Thailand, West Bengal, Sri Lanka, and West Africa. They have creeping stems and easily sprout or root from the nodes. They can also reproduce by seed, being self-pollinated. For these reasons, *E. stagnina* is locally regarded as a troublesome weed. Samples identified as *E. stagnina* comprise strains with chromosome number n = 18, 27, 54, and 63 (Yabuno 1968). The interior of the stems of the perennial strains is spongy; this character makes them suitable for underwater life, giving them reduced specific gravity and satisfactory aeration. In these strains, internodes elongate in time of water increase; they have a floating habit (Yabuno 1966).

## PHYLOGENETIC RELATION BETWEEN WILD AND CULTIVATED SPECIES OF *ECHINOCHLOA*

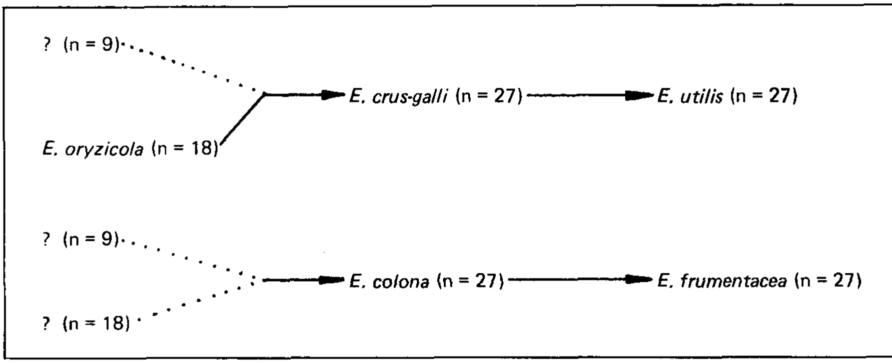
Wild *Echinochloa* species now most distributed in the world are the annual *E. crus-galli* predominant in temperate regions, and the annual *E. colona* naturally growing in subtropical and tropical regions. Both species are hexaploid (2n = 6x = 54), but differ from each other in genome constitution; their $F_1$ hybrid is sterile (Yabuno 1962).

*E. utilis,* which has been cultivated for food or feed in Japan, Korea, and China, has the same genome constitution as *E. crus-galli; E, frumentacea,* which has been

**Table 5. Chromosome numbers of *Echinochloa pyramidalis* and *E. stagnina.***

| Species | Strain | Locality | Chromosome number (2n) | Growth habit |
|---|---|---|---|---|
| *E. pyramidalis* | K64-1 | Kitale, Kenya | 18 | Perennial, floating |
| | C.P.I. 17102 | Nigeria | 36 | ” |
| | 64-3 | Mopti, Mali | 72 | ” |
| | 64-5A | Mopti, Mali | 72 | ” |
| | 64-10 | Yagoua, Cameroun | 72 | ” |
| | 64-11b | Kalahari | 90 | ” |
| *E. stagnina* | 60-1 | West Bengal | 36 | Perennial, floating |
| | 64-4 | Mopti, Mali | 54 | ” |
| | 64-8 | Tombouctou, Mali | 54 | ” |
| | W662[a] | Northwest of Australia | 108 | Annual, nonfloating |
| | 60-10[b] | Agartala, Assam | 126 | Perennial, floating |
| | 60-15[b] | Sadiya, Assam | 126 | ” |

[a,b] Michael treated as *E. macrandra* and *E. picta,* respectively.




**4.** Phylogenesis of 2 cultivated species of *Echinochloa* (Yabuno 1962, 1966).

cultivated in India, has the same genome constitution as *E. colona* (Yabuno 1962).

Considering the results of cytogenetic studies described herein, I have concluded that *E. utilis* and *E. frumentacea* originated from *E. crus-galli* and *E. colona,* respectively. The presumed phylogenesis of the two cultivated *Echinochloa* species is shown in Figure 4 (Yabuno 1966).

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# WILD RICE AND ITS CONTROL

S. Wirjahardja, E. Guhardja. and J. Wiroatmodjo

Wild rices recognized as weeds of cultivated dryland rice are *Oryza rufipogon, O. nivara, O. longistaminata. O. barthii, O. punctata,* and probably *O. officinalis.* Keys to the differentiation of wild rice species from cultivated rice are provided. The distribution of wild rice is given and the nature of its competitiveness with cultivated species is discussed. Cultural control methods as well as chemical control treatments are outlined.

*Oryza* is characterized by the development of a pair of auricles at the base of the lamina and rudimentary glumes at the upper part of the pedicel. Tateoka (1964) utilized these characters to re-classify *Oryza subulata* into *Rhynchoryza subulata.* Based on these characters, many species are still classified under *Oryza.* Of the approximately 20 species of *Oryza,* only 2 are domesticated — *Oryza* sativa, which is cultivated in the Asian tropics and subtropics, and *O. glaberrima,* which is cultivated in Africa. Other species, known as wild rice, are not cultivated and some of them become noxious weeds in cultivated rice fields. None of these *Oryza* species are related to the wild rice of North America *(Zizania aquatica),* which is considered a culinary delicacy, not a weed.

It is generally agreed that the two domesticated rice species derive from the same ancestor through two parallel series of evolution — *O. longistaminata, O. barthii,* and *O. glaberrima* in Africa and *O. rufipogon, O. nivara,* and *O. sativa* in Asia

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(Chang 1976). In these evolutionary lines, the wild and domesticated types sometimes existed in the same place (sympatric) and produced hybrid swarms of many intergrades (Oka and Chang 1961, Chu and Oka 1970). A collective term, the *spontanea* type of *O. sativa,* applies to hybrid progeny among the Asian species (Chang 1976). These hybrids are the weeds called red rice, because they have a dominant red pericarp.

The wild rices which have been recognized as weeds in rice fields are *O. rufipogon, O. nivara, O. longistaminata, O. barthii, O. punctata,* and probably *O. officinalis.* They create a weed problem in dryland rice.

## CHARACTERISTICS AND DISTRIBUTION OF WILD RICE

The revised names *O. rufipogon* and *O. nivara* were proposed by Sharma and Shastry (1965) to differentiate them from field *spontanea,* which consists of hybrid swarms, as a result of introgression between *O. sativa* and its wild relatives. Through this usage, the ambiguous name *O. perennis* is discontinued. The two wild rice species resemble *O. sativa* (Table 1).

The weediness of wild red rice is attributed to its competitiveness with cultivated rice and to its ability to cross-pollinate. The grains of wild rices have strong and long dormancy and are able to survive in the soil for years. Wild red rice possesses genotypically dominant red pericarp and a habit of easily shattering ripe grain. These will be expressed phenotypically in its hybrid, reducing the quality of the rice crop. The red pericarp results in milled rice with a dirty whitish or yellowish color.

Grain with a red pericarp is acceptable or even preferred in some areas of India, Sri Lanka, and Indonesia (Grist 1978).

According to Nagao and Takahashi in Grist (1978), the red pigment is provided by anthocyanin pigment and governed by two complementary genes, *Rc* and *Rd.* Other anthocyanin genes, such as *Pl,* also confer red seed coats.

Parker and Dean (1976) reported the areas where red rice is a problem: the southern part of the USA, Guyana, Brazil, Surinam, Venezuela, Colombia, and West Indies. In Asia, the areas are India, Thailand, Indonesia, Bangladesh, and Malaysia. In Europe, red rice was reported in Italy and Bulgaria. In Africa, red rice occurs sporadically in rice-growing areas where *O. sativa* has been cultivated. It is not clear whether red rice refers to the Asian wild relatives or the African taxa. The strong rhizomatous *O. longistaminata* is a noxious weed in many parts of Africa, including Mali, Guinea, Senegal, Sierra Leone, and Nigeria (Parker and Dean 1976). It also was found in Ivory Coast, Upper Volta, Nigeria, Benin, and Cameroun. Another species similar to *O. rufipogon,* called *O. perennis* ssp. *madagascariensis,* is found in Malagasy. Similarly, the strong rhizomatous wild species of Australian *O. australiensis* is a potential noxious weed.

*O. barthii* is an annual weed closely related to the African rice cultigen *O. glaberrima* (Table 2). *O. barthii* is its nuisance weed. It is widely distributed in Tanzania and from Mauritania up to Sudan and Zambia.

Where *O. sativa* is cultivated in Africa, cultigen *O. glaberrima* to some extent may be considered a weed, since its red pericarp and ready shattering are both controlled by dominant genes.

**Table 1. Key to differentiation of wild rice species *Oryza rufipogon* and *O. nivara* from cultivated *O. sativa.***

| Character | Species | | |
|---|---|---|---|
| | *O. rufipogon* | *O. nivara* | *O. sativa* |
| Branching | Extravaginal | Intravaginal | Intravaginal |
| Growth habit | Decumbent | Semidecumbent to erect | Erect |
| Spikelet shape | Slender | Bold | Variable |
| Apiculus | Blood red | Purple or green | Green |
| Pericarp | Red or purplish | Reddish-dirty white | Variable |
| Anther length | Long | Medium | Medium |
| Awn | Slender/flexuous and frequently reddish | Stout, long and frequently reddish | Slender/awnless to awned |
| Life-span | Perennial | Annual | Annual |
| Habitat | Stagnant and seasonal swamps | Drainage ditches and shallow ponds | Domesticated culture |
| Grain shattering | Readily before fully ripe | Before fully ripe | Variable but less shattering than wild |
| Grain dormancy | High | High | Variable |

**Table 2. Key to differentiation of wild rice species *Oryza longistaminata* and *O. barthii* from cultivated *O. glaberrima.***

| Character | Species | | |
|---|---|---|---|
| | *O. longistaminata* | *O. barthii* | *O. glaberrima* |
| Ligule | Long, up to 45 mm, tips acute | Short, up to 6 mm, tips round or truncate | Short, up to 6 mm, tips round or truncate |
| Panicle | With secondary and tertiary branches | With secondary and rarely tertiary branches | Without secondary branches |
| Grain | Hispid | Hispid | Glabrous |
| Awn | Up to 8 cm, rigid | Up to 16 cm, pink or red, stiff, hispidulous | Awnless or short awned, hispid |
| Life-span | Perennial | Annual | Annual |
| Rhizomes | Present | Absent | Absent |

*O. punctata* and *O. officinalis* are both annuals, but *O. punctata* is native to Africa while *O. officinalis* is of Asian origin. Both have small grain, 5.00-6.40 mm long for *O. punctata* and 3.60-5.40 mm long for *O. officinalis* (Tateoka 1962).

*O. punctata* is distributed from east to west Africa. In Swaziland, it is reported to be a problem weed because it shatters its grain and contaminates the rice (Armstrong cited in Parkerand Dean 1976). Although O. *officinalis* has not been reported to be a weed, the possibility is high because it is widely distributed.

## CULTURAL CONTROL

Weeds are pioneer vegetations that usually require a considerable light intensity to germinate, grow, and develop. Therefore, it is expected that weed seed will not germinate when it is flooded or buried in the mud (for example, *Echinochloa crus-galli* and *Fimbristylis littoralis* seeds). Parker and Dean (1976) found that seed of *O. punctata* did not germinate in water nor in water-saturated soil. However, the perennial wild rice in water-saturated soil or when flooded can propagate through bud germination of stem cuttings or rhizomes. This happens for both *O. longistaminata* and for *O. rufipogon.*

Nonetheless, with clean seed uncontaminated by wild rice, infestation of wild rice can be prevented:

- By direct sowing a pregerminated crop on fields that have been flooded or cultivated, as is done in various places in Asia.
- By puddling the soil before broadcasting rice seed, as is done in the United States, Guyana, and West Africa.
- By row seeding, where wild rice growing between rows can easily be recognized and weeded out.
- By growing rice cultivars with a purple leaf to differentiate it from wild rice, so the wild rice can be easily weeded out, as is done in India. However, because wild and domestic rices can cross-pollinate, it is possible that wild red rice may also have purple leaf.
- By growing short-season rice cultivars that are harvested long before wild rice shatters its grain, as is done in USA, Guyana, and West Africa. This practice can interfere with the cycles of wild rice in the field, although wild rice grain which has been inadvertently harvested still will contaminate the yield.
- By deep plowing to bury wild rice seeds and prevent them from germinating. Ducks also may be kept to graze the seed and seedlings of wild rice.
- By using crop rotation of rice and secondary crops to reduce the infestation of new wild rice seed.

## CHEMICAL CONTROL

Herbicides commonly used to control weeds in rice fields, such as 2,4-D, and MCPA, are not selective toward red rice but are useful to control volunteer rice. MCPA and 2,4-D have been used against volunteer rice in the Indonesian Seed Centre. EPTC also could control wild rice when it was incorporated 1 month before seed broadcasting. Glyphosate and paraquat may be used against red rice in the nursery.

Molinate at 3-4 kg/ha selectively controlled red rice in domestic rice (Wirjahardja and Parker 1977). The herbicide antidote 1,8-naphthalic anhydride (NA) can help prevent crop injury from molinate. The antidote was applied as a grain dressing at 0.5-1.0% weight/weight. This method was used by Parker and Dean (1976) against *O. punctata* growing in rice cultivar Blue Bonnet, which is grown as a dryland rice in Swaziland.

It was also reported that dalapon at 10–15 kg/ha and diuron at 5 kg/ha could control rhizomes of *O. longistaminata,* but the chemical residues took a long time to degrade. For example, dalapon can damage transplanted rice seedlings 4 weeks after treatment. Glyphosate, which does not have a residual problem, was found to be effective against *O. longistaminata.*

Parker and Dean (1976) tested 18 herbicides on *O. punctata* grown with Blue Bonnet, IR5, and IR8. They found that molinate applied preplanting and incorporated into the soil was selective at 1-2 kg/ ha, alachlor applied preemergence was selective at 0.75 kg/ ha, and metalachlor applied preemergence was selective at less than 0.75 kg/ ha. The selectivity of these herbicides can be increased if the rice cultivars are protected with NA. Although rice cultivars suffer some damage due to NA, they soon recover.

Wijahardja and Parker (1977) worked with molinate, alachlor, and thiobencarb on *O. punctata,* three types of red rice from USA, and two types from Swaziland. When the wild rices were grown with Blue Bonnet and IR28, alachlor at 0.9 kg/ ha applied preemergence was selective against *O. punctata* if the rice cultivars were protected by NA. Molinate at 3 kg/ha incorporated preplanting was the most selective against all red rice in the experiment, provided that the rice cultivars were protected with NA. Thiobencarb at 4 kg/ ha incorporated preplanting was safe in IR28 even without NA, but Blue Bonnet required NA. Both thiobencarb and molinate were incorporated preplanting, a technique not easy to follow in the field. Alternative methods of applying these herbicides need to be investigated.

Apparently some red rices have differential tolerances towards thiobencarb and molinate. For example, two of three red rices from Swaziland were found to be more tolerant of thiobencarb.

Another series of experiments carried out by Wijahardja and Susilo (1979) used six IR cultivars and one Indonesian red rice and herbicides metolachlor, alachlor, molinate, and thiobencarb. The most selective herbicide was thiobencarb. In experiments with cuttings of the wild perennial *O. rufipogon,* the same herbicides ACR 1207 and thiobencarb at 6 kg/ ha killed the wild perennial *O. rufipogon,* but ACR 1207 at 4 kg/ha did not have any effect. ACR 1207 at 4 kg/ha suppressed red rice in IR36 and in improved dryland rice Gata cultivar. The effectiveness of NA protection on dryland rice was confirmed, but even with the protectant, IR36 was injured by the herbicides.

## CONCLUSION

The work needed in understanding the wild rice problem includes:

- inventory of the Occurrence of wild rice in rice-growing areas;
- prevention of infestations in rice fields;
- studies on ecophysiological aspects such as seed germination, dormancy, and competitiveness; and
- investigation of control methods.

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## DISCUSSION

GONZALEZ: We decreased red rice field infestations in some Latin American countries using certified seed. Have you certified seed in your home country and can you promote the use of certified seed? I think certified seed is the first step, followed by other weed control methods.

*WIRJAHARDJA:* We have a certified seed procedure, but not for wild and red rice because red rice in Indonesia is accepted and cultivated in several places. The certification is directed toward preventing common weed seed contamination only, such as *Echinochloa* spp. seed, and Cyperaceous seed. But in the near future, wild rice, particularly *O. rufipogon,* is likely to be a problem in direct-seeded rice, which is more and more practiced in Indonesia — and certified seed will need to be directed to wild rice seed prevention.

*SILVEIRA* (comment): In Brazil, in a sample of 500 grains. we are allowed to have 15 seeds of red rice and 1 seed of black rice.

SUNDARU (comment): In Indonesia, we have seed certification for weed seeds but not for red rice. Seed can be sold to the farmers if it is contaminated with red rice but if it has more than 10-15% red rice then it will not be accepted by the Seed Center. There is no regulation for red rice yet.

VONGSAROJ: What rate of naphthalic anhydride (SA) did you use in your experiments? Did you find any species of the hybrid between rice and wild rice? We have found it in Thailand.

*WIRJAHARDJA:* Red rice itself is a hybrid between cultivated rice and wild relatives. We tried chemical control using herbicides, such as thiobencarb, and we protected the rice with NA. We had good results with 4 kg thiobencarb/ ha incorporated preplanting. This was an experiment in the greenhouse. We haven’t tried it in the field. We used 1% NA weight by weight.

COX: In Australia, we have small areas of ratoon rice. Where there is dropped seed, we get two different maturities of rice and it would be desirable to take out the dropped seed. One of the techniques we have been looking at is the use of the phenoxy herbicides 2,4-D and MCPA. Ratoon crop rice appears to act physiologically more mature than seedling rice. By using 0.68 kg MCPA/ha, we find it is not only possible to take out broadleaf weeds and sedges, but we can also take out 1- and 2-leaf rice seedlings. Have you investigated the use of phenoxy herbicides for the control of wild rice?

*WIRJAHARDJA:* This has also been done — not against red rice, but against volunteer rice — at the Seed Center in Indonesia.

DAS GUPTA: Due to dormancy and staggered germination of seeds, *O. barthii* isdifficult to control. What is the effective control method for this wild rice?

*WIRJAHARDJA:* We don't have any experience with *O. barthii* control, chemical or cultural. As far as we know, there is no report yet concerning *0. barthii* control. But it could be done, as with red rice control.

DAS GUPTA: Please suggest methods to control the rhizomes of *O. longistaminata.* This is a serious weed in deepwater or floating rice in Mali (West Africa).

*WIRJAHARDJA:* There are reports of chemical control on *O. longistaminata* by using dalapon at 10-15 kg a.i./ha and diuron at 5 kg a.i./ha. Glyphosate was also reported effective to control rhizomes of *O. longistaminata.*

# RED RICE AND ITS CONTROL

J. B. Baker and E. A. Sonnier

Infestation of rice fields with red rice results in severe economic losses because of reduced quality and lower yields. An integrated program is required to control red rice in the rice crop, reduce the seed bank in the soil, and prevent its introduction into clean fields. The elements of an integrated red rice control program are discussed, including crop rotation, water planting, water management. herbicide use, and other cultural and biological control methods.

Red rice is a weed of rice in many countries. Holm et al (1979) list 7 *Oryza* species as weeds in 41 countries — most of which grow rice. In 13, the weedy rices are considered serious, major, or common. Matsunaka (1975) does not list red rice as a troublesome weed of rice in the Asia-Pacific region, but he mentions it as one of the most troublesome weeds in U.S. rice. Because of the confusion that exists in the literature as to the proper taxonomic classification of various red rices, it is difficult to precisely describe the extent and severity of the red rice problem.

We use the term red rice to refer to plants considered by many to be *Oryza sativa* or by others to be *O. rufipogon. O. rufipogon* differs from *O. sativa* in the relative ease of shattering of the mature seed (Tateoka 1963). Ease of shattering, along with the pigmented aleurone layer and a unique seed dormancy, are the characteristics

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that make red rice a weed. The red aleurone layer reduces grain quality — the intense milling required to remove all traces of the pigmented bran layer results in a lower head rice yield. The shattering of the grain results in a harvest loss and reinfests the soil with seed. The seed dormancy mechanism assures a reservoir of seed for future years, which serves to stabilize the red rice ecotype.

Well-documented estimates of the financial loss attributable to red rice are hard to find. In a survey in Guyana 80-90% of the samples of harvested rice had more than 2% red rice, and some had more than 40% (Rai 1973). That undoubtedly affected quality. But the financial loss to the farmer is hard to determine because the discount for red rice varies with market conditions. In a survey in Louisiana, 33% of the rice purchases were discounted an average of $6.17/ t because they were infested with red rice (Traylor and Hill 1963). In 1963 that represented an estimated annual loss of $2,070,000 to Louisiana rice farmers. The financial loss due to reduced quality, however, is not nearly as great as the loss due to decreased yield. In red rice control studies, Sonnier (1974) reported yield losses as great as 65%. Research by R. J. Smith (cited by Huey and Baldwin 1978) showed a 49% yield reduction and a three-step reduction in grade, which together resulted in an $802.17 ha loss. Huey and Baldwin (1978) estimated the total loss to Arkansas rice farmers to be $12-15 million annually.

Although red rice is a serious problem in only a few rice producing countries, other rice producing countries should be on guard to prevent it from becoming a problem in their fields. This applies to areas within a country as well. Farmers in the U. S. have been unsuccessful in preventing the spread of red rice into new rice production areas.

## APPROACHES TO RED RICE CONTROL

A successful red rice control program must use an integrated system that involves all possible methods of preventing the introduction of red rice into clean fields and reducing the infestation of red rice seed in the soil to prevent reinfestation.

An integrated red rice control program must have the following elements: crop rotation, water planting and water management, herbicide use, and other cultural and biological control methods.

### Crop rotation

Red rice-infested fields should be rotated to upland crops in which red rice can be controlled. Smith (1976) showed that rotation schemes of 2 years of soybean or grain sorghum and 1 year of rice will reduce the severity of the red rice problem. Propazine and tillage gave 100% red rice control in grain sorghum. Herbicides and tillage gave 98-100% control in soybean. There was 70-80% less red rice after 1 rotation cycle and 90% less after 2 cycles. Rotation provides for tillage to stimulate red rice germination, and tillage and herbicides to control the red rice and prevent reinfestation.

### Water planting and water management

Dry seedbed preparation followed by dry seeding and delayed flooding will result in a much higher infestation of red rice plants than preparing a seedbed wet, planting into the flooded field, and keeping the soil saturated. Continuous waterlogging of the soil may account for the lack of a red rice problem in many rice producing areas where the soils are puddled, the rice is transplanted, and the fields are not drained. Louisiana rice farmers minimize the red rice problem in mechanized rice production by using the following cultural practices:

- minimum tillage before flooding,
- finishing seedbed preparation in the water,
- sowing presprouted seed into the water, and
- managing flooding to allow stand establishment and yet inhibit red rice germination.

Sonnier (1977) showed that the best red rice control is obtained by continuous flooding. A drainage of 14 days resulted in a high number of red rice plants. A 5-day drainage resulted in a red rice population between that of continuous flooding and 14-day drainage.

Although continuous flooding gives the best red rice control, most Louisiana rice farmers are reluctant to use it. Under continuous flooding the developing seedling does not establish a good root system; it tends to float in the water and is often blown to one side of the field. Farmers prefer to drain the field after seeding and to reflood it gradually as soon as the seedling initiates roots, usually about 5-7 days after planting. This method is probably of value only in areas where the land is fairly level and the floodwater can be precisely controlled.

**Herbicide use**

Until fairly recently it was assumed that selective control of red rice was not possible. Smith (1971) reported on the selective control of red rice in dry-seeded rice in which the crop seed was treated with 1,8-naphthalic anhydride. Seed treatment increased the tolerance of the crop for molinate and made selective control of red rice possible. But only 60-70% control was obtained in field studies. Baker and Henry (1971) reported inadequate control in field studies, and Henry and Baker (1971) reported on the hypersensitivity of red rice to molinate. Today, it is recognized that preplant incorporated molinate can be used in water-seeded rice to control red rice.

For best results molinate should be used in conjunction with proper water management. When used with early flooding, red rice control with molinate is as good as that obtained with continuous flooding, and the problems of stand establishment under continuous flooding are avoided (Table 1).

**Table 1. Influence of water management and herbicide use on stand of red rice and rice cultivar Saturn.**

| Water management | Herbicide | Plants [a] (no./plot) | |
|---|---|---|---|
| | | Red rice | Saturn |
| Continuous flooding | None | 11.5 a | 28.0 a |
| Brief drainage | None | 61.5 b | 77.0 b |
| Prolonged drainage | None | 138.25 c | 93.5 b |
| Brief drainage | Molinate ppi [b] (4.5 kg/ha) | 2.25 a | 78.0 b |

[a] Plot size needed. In a column, means followed by a common letter are not significantly different at 1% level. [b] ppi = preplant incorporated.

### Other cultural and biological control methods

Although the methods just described are the backbone of a red rice control program, all other feasible procedures should be used to free the soil of red rice and prevent infestation. Red rice-free seed and clean equipment should be used in all field operations. Red rice is often carried from one rice field to another when equipment is used in several fields. Field equipment should be cleaned to remove seed lodged in mud on the tires or elsewhere on the equipment. When rice is aerial seeded the aircraft and related equipment should be cleaned,

After harvest the field should be managed to encourage rodents and birds to feed on the shattered red rice. Plowing soon after harvest only reinfests the soil with the shattered seed, which may remain viable for many years and germinate whenever environmental conditions are favorable.

Hand weeding to remove red rice plants may be justified when the infestation is low, labor is inexpensive, and the value of the crop depends upon its being free of red rice (as in the case of seed rice).

High crop seeding rates may be used to reduce the tillering of red rice. Sonnier (1969, 1970, 1971) showed that doubling the seeding rate from 100.8 kg/ha to 201.6 kg/ ha reduced the production of red rice seed by 31-56%.

Seeding cultivars that mature earlier than red rice has been suggested (Rai 1973) to allow crop harvest before red rice seeds mature. Some Louisiana farmers go an additional step and apply a preharvest desiccant to stop production of viable red rice seed. While these steps may accomplish their goal, they fail to prevent the yield reduction that occurs if the red rice competes all season.

Seeding of purple leaf cultivars has been suggested to facilitate hand weeding of the green-leaved wild rice (Singh and Sainin 1960).

These cultural control methods raise the possibility that we may eventually have earlier maturing red rice or purple-leaved red rice. In fact, we may soon have molinate-tolerant red rice.

## DIFFICULTIES OF IMPLEMENTING RED RICE CONTROL

Despite the demonstrated success in controlling red rice, many farmers still have serious red rice problems. An effective red rice control program requires more dedication than many farmers have. Many of the proposed control steps cannot be employed where careful water management is not possible.

One of the biggest impediments to successful red rice control in Louisiana is the 1-year lease common between most farmers and the landowners. This lease does not favor an approach to red rice control that requires a program extending over 1 year. A more effective contract would be one which covered several years and detailed a crop rotation plan that specified alternate crops to be grown and herbicides to be used. Landowners and farmers alike would benefit from this improved contractual arrangement. This is one area in which an educational effort by extension personnel would probably improve the acceptance of a red rice control program.

In summary, red rice has been, is, and will be a problem that needs the attention of research and extension personnel. The control procedures described here will not apply to all types of rice culture, but they suggest things that can be tried. Herbicides that will selectively control red rice in dry-seeded rice and cultivars tolerant of herbicides that are toxic to red rice may be developed. Growth regulators to prevent panicle formation in red rice without reducing the yield of domestic cultivars are possible. And other chemicals that will break red rice seed dormancy and reduce soil infestation could be developed.

Whenever new control procedures are developed, extension personnel must actively disseminate the new technology by educating farmers and landowners. Increased acceptance of a new technique is more Likely when all parties in a contractual arrangement are made aware of the benefits of controlling red rice.

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## DISCUSSION

GONZALES: In one slide you showed a low seedling rate of 28 seedlings/m$^2$ in plots that were not drained. Did you use pregerminated seed? Was the water warm or cold?

*BAKER:* Pregerminated seed was used. The stand of rice, expressed as seedlings/plot, is an average of experiments conducted over a 3-year period at various times during the planting season. Early in the season, when water temperature is lower, the success of stand establishment with a continuous flood is greater than it is later in the season when water temperature is higher.

DE DATTA: What does the red rice taste like?

*BAKER:* Perfectly good.

DE DATTA: Why is it reducing grain yield, if both are *Oryzas?*

*BAKER:* It shatters. Even if you were able to stop seed head production, say 2 weeks before maturation, you would still have the same loss because the plant has grown there all year. This is one of the fallacies of stopping seed production. If you plant an early maturity cultivar that you can harvest without getting red rice contamination, you would still have the yield reduction because of competition. Although this helps on quality it doesn't help on yield.

TEMPLETON: What are the certification limits?

*BAKER:* I believe that a single plant in a field is enough to take it out of the certification program. I think that no red rice is allowed in certified seed.

HUEY (comment): We have three classes of seed that we sell: foundation, registered, and certified. There is zero tolerance in Arkansas on foundation and registered seed but there is a tolerance of two seeds/500 g in certified seed and it is one plant/acre on field inspection. We looked at this in other states, they do differ. They have agreed among the seed trade in the past year to phase out the tolerance in certified seed, reducing it in half for the first 2 years with the aim of having zero tolerance by the next 2 years. This has been a problem not only in certified seed but in seed purchased by the farmers of which the quality or purity is unknown.

*BAKER:* Probably the majority of our seed rice is not under any certification program. Farmers just take a clean field and treat it or whatever and that is going to be their seed rice. At least that is the case in Louisiana.

EASTIN (comment): Our (Texas) certification program is fairly similar to Arkansas. We are allowed 1 seed/ 2 lb. The problem we have is that many of the producers, when they buy what we called bagged and tagged seed (certified seed), assume it is free of red rice seed, but legally it doesn't have to be. We are also on this phase out program. Many producers, particularly those that already have red rice, say what difference does it make if I plant a few more seeds if I already have it in the field? The problem with this is that if we come up with an antidote, then they are going to apply this antidote to red rice and then plant it. They will be getting rid of the natural population but planting it at the same time.

COX: I would like to know how common reductions in yields of 88% are? What population of red rice or how many tillers/$m^2$ would result in a reduction of 55%?

*BAKER:* The 88% was the value of the crop.

Cox: How common is that?

*BAKER:* There is about a 50% yield reduction. Eighty-eight percent of the reduced value was due to yield reduction. That doesn't mean 88% of the value of the crop. If you had a 50% yield reduction, 88% of that 50% would be 44%.

Cox: How many tillers/ $m^2$?

*BAKER:* A ratio of 50:50 red:white would give you a 50% yield reduction roughly because you harvest very little of that. Almost all of it shatters.

SMITH (comment): In some experiments where we were getting about that level of yield reduction, the red rice panicles were 60–75/$m^2$.

SEAMAN (comment): There is no red rice problem in California. I have difficulty in finding a specimen of red rice for my weed collection. From 1920 to 1940, there was a tremendous build-up of the percentage of seed lots from all over the state that were severely contaminated with red rice. Now, there is no problem. I attribute this to our continuous flooded rice culture and the use of molinate and other herbicides.

*BAKER:* I think this may possibly account for the wide distribution of this problem around the world. In the cultures where you have rice planted under waterlogged soil conditions you are not as likely to have a red rice problem. If you are dry seeding and at the same time have conditions suitable for dormant red rice seed germination, you are more likely to have a problem.

MATSUNAKA Dr. Kim, the map showed your country was so infested by red rice. Why?

*KIM:* The first slide that Dr. Baker showed gave the distribution of red rice throughout the world. I don't think that we have that much in Korea. You showed that Korea had a very severe infestation of red rice, but at the moment we do not have a severe infestation.

*BAKER:* I pointed out that I thought there were inaccuracies in that slide. There are countries which are not shown as having a red rice problem that the data show are very high. This is what was shown in the "Geographical Atlas of World Weeds." This is a reflection of the difficulty of accumulating this sort of information. I am not completely sure how this list was accumulated but I imagine it came from questionnaires. Some people do not respond to questionnaires; therefore, nothing is shown. This does not mean that they do not have a problem. Look at the U.S., it looks like we have a big area infested with red rice, yet it is only small areas within the country that are infested. So if one area within a country has a problem, it appears as a big area in the map. This is not necessarily the case.

SEAMAN (comment): The other important component in red rice control in California would be our certified seed program in which we do not allow any red rice seed in the normal seed sample. Zero red rice is allowed even in the lowest commercial grade of rice seed.

*BAKER:* We have only shifted to rotations of our rice crops with soybean in recent years, but I can already see the effects of this rotation coupled with water seeding in the overall severity of our red rice problem. I think we are making progress. I think the fact that we no longer have acreage control can also help. For many years rice production in the US was under a governmental program. In Louisiana we had a unique situation. The farmer did not have the allotment, the land owner had the allotment. Therefore, the farmer could not move off to a clean field to grow his rice; the rice had to stay on this infested soil. Recently, the controlled acreage situation has changed. Consequently, I think we are going to see an increased awareness on the part of the land owners as to their responsibility in this weed problem.

SETH. Dr. Seaman, do you have any establishment problem or is this because you sow pregerminated seed? What is the difference between the two areas?

*SEAMAN:* I think the main difference is temperature. We can water seed successfully and get pretty good stands because our temperatures are lower and the water will hold more dissolved oxygen for one thing. Another thing, our breeders have been developing cultivars that will grow under those conditions and give us good stands. Since we have changed from dry-seeding to continuous flooding culture, we have been fighting stand establishment problems as well as weed problems ever since.

*BAKER:* Another reason for the continuous flood situation in California is that their water comes from melted snow. They put it in the field ice cold and it warms up. They do not want to lose that warm water. They are not going to drain the field and reflood with ice water.

# INDUSTRIAL CONSTRAINTS TO THE DEVELOPMENT OF WEED CONTROL TECHNOLOGY

R. W. Schumacher

Industrial development and successful introduction of new weed control technology such as herbicides constitute a high risk exercise. The current industry average for successful agricultural chemicals is 1 compound/20,000 compounds synthesized and screened. After a compound is identified, about $25-$50 million and 8-10 years of development and regulatory research are required before a new herbicide is released to farmers. To ensure a continuous flow of new products to farmers, greater emphasis is required to define existing weed control problems, including the socioeconomics of the problem areas and the systems available to deliver the technology to farmers. A system for new and evolving technology is also needed to encourage the flow of technology into problem areas. Weed control technology in the future will include more emphasis on mixtures, problem-specific chemicals, introduction of antidotes, and development of specialized delivery or application systems.

Financial and human resources are the primary internal constraints an industry or company faces in developing new weed control technology or any other technology. A company is similar to most other institutions in that it has limited resources and can invest in and work on only a limited number of projects. Because most

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companies are publicly owned, the stockholders expect and are entitled to a reasonable return on their investment. Consequently, before investing in new areas of research or technology, management must make a number of decisions on the market potential, the possibility of a breakthrough, and the profit potential of the new product.

Questions that must be answered before investing in weed control technology or a new herbicide include:

- What weed control problems exist?
- Are problems large enough to justify the effort'?
- Are the problems so difficult that only a few companies would have the capability of solving them?
- Would the solution make a significant contribution'?
- Is there a system whereby the product can be commercialized and used profitably by the farmer?
- Can the company obtain protection on the new product or technology to permit a reasonable return on its investment? (Some products can be technical successes and commercial failures.)

Using these questions as a base, I will review some factors that affect the development of weed control technology.

## OPPORTUNITIES

We are all aware of the impact that the more than 600 weed species of the world have on crop production, and the need to effectively control them to increase food production. Annual crop losses due to weeds are estimated at 12% of the potential production value in Asia and almost 10% for the world. The impact of weeds on individual unweeded fields is even more dramatic. Sharma et al (1977) reported 50% yield reductions in direct-seeded rice and Smith (1974) reported more than 60% yield reduction from *Echinochloa crus-galli* infestations. The opportunities for new weed control technologies in rice are particularly numerous in view of the 143.5 million hectares planted to this crop and the various cultural practices employed in the 111 countries that grow rice.

Market size alone cannot be used to make a decision to invest in developing a new herbicide, particularly in view of the high costs associated with development and introduction. The socioeconomic parameters of the world markets must be analyzed to determine if the product can be used profitably by the farmers. The laws of the countries where the product will be sold also must be reviewed to determine regulations that could prevent or delay sales of the product. Laws that protect the new technology are also reviewed. Without adequate patent or similar protection in major markets, it is highly unlikely that new technology would be introduced. The return on an unprotected investment is questionable.

The nature of the problem or market must be clearly defined. Without a clear understanding of the problem including target weed species, climatic conditions, soil types, etc., the chemist and laboratory scientist can waste valuable time and resources pursuing unprofitable leads. Similarly, without an adequate level of expertise in a particular area or an adequate number of trained persons, even good leads can be lost and resources wasted. Definition of the market will also prevent the investment of funds in areas where competition is high or where current technology is acceptable.

## SOLUTIONS

Solutions to weed control opportunities do not come easily. Carpenter cited by Cleveland (1978) estimates that only one out of 20,000 compounds screened for pesticidal activity will be a successful agricultural chemical.

A successful agricultural chemical cannot be identified until it reaches the market. And it cannot reach the market without substantial investment, currently estimated in excess of US$20 million excluding the cost of a manufacturing facility. The manufacturing facility will add an additional $20 to $40 million to the cost.

The agricultural chemical industry then is a high technology-high risk business as demonstrated in Carpenter's success ratio. Research and development (R&D) expenditure as a percentage of sales for the industry is 8 to 10% annually, or 4-5 times higher than for the chemical industry as a whole. The Council for Agricultural Science and Technology (CAST) compiled R&D expenditures of members of the National Agricultural Chemicals Association (Anonymous 1981). The data are summarized in Table 1. From 1968 to 1978, R&D expenditures increased from $56.2 million to almost $290 million for the 36 member companies. Average company expenditures in 1978 exceeded $8 million annually. Expenditures by companies with active screening and development programs were considerably higher than the $8 million average.

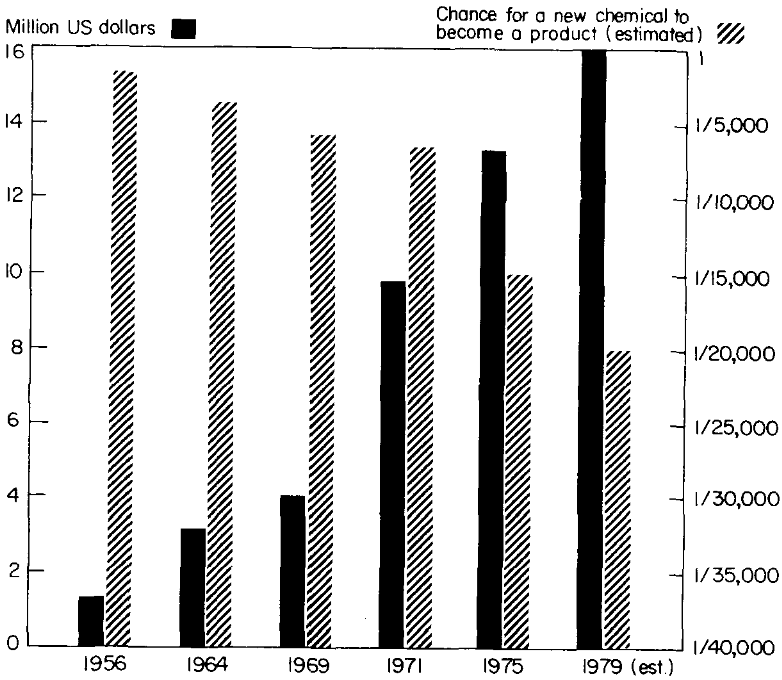
United States companies annually screen about 3,000 new compounds each, and Japanese and European companies each screen 3,000 to 5,400 candidates per year (Anonymous 1978). Expenditures for R&D increased from 1968 to 1978; the number of new agricultural chemicals introduced declined. The estimated ratio of compounds screened to products introduced dropped from 1:2000 in 1956 to 1:20,000 in 1979 (Fig. 1). The cost of introducing a new agricultural chemical increased more than tenfold during the same period (Mullison 1975).

More recently the development and introductory cost for a new agricultural chemical was placed at $53 million, a fivefold increase since 1973 (Table 2). A more conservative figure from the United States Environmental Protection Agency

**Table 1. Annual research and development expenditures for agricultural chemicals by members of the National Agricultural Chemicals Association.[a]**

| Year | Total R&D[b] (US$x$10^6$) | Total sales (US$x$10^6$) | Member companies (no.) |
|---|---|---|---|
| 1968 | 56.2 | 691 | 33 |
| 1973 | 110.7 | 1417 | 36 |
| 1978 | 289.6 | 3607 | 36 |

[a]Source: Council for Agricultural Science and Technology 1981. [b]R&D =research and development.




**1.** Estimated cost of developing an agricultural chemical and estimated probability of its being introduced as a commercial product (adapted from Mullison 1975).

**Table 2. Estimated cost for development and introduction of a new agricultural chemical in the United States by National Agricultural Chemicals Association members.[a]**

| Year | R&D[b] cost (US$x$10^6$) | R&D[b] man-years (no.) |
|---|---|---|
| 1973 | 9.98 | 321 |
| 1976 | 22.19 | 358 |
| 1978 | 53.13 | 1079 |

[a] Source: Council for Agricultural Science and Technology 1981. [b]R&D = research and development.

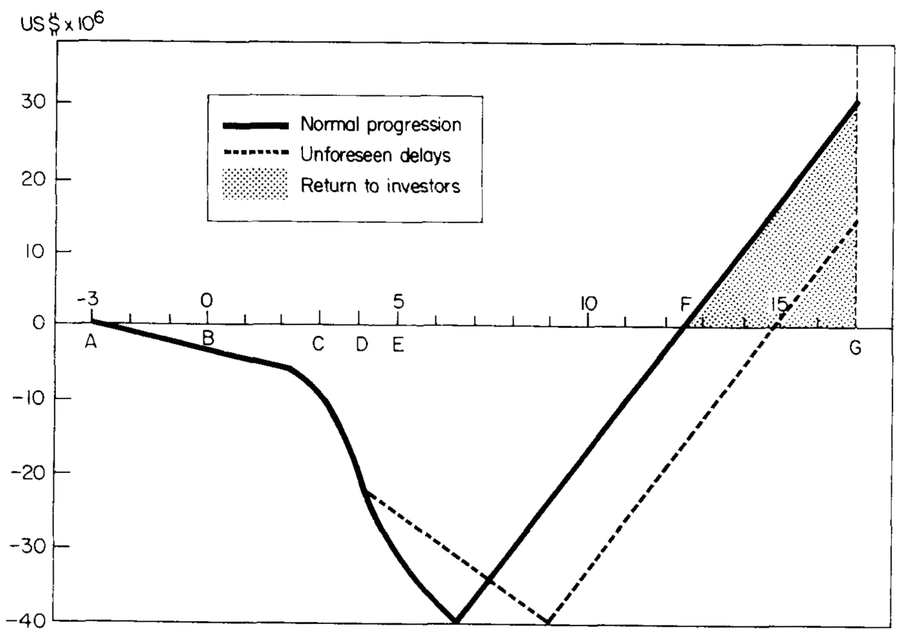
placed new product development and introductory costs at more than $30 million, a threefold increase since 1973. Both estimates are in constant 1972 dollars and exclude the cost of a manufacturing facility. The estimates indicate that finding a successful solution to a weed control problem is difficult and expensive.

An analysis of R&D expenditures over the last 10 years suggests that additional government regulations may be responsible for at least some of the reduction in new product introductions. The most striking feature is the decline in the share of funds devoted to innovation or discovery activities. Funds and time devoted to synthesis, screening, and field testing declined from about 65% of R&D expenditures in the late 1960s to about 42% in the late 1970s.

Although there has been a slight increase in expenditures for formulation and process development, the most sizable increases in expenditures are in registration, administration, environmental testing, and residue analysis. Their combined total increased from 6% of R&D expenditures before 1971 to more than 27% since 1975. This shift in fund allocation is attributed to a combination of increased public concern and increasingly stringent regulatory requirements. The regulations have not only prompted a shift in R&D funds, but have also lengthened the overall development and registration process.

Figure 2 demonstrates the overall impact of the development and regulatory process on the investment of a corporation in new weed control technology. The cash flow curves in Figure 2 are based on the following assumptions:

| | |
|---|---|
| Pesticide sale price | $7.33/kg |
| Volume | 4,545,455 kg/yr |
| Net profit after tax | 14% of sales |
| Fixed capital | $20 million |
| Working capital | 50% of sales |
| Sales and administration | $3 million |
| Other expenses | $1.5 million |
| Cumulative research and development expenses (6 years) | $14 million |




**2.** Hypothetical cumulative cash flow of a pesticide from synthesis to patent expiration (adapted from Riggleman 1979). A = initial synthesis and screening, B = US patent issued, C = first label registered, D = commercial plant construction, E = commercial sales begin, F = breakeven point, G = patent expires.

It takes 13 years to reach the breakeven point (F), the point at which stockholders recover their investment. Beyond the breakeven point, cash flow is positive and the investors begin to earn a return on the money they have risked. When the patent expires in year 17, competitors can be expected to enter the market and the slope of the curve flattens out. When the cash flow curve finally parallels the axis, costs equal dollar sales, no further earnings accrue, and the product will likely be terminated.

It is the shaded area under the triangle that interests investors and stimulates the introduction of new weed control technology. The impact of a 2-year delay in registering the product moves the cash flow recovery line to the right — cumulative earnings are significantly reduced. These unforeseen delays are detrimental to the agricultural chemical industry as a whole. They will eventually reduce the flow of technology to the farmer.

## RETURNS

The development of new agricultural chemical technology is time-consuming and expensive and exposes investors to a large amount of risk. For the new technology to spread to other countries, particularly developing countries, protective legislation must exist. The most common form of technology protection is the patent whereby a government entity permits the inventor exclusive rights to the invention for a fixed period to recover the investment and secure a profit. There is little incentive to invest in new weed control technology without patent protection, and investment capital will be channeled into other investment areas.

The implementation of pesticide regulations or registration guidelines has aided the spread of technology to countries that lack patent laws. Registration guidelines that honor the exclusive use of the submitted data by the originator are almost as strong as patent laws. Costly and time-consuming procedures, effective control of toxicology, metabolism, and residue data will encourage the spread of technology in the best interests of the citizens of the receiving countries.

## FUTURE DEVELOPMENTS

Future weed control technologies will take many forms, but will likely be centered around four major areas.

**Product mixtures**

Because of the continuing high cost of introducing new products, there will be greater emphasis on using mixtures of existing products. These mixtures will include three and four products to tailor weed control to the problem in a small geographic area.

**Problem-specific products**

There will be increased emphasis on developing products for specific problems. This can be seen today with the introduction of new products for weed control in cotton and soybean.

**Antidote development**

There will be greater emphasis on developing antidotes, or crop protectants to permit increased usage of existing products in crops without natural tolerances for the herbicides.

**Specialized application equipment**

There will be greater emphasis on the development of specialized application equipment such as wiping equipment to selectively place a nonselective chemical such as glyphosate on the crop. Other forms of application technology will, through placement, electrical charge, or other means, improve the unit activity of the herbicide and of crop tolerance as well.

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## DISCUSSION

DE DATTA: Quite often herbicides being developed for the Asian tropical region have already found a market in the Western world. In the case of butachlor, it is the other way round. We developed it here for the tropics and it found a place. Now, it has been looked at for a number of years to see whether it can be registered in the U.S. The message is: if industry people look at these areas specifically, there are products that are being synthesized. We should look at only those that have shown some efficacy. Initial testing and screening can be done by industry. My feeling is that we should not always be looked at as a leftover. If there is a market in Asia that is fine, but we must have the Japanese and Western market first. A very good point is that you have to make money. I don't think that you should look at the other side and neglect it. I think there is an equally impressive market if the product is good. Butachlor is an example that you can cite — it came from the developing countries and is now moving to the developed country.

*SCHUMACHER:* I think the thing that is most critical is being able to define exactly what that market is. We have to look beyond just the physical size, but as we go in, if we look at upland rice or dry-seeded rice, we are going to work together in precisely defining exactly what we need. I don't think any company is turning its back on Asia. I think, to some extent, it has been a lack of awareness of the opportunities that exist.

MATTHEWS: The role of this conference has been to pool and exchange knowledge at all levels. In industry, as far as 1 know, there is no pooling or exchanging of knowledge in the developing of compounds. Therefore, Company A screens 100.000 to develop I; Company B does the same and they may be screening exactly the same compounds. Surely, there must be, at this level of technology, enough ethics among the commercial world to pool and exchange knowledge at the screening level.

*SCHUMACHER:* To look at this in a different light. If 1 remember correctly when DNA was discovered there was a tremendous amount of competition between the academic researchers who were doing the work to the point of giving out erroneous information to fellow researchers working on DNA research. I think that you have to look at the screening and technology as technology that we are offering for sale. It is the one proprietary thing that we have. I do not believe that companies will be sharing products. I don't think they should. I think if nothing else it could be a deterrent to innovation.

SETH (comment). Market forces are slowly pushing the chemical Industry in that direction but at what stage we are going to be cooperating more closely remains to be seen. If patent protection is involved, I doubt if people will be giving away their products to other companies. After all they have to protect their shareholders' interests. There is already a lot of cooperation between companies; in the future there is going to be more. I suspect that the smaller company will have very little chance of survival.

MENCK (comment): In my opinion it is not a matter only of the compounds to be screened. What put the pressure on us are the costs of all the side studies that have to be made, such as toxicology, metabolism, residue studies. These are actually the highest costs, not so much even on the biological side compared to the others that I mentioned.

BAKER (comment): This lack of cooperation sometimes pays off to the industry in that it extends the patent period. If you can get into an argument over who has the patent you can be selling the product for quite a few years before you actually get the patent and then your patent protection is extended for a longer period of time.

EASTIN (comment). I don't think ethics in industry is any worse than it is in the general public. Until we can raise that in the general public we can't expect industry to do better. I know of companies that do develop or have screened the same chemical because they have come out with the same chemicals. But if they had an agreement, are they going to share the profits when one of them finds something? Industry is profit oriented just like farmers.

SCHREIBER (comment): The Weed Research Organization in England has screened a number of compounds at a very late stage of development. They have a statement on one of their application forms that states: if we have a compound that is identical with another company's compound do you want us to inform you and them of this association, i.e. you both have the same compound. In every case the answer has been no. We have had the same situation in the U.S. where we have looked at a lot of confidential material and we have asked the same question and in every case the answer is no.

SETH (comment): It is very difficult for us in this room to judge accurately at what stage cooperation ought to be. I think it is best left to the boards of the companies.

BAKER. In the case of the development of mixtured, how does the industry view the acceptance of responsibility for the statements on the label?

*SCHUMACHER:* When mixtures are recommended on the company's label, the company making the recommendation accepts responsibility for the statement on the label.

MICHAEL: We have heard that the toxicological tests that are required in the development of a promising herbicide are one of the major factors in the cost. Is it the case that the development of mixtures is not subject to intensive toxicological tests. The idea that mixtures of herbicide A and herbicide B may be perhaps more toxic than either herbicide alone comes to mind. Is it not that the same toxicological tests are involved in the development of antidotes or safeners?

*SCHUMACHER:* I am unaware, at least in the agricultural chemicals, of a synergistic effect from a toxicological standpoint. With antidotes and safeners, we are running programs with toxicology. residue. and metabolism, but the one thing that is being achieved through uses of antidotes and safeners is that existing products can be used on a broader base.

SETH (comment): Many of the registration schemes require demonstration that there is no synergistic effect in mixtures.

# CONSTRAINTS TO THE ADOPTION OF NEW WEED CONTROL TECHNOLOGY IN RICE

G. L. Denning, S. K. Jayasuriya, and B. A. Huey

New weed control technology involving the use of herbicides has emerged for use in developing and developed countries. Adoption has varied among countries and rice-growing environments. This paper examines the factors affecting adoption, with particular emphasis on institutional factors. In some developing countries, inadequate labeling of herbicide containers, complexity of chemical weed control technology, and poor research-extension linkages constrain farmer adoption of the new weed control methods. The need to train extension personnel is emphasized and the responsibility of chemical companies to assist is argued. In developed countries, practical training of extension workers on weed identification and recognition of field situations affecting herbicide effectiveness is also required.

As labor becomes relatively higher priced, shifts away from labor-intensive weed control techniques will likely occur in tropical Asia. However, if the real price of rice declines and costs continue to rise, the shift could be toward lower levels of weed control. Government policies have been and will continue to be an important influence on adoption of new weed control practices in both developed and developing countries.

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The green revolution in tropical Asia brought with it large changes in rice cultural practices. The widespread replacement of traditional tall cultivars with semidwarf cultivars and the use of high fertilizer rates increased weed problems (De Datta 1981) and stimulated the application of new weed control technologies.

Similar changes have occurred in irrigated rice areas in the more developed countries, such as in the southern United States. Shifts from water seeding to dry seeding occurred when safe and effective herbicides became available. New high yielding, lodging-resistant cultivars responsive to high levels of nitrogen were introduced only when effective weed control became possible (Smith et al 1977).

Use of herbicides, particularly of 2,4-D, has been the most prominent new weed control technology. Herbicides are supplemented by row planting and rotary weeding in wetland areas and by crop rotation in both wetland and dryland areas. The adoption of herbicides by Asian rice farmers varies among countries (De Datta and Barker 1977). However, herbicides still are more widely used in the more developed countries, such as the U.S., and in countries with large farms, such as Brazil.

## TECHNICAL CONSTRAINTS

The widespread adoption of herbicides in the irrigated areas of Asia strongly suggests that the technology is effective and economical for controlling weeds in this environment. De Datta (1981) asserts that the effectiveness of phenoxy acid herbicides has been demonstrated repeatedly in transplanted rice. With suitable tillage and good water management, application of 2,4-D and MCPA is as effective as the best combination of selective herbicides and hand weeding. Since 2,4-D is readily available and relatively inexpensive, its adoption by farmers growing transplanted rice in irrigated areas would not be constrained by technical inadequacies.

Weed control in wet-seeded rice (pregerminated seed broadcast on puddled soil) is more difficult than in transplanted rice (De Datta 1977). Manual and rotary weeding are impractical and chemical weed control is needed. De Datta has found that selective herbicides such as butachlor and thiobencarb are effective, provided good water management is possible. In the Bicol region of the Philippines, adoption of butachlor applied preemergence, followed by 2,4-D applied 15 to 20 days after seeding, has been high. Where good water management is not possible, herbicides have been less satisfactory in controlling weeds.

Herbicides have been less effective with dry-seeded wetland rice. De Datta (1981) states that most herbicides effective in wet-seeded rice do not give consistent weed control in dry-seeded rice. Dry seeding usually is used in rainfed areas as a means of increasing cropping intensity. But because fields may be flooded or dry, herbicide effectiveness is adversely affected.

The need for effective herbicides in dryland rice would appear to be even greater than in wetland rice because of the impossibility of flooding. At present, most dryland rice areas in Asia are relatively remote and labor costs are low, conditions that favor hand weeding. However, as the infrastructure develops, labor costs rise and the need for effective alternatives increases. De Datta (1977) believes that chemical weed control in dryland rice can be effective and economical.

Cultural and mechanical practices are important components of weed control programs for rice in the U.S., but herbicides are essential. Most U.S. rice is treated with herbicides each year and about 80% of the rice fields receive multiple treatments (Smith 1981). In Japan and the Republic of Korea, almost the entire rice-growing area is treated with herbicides because high labor costs discourage hand weeding (De Datta 1981). In Taiwan, expenditures for herbicides increased 30% after industry absorbed more rural labor (Chandler 1979).

It appears that effective technologies to control rice weeds exist in most rice environments. The extent to which herbicides are adopted will depend on their cost relative to the cost of labor and the price of rice and on various socioeconomic and institutional constraints.

## BASIC ECONOMIC CONCEPTS

In addition to direct methods of weed control — manual, mechanical, and chemical — other operations and inputs, such as land preparation, crop establishment methods, and irrigation, serve as weed control techniques. Each utilizes different resources or uses the same resource (for example, labor) at different times. A farmer can choose from a range of practices or combinations to attain any given level of weed control, subject to certain technical limitations.

A specified level of weed control can be achieved by combinations of labor and nonlabor inputs. This implies that labor can substitute (within limits) for other inputs to control weeds. This point is important, because weed control practices which complement other components of new rice technology are significantly different from practices involving applications of plant nutrients (fertilizers) or insecticides. For example, human labor is not a real substitute for nitrogen. But pulling a weed or killing it with a herbicide achieves the same effect.

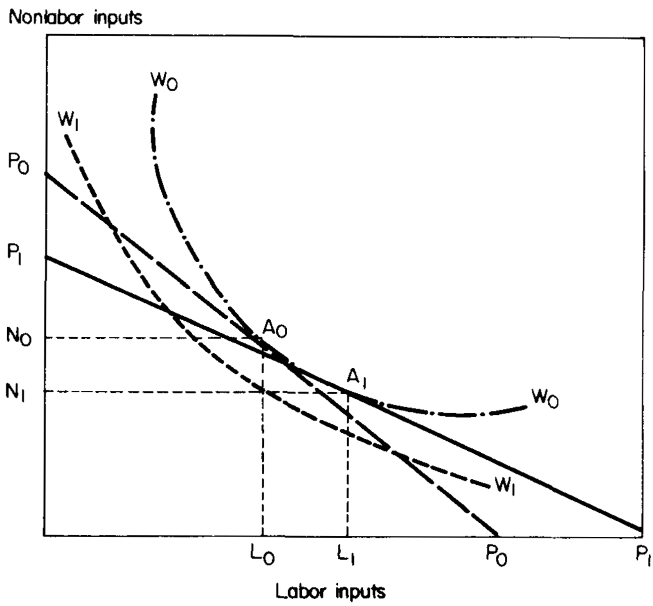
Figure 1 illustrates the basic economic concepts used in analyzing weed control practices. $W_oW_o$ represents combinations of labor and nonlabor inputs (herbicides, machinery, etc.) which will achieve a particular level of weed control. (In practice, not all combinations are likely to be feasible. $W_oW_o$ can then beconsidered as a series of discrete points or combinations of two inputs which will give the same degree of weed control.) Higher levels of control can be achieved by using higher levels of both inputs. For any desired level of weed control, a similar relationship can be specified.

For a given output price and production technology, maximum profits can be obtained by achieving an adequate level of weed control at minimum cost. Achieving a $W_oW_o$ level of weed control at minimum cost maximizes producer profits.

Because prices of labor and nonlabor usually are not identical, different combinations have different costs. It can be shown that the minimum cost combination of inputs $W_oW_o$ is that defined by the point of tangency between $W_oW_o$ and the line $P_oP_o$ whose slope is equal to the price ratio of labor to nonlabor. This is the combination of $L_o$ labor and $N_o$ nonlabor inputs.

This price ratio can change. When this occurs, the farmer who attempts to maximize profits will shift to a different input combination.

The postulated shapes of the curves imply that 1) within limits, one input can be substituted for another, 2) when the level of one input increases, increasingly larger amounts of it will be needed to compensate for reduction of the other input, and 3)




**1.** Effect of relative prices of labor and nonlabor inputs on optimum weed control technology.

after a certain point (defined by available technology), one input cannot be substituted for another.

If prices change, the new ratio is shown by the line $P_1$ $P_1$. Then the farmer will shift to a different combination of $L_1$ and $N_1$.

The optimum combination of inputs to achieve a given level of weed control depends on the relative prices of the inputs. Hence, the optimum technique for two farmers will be different if they face different prices. If prices vary over time, the optimum technique will be different for the same farmer at different times.

In areas where labor is scarce and rice production is higher than subsistence level, herbicides become a viable substitute for labor. When herbicide costs become prohibitive, eliminating the profit incentive, a change to intensive labor inputs will not occur. Rather, the rice-growing area will be reduced as farmers change to more profitable enterprises with less weed control demand. For example, in California the shifts may be from rice to other field, horticultural, fruit, or nut crops. In the southern US., food crops such as soybean, sorghum, and small grains may be substituted for rice. Weed control inputs for these crops are frequently less costly than those for rice.

A more efficient technology allows the same weed control level to be achieved by lower input combinations (such a technology can be represented by curve $W_1$ $W_1$). The effect is to increase farmer profits and to reduce the overall level of resources used for weed control. Depending on the nature of the technology, inputs may be combined in the same or different ratios. For example, a more effective herbicide is likely to shift the optimum input combination for weed control to a less labor-intensive, more cash-intensive one.

From the point of view of society, if the prices a farmer faces reflect the actual scarcity (or abundance) of goods, then overall welfare in an economic sense is maximized when the farmer uses the optimum technique. This is when private and societal interests coincide. Any factor which constrains the farmer from using the optimum technique reduces private profits as well as social welfare.

In reality, this condition often does not hold. Frequently, the technique which is optimum for the individual farmer is different from that which is optimum for society as a whole.

A weed control practice may not be adopted by farmers because it is not perceived to be the most profitable: either the particular practice is not the most profitable or farmers lack relevant information. On the other hand, often farmers will not accept a recommended practice because it is not the economically optimum technique for them in the context of relative prices, resource endowments, and the overall farming system.

Farmer rationality is now widely accepted in both developed and developing countries. Numerous studies have demonstrated that farmers in the aggregate act rationally in their economic decisions and response to new opportunities and changing prices.

When we discuss new weed control technology, often there is an implicit assumption that in some sense the new technology is superior to the farmers' traditional technology. It is useful to stress that economically rational farmers will adopt new technology only if it is more profitable than the traditional.

Not so long ago, a technology was often recommended because it gave higher crop yields. When such technology also raised farmers' profits, acceptance was rapid. The diffusion of hybrid maize technology in the U.S. (Griliches 1957) and of modern wheat and rice cultivars in Asia are examples. But when higher yields did not lead to more profits, the result was rejection by farmers and frustration and demoralization in the extension services.

That recommendations to farmers should be based on economic evaluation of agronomically promising technologies is widely recognized. But it is easy to overlook many aspects of the small farmer's situation when evaluating a new practice.

## SOCIOECONOMIC CONSTRAINTS

Wide differences exist within the small farmer sector. Farmers can be differentiated by farm size, tenure, income, education, access to markets, and a host of other characteristics that impinge on their farming decisions, even when they farm in similar biological and physical environments.

We can consider all these factors as affecting, directly or indirectly, the effective costs farmers face when making their technical/allocative decisions, including the choice of weed control techniques.

Some farm-level economic factors have been shown to influence access to information. Many influence the effective price structure. For example, better access to inexpensive institutional credit lowers the effective cost of capital (and purchased inputs) to a farmer. A technique which uses higher levels of such inputs then becomes more attractive. A small farmer with a relatively large supply of family labor is likely to consider that the effective price of labor is relatively low if off-farm employment opportunities are scarce.

**Farming systems**

Generation as well as evaluation of new farming technologies, including weed control technology, must consider the overall farming system within which rice cultivation takes place. In the less developed countries, farms are typically complex, multi-enterprise systems. The role and importance of rice cultivation vary across farming systems. A technology which appears to be profitable when the rice enterprise is considered in isolation may overstate benefits and understate costs when the whole farm is considered.

A farmer who practices rice-fish culture may be reluctant to accept chemical weed control practices that include chemicals toxic to the fish in his rice paddies. If a farmer's livestock are affected by the herbicides used on rice, an economic analysis of herbicide use should recognize potential costs. The overall cropping system must also be considered because some weeds, such as red rice, may be more effectively controlled by rotating crops.

An analysis of farmer nonacceptance of recommended weed control practices in Pakistan showed that farmers consider the weeds which grow in the rice paddies to be a very important source of livestock feed (Flinn 1981, personal communication). Because livestock are a major component of the farming systems, farmers do not want to remove weeds until they have reached a certain stage of growth.

Tenure arrangements create further disincentives. The weeds are harvested and utilized by the tenant farmer, but any increased rice yield resulting from earlier weeding is shared with the landowner.

In the U.S., where labor is scarce, large-scale farming has increased herbicide usage and reliance on aerial application. IRRI cropping systems researchers found in the late 1970s that one reason farmers in Pangasinan, Philippines, were reluctant to adopt dry-seeded rice techniques was that weeding had to be done during a period when other farm operations and activities placed heavy demands on labor resources.

**Farm size**

Farm size is associated with other characteristics and, within a given environment, usually correlates closely with income. There is no evidence that small farmers have lagged behind large farmers in their weed control levels. Indeed, there is evidence that the smallest farmers have committed as much or more of their resources, particularly labor, to weeding than have larger farmers. This has been observed in Bangladesh (Ahmed 1980), the Philippines (Mandac 1978), and Indonesia (Palmer 1977). In a review of studies in Indonesia, Philippines, Bangladesh, and Malaysia, Palmer (1976) states:

> Labor requirements for weeding have very definitely risen and especially amongst pure tenants and all small farmers. Where cash costs are kept to a minimum, there is less inclination to use weedicides instead of family labor. Hired labor may supplement family labor and this explains why some small farmers spend more on hired labor for weeding than large farmers.

But this is not a universal pattern. Data from two villages in Laguna, Philippines, show no significant differences in weeding inputs among different size farms (Table 1).

Generally, we can attribute differences in weed control method to the farmer's resources. Smaller (and poorer) farmers with higher labor-land ratios tend to use more labor and less capital. Larger (and richer) farmers are more likely to use herbicides. The differences may be less pronounced where substantial off-farm employment opportunities exist, as smaller farmers have the option of working for cash employment.

This is perhaps the reason no size- or tenure-related differences were observed in the highly commercialized Laguna area in the Philippines. A study in Thailand also showed no significant differences in adoption of herbicides among farm size groups (Green 1970). Chandler (1979) predicts that chemical control of weeds will become a common practice on farms larger than 2 ha as labor costs rise (or become scarce) and as herbicides become less expensive.

**Tenure**

Tenure is often cited as a major constraint to adoption of better farming practices because, as the net gain to the operator from additional inputs is substantially reduced by output sharing, the incentive to apply high input levels declines. Therefore, it is likely that tenant farmers will apply lower input levels than owner-operators. Tenants may not have the same incentive as the owner-operator to use intensive weed control techniques.

However, the nature of the tenure contract and the farming environment can significantly modify these generalizations. Many tenure contracts are both output and input sharing, with landlords paying some of the costs, particularly cash costs. In a high-risk production environment, tenure contracts may lead to risk sharing.

Tenure status often correlates with farm size, income level, and access to credit. Although conditions vary widely within and across countries, generally tenant

**Table 1. Weeding labor and herbicide use by farm size, Laguna, Philippines[a]**

| Farm size (ha) | Reporting farms (no.) | Weeding (days/ha) | Herbicide cost (US$/ha) | Farms applying (%) |
|---|---|---|---|---|
| | | *1976 wet season* | | |
| 3-5 | 9 | 19 | 2.60 | 100 |
| 2-3 | 8 | 38 | 3.55 | 100 |
| 1-2 | 23 | 35 | 3.65 | 87 |
| 1 | 11 | 39 | 3.80 | 64 |
| Total or av | 51 | 33.5 | 3.50 | 86 |
| | | *1977 dry season* | | |
| 3-5 | 3 | 29.0 | 0 | 0 |
| 2-3 | 7 | 22.0 | 0.80 | 43 |
| 1-2 | 18 | 43.7 | 1.15 | 39 |
| 1 | 14 | 42.0 | 0.35 | 14 |
| Total or av | 42 | 38.5 | 0.95 | 28 |

[a]Data collected by M. Kikuchi.

farmers tend to operate small farms, and have low incomes and limited access to formal credit markets. On the other hand, they often get credit from landlords. It has been reported that, in the Philippines, lessees are at a disadvantage compared to share-tenants who have the credit patronage of their landlords (Palmer 1976).

As expected, studies in different parts of Asia do not show a uniform relationship between tenure status and weed control technology. A study in West Malaysia, showed that owners used more herbicides than tenants, but yield differences were slight (Bhati 1976). Analysis of farmers' weed control practices in a village study in Laguna, Philippines, showed no difference in expenditure on herbicides between tenants and lessees (Table 2). The average labor input for weeding was higher among lessees, but not significantly different. A Bangladesh study indicated that tenancy in certain areas depressed hand weeding inputs (Ahmed 1980).

In a recent USA study, average farm size in northeast Arkansas, the leading rice producing state, was found to be 533 ha, with a 1-to-6 cropping ratio of soybean to rice (Mullins et al 1981). Average rice area per farm was 429 ha for California, 325 ha for the upper Texas coast, 304 ha for the Mississippi River Delta, 192 ha for northeast Arkansas, and 136 ha for southwest Louisiana. The majority of the rice farmers share or cash-rent most of the land they farm, with shares ranging from 20% to 50% of gross returns. However, this is not necessarily a restraint on herbicide use. Landowners at the high rent levels shared in herbicide and aerial application costs as well as in cost of water and other production inputs. This can be an incentive for farmers to use herbicides, because it reduces the risks from weed control failure and to some extent overcomes tight credit or high interest rates, or both.

## Labor

Labor for weeding can come from the family or from the community. In areas with high man-to-land ratios and rapid population increases — conditions typical of many densely populated regions of tropical Asia — small farmers can draw on abundant labor reserves. Even before the introduction of high yielding cultivars, the irrigated small rice farms of Java used high labor inputs (Palmer 1976) and paddies were relatively weed free.

The greater demand for weeding labor induced by recognition of the potential economic benefits to be gained through better weed control led to important changes in village-level social institutions (Kikuchi et al 1979, Collier et al 1972). Where population density was high, changes in labor contracts occurred. A laborer could obtain the right to participate in rice harvesting (for a crop share) only by agreeing to

**Table 2. Weeding and herbicide use by tenure status, Laguna, Philippines, 1976 wet season.**[a]

| Tenure | Reporting (no.) | Weeding (no.) | Herbicide cost (US$) | Farms applying (%) |
|---|---|---|---|---|
| Share-tenant | 12 | 23.6 | 21.02 | 92 |
| Lessee | 29 | 37.5 | 23.66 | 79 |
| Total or av | 41 | 33.4 | 22.88 | 83 |

[a]Data collected by M. Kikuchi.

do free weeding. Examples are the gama system in Central Luzon, Philippines, and the ceblokan system in Java. In this way, those who control the land obtained weeding labor at low cost while maintaining a patron-client relationship with the laborers. They utilized the competition among the growing numbers of the landless poor to capture the benefits of increased productivity. Real wages were kept down without socially unacceptable changes in crop sharing arrangements.

Such institutional changes probably have delayed or lowered the adoption of higher herbicide usage by keeping labor costs relatively low. Where sociocultural or political institutions were not conducive to such changes, the incentive for herbicide use was greater. The more overt antagonism between landowners and agricultural workers in parts of India has been cited as a factor inducing greater capital use in farm operations (Hayami 1981).

Even where inexpensive bonded weeding labor becomes available, adequate supervision is needed to ensure that weeding is done properly. This adds to the supervisory and management requirements of modern rice technology. When a farmer's time itself becomes more valuable because of greater off-farm opportunities and other demands, the effective cost to the farmer of labor rises and can be an incentive to higher herbicide use.

Credit may be an even more important constraint to adequate weed control when labor is not an effective substitute for herbicides, as is likely to be the case in broadcast and dryland rice culture systems.

## INSTITUTIONAL CONSTRAINTS

### Information transmission by extension

The adoption of new weed control technology will depend to a large extent on how well farmers are informed about availability, means of application, and benefits of the technology. Parker (1972) emphasizes the importance of a strong research-extension linkage.

In the U.S., where close ties exist among research, extension, industry, and regulatory agencies, there is often extensive cooperation in developing educational information, recommendations, and use labels. Farmers may obtain the same basic information on specific herbicides from advertisements, publications, mass media, grower meetings, and labels from industry and governmental sources. The constraint is not lack of information, but farmer's doubt that economical and effective weed control will be obtained in a specific field situation.

In the developed countries, more in-the-field training to identify weeds and to recognize weed situations requiring precise timing of specific herbicides or combinations of herbicides would provide needed experience, especially for new extension workers with the background to make sound recommendations. Innovative computer systems designed for retrieving weed control data or herbicide performance information also may be in demand soon, not only among extension workers and industry representatives but also among farmers and private consultants.

In most of Asia, extension officers have the major responsibility for bringing information to farmers. But Akobundu (1980) believes that poor communication of research information has limited adoption of new weed control technologies in

Africa. Doll (1980) reports that the research-extension link common in the U.S. and Canada is largely absent in Latin America. The same could be said of most tropical Asian nations, although some improvement may be anticipated with widespread implementation of the Training and Visit (T&V) System of Agricultural Extension. T&V requires a strong research-extension interaction through deployment of subject matter specialists who receive technical information from researchers and who are required to transmit it to extension personnel at regularly scheduled meetings.

Doll (1980) reports little opportunity or incentive in Latin America to publish the results of research. Although independent research is conducted in the Philippines by University of the Philippines at Los Baños, the Bureau of Plant Industry, and IRRI, there is a considerable time lag before this information reaches field workers.

Extension personnel have relied heavily on information from chemical companies in recommending weed control practices to farmers. Chemical company representatives are frequent visitors to government agriculture offices, where they provide brochures, posters, and even T-shirts to promote their products. The companies marketing herbicides and other chemicals have a considerable social responsibility to ensure that the information they provide is clear and accurate. With their considerable financial back-up, these companies play a major role in the education of extension personnel in the developing countries of tropical Asia.

The rainfed wetlands and drylands of tropical Asia "where technology is consistently less effective and where it requires greater precision in application — are areas most poorly served by extension services. There, farmers are even more dependent on the information provided by chemical companies, mainly on herbicide container labels. Moody et al (1980) found serious inadequacies in the labels of Philippine company-produced phenoxy acid. In some instances, companies had even failed to provide recommended application rates per hectare. In the U.S., the Environmental Protection Agency (EPA) introduced a rigid system of labeling 10 years ago.

The complexity of new weed control technology has been reported to limit adoption in Latin American (Doll 1980) and Africa (Akobundu 1980). Parker (1972) believes that conventional selective herbicides for annual crops are not suitable for uneducated farmers. He advocates using educationally simple procedures to control weeds in rice, such as granular formulations where "a visible sense of quantity applied per unit area is retained and much of the educational problem is overcome."

Simplification of weed control practices, improved labeling of herbicide containers, and more intensive and practical training in chemical weed control for extension workers, particularly in rainfed areas, probably would increase adoption of new weed control methods by farmers in tropical Asia. Training extension workers in weed science also was identified as a need in Latin America (Doll 1980) and Africa (Akobundu 1980).

## Credit

Access to cash or credit is likely to determine whether many new weed control practices will even be considered as viable options by small farmers. Not only does lack of credit reduce a farmer's ability to take advantage of herbicides; it also reduces potential gains from better weed control and makes better weed control less attractive by lowering the farmer's ability to use other inputs, such as fertilizer, to increase crop yields.

How important is credit as a constraint to adoption of effective weed control technology? Moody and De Datta (1980) state that "in irrigated transplanted rice fields of Asia, farmers generally do an adequate job of weed control." They base this conclusion on studies conducted in a number of countries (IRRI 1979). Since those studies also report that many farmers faced credit problems, this may indicate that lack of credit has not been a major constraint in these areas.

However, effective weed control does not imply chemical weed control. Farmers' access to credit may not have been a major constraint to achieving adequate levels of weed control in irrigated, transplanted rice areas because labor could be substituted for herbicides. Access to inexpensive credit could make use of herbicides more attractive, but small farmers may be able to achieve similar levels of control by using labor-intensive weeding methods at lower cost.

Such substitution of labor for chemicals is not a viable economic option in the developed countries or where farms are large. There, high interest rates and high application costs are major restraints to wider use of chemicals.

Cooperatives, including farmer-owned organizations that purchase herbicides and lend capital for short-term or long-term investments and for marketing purposes, may be viable alternatives to tight credit and high interest rates in both developed and developing countries. However, the experience of agricultural cooperatives in the developing countries shows that such organizations are often beset with problems.

Proper timing of herbicide applications also is important to ensure their efficacy. Not only should a farmer know the proper time to apply the herbicide, he should also be able to procure it in time. Even if the herbicide is available in the market, the farmer may lack the cash to purchase it for timely application.

The pattern of cash flows on small, low-resource farms may be important here. For example, application of a preemergence herbicide requires that a farmer purchase it at a time when his cash reserves are likely to be low because they have already been used to meet land preparation and seed costs.

If the farmer is forced to borrow, the effective cost of the herbicide is higher because of the interest on the loan. If low interest credit is not available, this effective cost to the farmer may be as high as double the actual cost of the herbicide. Interest rates of 100% or more per annum are common in the rural areas of less developed countries. Even where formal sector credit is available at nominally low interest rates, small farmers often find it difficult to obtain such credit on time. The real cost of such credit is understated by the nominally low interest rates when farmers have to spend considerable time and effort to secure such loans.

In rainfed rice cultivation, risk factors also may act as disincentives to use of herbicides. Drought or floods, or both, can damage the crop. If funds borrowed at high interest rates are used to purchase inputs, the farmers may face considerable financial loss if a crop fails and may be forced deeper into debt.

In general, rainfed rice (wetland and dryland) is common in less developed regions where farmers usually have low cash incomes and assets, and also are poorly served by formal credit institutions, roads, markets, and extension services. Compared with irrigated areas, rainfed fields have higher weed problems and lower productivity.

Probably the most important reason for the lower level of weed control in rainfed rice cultivation is the lower potential productivity of rainfed rice. The additional crop gains from better weed control often cannot compensate for the costs of the control. Until recently, farmers in rainfed environments grew the traditional tall rices with low yield potential. Even where farmers have shifted to modern cultivars, low levels of fertilizer and other inputs usually keep average yields low (Mandac et al 1981). Lack of credit may be an important contributing factor, but it is difficult to assess its relative importance because simple and effective chemical weed control technology for rainfed rice was either unknown or unavailable till recently. Availability of inexpensive credit certainly appears to stimulate adoption of new rainfed rice technology that utilizes herbicides for weed control in direct-seeded rice (Nicolas et al 1980).

One encouraging feature observed in areas of the Philippines is the development of informal credit institutions to supply credit for agricultural inputs to farmers, once the economic profitability of a new technology has been demonstrated (Barlow et a1 1982). Such informal sector institutions usually are capable of delivering timely credit to farmers and are more accessible to large groups of small farmers.

## Government policies

Many factors in the farmer's production environment are influenced by governmental actions; thus, farm-level changes in technology cannot be discussed in isolation from general governmental policy directions and interventions.

In the U.S., governmental regulatory restraints limit herbicide use. For example, propanil is banned in most of California because of the risk of injury to highly susceptible fruit trees. The use of 2,4-D is banned in Mississippi and Arkansas, where cotton is grown. Other phenoxy herbicides are regulated by state government agencies. The new preemergence herbicides manufactured in the US. and sold in many parts of the world are not fully labeled for use in the US. Thiobencarb, butachlor, pendimethalin, oxadiazon, and acifluorfen can only be used on limited acreage by means of special localized registration procedures of the EPA.

In Arkansas during 1980, three herbicides (butachlor, thiobencarb, and acifluorine) were applied on limited acreage through emergency registration. But their availability in future seasons is not guaranteed. Butachlor had been tested sufficiently by 1973 to be recommended for general use, but it still has not been registered by the EPA. These regulations make it difficult for Extension Services to develop extensive weed control programs.

In the past two decades in many less developed countries of Asia, rice self-sufficiency has been a dominant development theme, accompanied by the objective of creating more employment for the expanding rural population. Modern rice technology has increased labor use and output. Generally it also has raised farm-level profits. This has been particularly true in the more favorable irrigated environments. By and large, societal objectives (as articulated by governments) and individual farmer's objectives tended to coincide. Government intervention to facilitate the spread of new rice technology owed much to this congruence of interests.

Governments acted to remove various institutional constraints to the adoption of new technology. Provision of inputs, extension advice, and low-interest credit facilitated the spread of new rice technology. The overall improvement in output was accompanied by increases in labor absorption. The increase in labor absorption came from increased cropping intensity and increased management inputs. Many of the management inputs related directly or indirectly to weed control practices.

In many countries, changes were instituted in rice markets, in input markets, and in credit and tenure institutions. Now, recent trends in weed control technology may pose new major policy issues.

The prevailing structure of prices in most developing countries owes much to government intervention. Currencies often are overvalued and domestic prices subsidized or fixed. These prices are not necessarily accurate guides to the relative scarcity or abundance of particular goods or resources. What may be profitable to an individual farmer may not be desirable for the societal point of view.

Of particular interest is the clear shift away from labor-intensive weed control techniques. In the Philippines, transplanting and weeding costs have risen much faster than the cost of chemical herbicides (Table 3). The increasing popularity of direct seeding and herbicides in both the irrigated and rainfed areas may be indicative of future trends elsewhere. In rainfed environments, these changes may be accompanied by higher cropping intensity and output, and total labor use over the year may remain relatively unchanged (Jayasuriya et a1 1981).

However, it is not likely that output in irrigated areas will increase with the substitution of herbicides for labor. Societal objectives of employment, equity, and income distribution may conflict with the implied consequences of new rice production practices. Careful social benefit:cost studies may be required for appropriate government action.

Economic development is characterized by rising wages for labor, leading to greater capitalization of agriculture. A study of changes in rice farming in Central Luzon indicates that this process may be underway in the Philippines (Cordova et a1 1981). If this is the case and if it represents a trend in other countries in the region, then less labor-intensive modern weed control technology will be more widely adopted.

However, government policies can exert a great deal of influence on trends. Policies which maintain or even lower the real price of rice while input prices go up squeeze farmers' profit margins. While better weed control may help to maintain yield levels, increasing herbicide and labor costs in the context of relatively declining

**Table 3. Changes in weed control costs in the Philippines.**

| | Costs (US$/ha) | | Increase (%) |
|---|---|---|---|
| | 1975 | 1980 | |
| Herbicide application | | | |
| 2,4-D Liquid | 7.26 | 8.35 | 16 |
| Granular | 6.84 | 9.19 | 34 |
| Butachlor Liquid | 12.74 | 14.86 | 17 |
| Granular | 13.42 | 16.22 | 20 |
| Transplanting and weeding | 8.22 | 13.33 | 62 |

rice prices may reduce its attractiveness. Thus, farmers may reduce inputs for rice production, resulting in lower rice yields, or they may switch to other feasible and attractive crops.

## CONCLUSION

The most serious constraints to adoption of new weed control technologies in developing countries are the complexity of technology — leading to extension difficulties — and the relative costs of chemicals, rice, and labor. Farming system considerations also may affect adoption.

In developed countries, a major constraint is the rigid control of herbicide registration. In addition, extension personnel often are overloaded with other activities, resulting in less than ideal coverage at the farm level.

These issues need to be addressed in a positive manner if widespread adoption of new weed control technology is to be realized.

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## DISCUSSION

MUKHOPADHYAY (comment): In the developing countries, you need a kind of training. Training is very important, not only to the extension workers but also to the administrators. In India, if the administrators are not aware of the use of herbicides, they do not make the policy to disseminate information to the changers. It is not the extension worker who decides the information to be disseminated to the farmer — it is the person at the top. We have in South Asia a type of sharecropper farmer. We also have seen timely weed control by hand weeding. We have seen the farmers who cultivate for themselves—the owner cultivators—do the practice better than the sharecroppers. We have a lot of absentee landlords who live in the cities and the fanners who are sharecroppers are the poor adoptors.

BAKER: A large labor force requirement is necessary for harvesting in the gama system. These people also are available for weeding. Suppose you develop harvesting techniques that do not require this labor, what happens to your weed control practices?

*DENNING:* If you have gone to mechanization of harvesting, it means that labor rates have gone extremely high. I think it is a sequential process. One of the first things to go would be hand weeding. because it is the hardest work. Hand transplanting may go too and planting becomes mechanized. The next stage may be harvesting, but by that time I think you have already passed the stage where you have switched to herbicides and have a low labor input for weeding.

BAKER (comment): In the U.S., I think it was due to the fact that the binder-thresher method of harvesting was replaced by the combine-dryer system of harvesting. Consequently, you did not need labor. Fortunately, 2,4-D came along at the same time and needs for industrial labor increased.

GREENLAND (comment). The question of displacement of labor is complex. The relationship of labor availability to farm size is also very important. As a general backup to development of machinery, we have a policy about the areas where these are likely to be used. Usually, farm size determines this. For instance, small threshers are moving very quickly in Thailand and Burma where the average farm size is 3-5 ha. There is also strong interest in Pakistan and the Punjab in India. In eastern India, we find no impact at all nor interest in that type of machinery. I think you can translate this to most of the rice areas. In Indonesia, for instance, there is a marked difference in what is needed in the transmigration areas where farm size is of the order of 5 ha. Without machinery and without available labor, they are unable to manage those farm sizes. It has been one of the significant problems. The more recent transmigration schemes have reduced that farm size. But they certainly need more machinery very urgently in many of those areas if they are to develop them successfully. In central Java, where farm size often is about 0.2 ha, there is not likely to be much impact. So one has to see machinery development, machinery for tillage, and herbicide use very much against the background of a wide range of conditions within the rice producing areas in the developing countries and to be sensitive to those differences. I think that one should recognize that the gama system is not a long standing traditional system in the Philippines. It is relatively recent and used since 1880-1900. The Philippine receptiveness to new technology is a reflection of the relative newness of the rate of change in most rice farming in the country.

COX (comment): In New South Wales, Australia, there is a general research levy of, I think, Australian $0.25/t of rice produced. Of that, 75% would be given directly to research projects and the remainder would go to extension funding. That may be the employment of a technical officer to take research findings and implement them on various farms throughout the rice-growing areas. Also, the rice growers contribute to a fund for the publication of literature on weeds, cultivars, and other developments at the research station which they feel they need to know more about. In addition, a healthy trend has developed recently in that a lot of the research officers based on research stations are doing trials in areas where the problems exist, rather than on the station. To see what is going on in these district research trials, the farmers have contributed funds to hire buses a couple of times a year to look at the trials throughout their district. They may have to travel over 200 miles. But it is the grower who is funding these projects.

*DENNING* (comment): At present, with the price of rice in the Philippines, 1 don't think farmers would be very happy to have even a few centavos taken off.

*HUEY* (comment): I know of no state in the U.S. in which there are farmer check-off funds designated for extension personnel or activities.

EASTIN (comment): One farmer cooperative in Texas earmarks one-half of its check-off for a specific extension person. This is voluntary.

TEMPLETON (comment): It should be emphasized that government stabilization of rice prices is extremely important to the rate of acceptance of new technology by rice growers.

# IMPACT OF THE CHANGING ENERGY SITUATION ON WEED CONTROL TECHNOLOGY

D. T. O'Brien and M. Kikuchi

Since the mid-1960s, the introduction of new rice cultivars and associated changes in the methods of production have resulted in large increases in yields in many areas of Asia. However, the higher yields have been obtained with increased use of fertilizers and pesticides, irrigation, and more intensive crop management. Scientists who are concerned about increasing rice production and improving human welfare need to consider the appropriateness of their research efforts in the light of the changing energy situation and the increases in the prices of oil-based farm inputs. Economic analyses of possible farm-level adjustments, government policies, and national and international impacts are also needed.

The major significance of the energy situation to rice production is through its effect on the prices of farm inputs, the consequent adjustments in the methods and levels of rice production, the resultant effect on the price of rice, the effect on the welfare of producers and consumers, and the impact on the national economies. A series of comprehensive studies is necessary if the above effects are to be measured.

Most inputs used in rice production interact with each other and have either a primary or secondary weed control component (Moody 1978). Primary weed control methods include hand weeding and herbicide application. Secondary methods include cultivation, planting method, planting density, cultivar grown, fertilizer, water management, and crop rotation. Consequently, adjustments in many aspects of a rice production process need to be considered if clear notions of the impacts of the changing energy situation on weed control are to be obtained.

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## ENERGY AND RICE PRODUCTION

Rutger and Grant (1980) have estimated energy input levels per hectare of rice for two specific locations in the United States and the Philippines (Table 1). The average rice yield of 6.5 t/ha and the consequent energy output level in the United States are about twice those of the Philippines. However, the total (nonhuman) energy input for rice production in California is almost four times that of the Laguna system. Consequently, the energy efficiency ratio (ratio of energy output to energy input) of the US. system is about half that of the Philippines.

The most interesting aspect of the energy input levels of the two systems is the relative amounts of machinery and petrochemical-based inputs (fuel and chemicals). They are what will be affected both directly and indirectly by oil prices.

Fuel is the largest component of the total energy input for both systems (29% of total nonhuman energy for the U.S. and 47% for the Philippines), although the

**Table 1. Energy input and output levels per hectare for rice production in the United States and the Philippines (adapted from Rutger and Grant 1980).**

| | Sacramento, California[a] | | Laguna, Philippines[b] | |
|---|---|---|---|---|
| | Quantity | Energy content (thousand kcal) | Quantity | Energy content (thousand kcal) |
| | | *Input* | | |
| Labor | 23.6 h | (7)[c] | 814.4 h | (228)[c] |
| Machinery | 37.7 kg | 742 | 4.5 kg | 81 |
| Gasoline | 55.2 liters | 558 | 131.3 liters | 1,327 |
| Diesel fuel | 225.4 liters | 2,573 | | |
| Electricity | 29.1 kwh | 85 | | |
| Nitrogen | 132.3 kg | 1,945 | 33.0 kg | 485 |
| Phosphate | 56.0 kg | 168 | | |
| Zinc | 9.8 kg | 49 | | |
| Insecticide | 0.6 kg | 50 | 3.2 kg | 256 |
| Herbicide | 4.0 kg | 354 | 0.7 kg | 70 |
| Copper sulfate[d] | 11.2 kg | 56 | | |
| Seed | 180.5 kg | 722 | 88.0 kg | 352 |
| Irrigation | 250 cm | 2,139 | 15 cm | 227 |
| Drying | 6,969 kg | 1,394 | | |
| Transportation | 451 kg | 116 | | |
| Total | | 10,951 | | 2,798 |
| | | *Output* | | |
| Rice yield | 6,513 kg | 19,226 | 3,232 kg | 9,541 |
| | | *Energy efficiency ratio* | | |
| kcal output/kcal input | | 1.76 (1.75)[e] | | 3.41 (3.15)[e] |
| 1000 kcal output/h of labor | | 815 | | 12 |

[a]All input quantities except machinery and irrigation are from FEDS 1977. FEDS inputs are 104% of actual in order to account for about 4% reseeding. [b]Data for 1972-73 wet season. [c]Assuming 280 kcal energy/hour of labor, from Kuether and Duff (1979). [d]Copper sulfate is used as a herbicide in the U.S. [e]Includes energy content of labor.

absolute amount of fuel consumption in the U.S. is more than twice that of the Philippines. In both systems, the next largest component is fertilizer, which accounts for about one-fifth of the total energy input in each case. Herbicides are a small component, constituting only 3.7% of total energy input in the U.S. and 2.5% in the Philippines.

In contrast to its low energy efficiency level, the U.S. system of rice production shows high "labor productivity" (kcal of output per hour of labor) relative to the Philippine system. This is due both to the low level of labor input and to the high level of energy output in the U.S.

Kuether and Duff (1979) have estimated that human energy contributes only a small portion of total energy input to rice production in the Philippines. The estimated human energy for rice production is not the food energy intake to provide labor, but the energy output of laborers while performing farm tasks. The energy efficiency ratios, based on their energy input estimates, are even higher than the Rutger and Grant (1980) estimate for Laguna. If the average human energy requirement of 280 kcal/hour of labor estimated by Kuether and Duff is assumed for the Rutger and Grant case, the energy efficiency ratio for Laguna (Table 1) is reduced from 3.41 to 3.15, while that for California is revised from 1.76 to 1.75. These figures compare with an estimate of 1.92 for Japanese rice production in 1970 (The Committee on Agriculture Policy Research, Japan, 1978). Even taking human energy into account, the U.S. system of rice production has an energy efficiency level that is still only around half that of the Philippine system.

It may appear that the U.S. rice production system is more vulnerable than the Philippine system to rising petroleum prices and associated increases in prices of other petroleum-based inputs. The lower level of energy use and the higher energy efficiency ratio of the Philippine system, however, do not necessarily mean that it will be unaffected by rising oil prices. Energy input in the form of fertilizer is still a substantial share of total energy input in the Philippine system, and if farm equipment such as hand tractors and threshing machines is adopted, significant increases in total energy input will result.

Direct measures of weed control are likely to be affected only slightly by the changing energy situation. Herbicides represent only a small portion of the total energy input in both the U.S. and the Philippine systems. Even if the estimates of human energy for weeding are added to the energy in the form of herbicide, the energy input levels for weed control represent only 3-4% of the total energy input.

## PAST AND PROJECTED WORLD PRICES

In the latter part of 1973, the supply of oil from the Organization of Petroleum Exporting Countries (OPEC) was severely curtailed. The price of oil increased by 42.8% in 1973 (Table 2). The price of urea fertilizer increased to almost twice that of 3 years earlier. The price of rice more than doubled, partly because of the worldwide food shortage during 1973-74. By 1974, the price of oil was over five times that of 1972. Urea fertilizer reached an all-time high price of $316/t in 1974 but declined to $198 in 1975. Rice prices continued to increase, reaching $542/t in 1974. Prices had stabilized somewhat by 1975, but were still well above the "pre-energy crisis" levels.

**Table 2. Actual (1960-79) and projected (1980-90) world prices for crude oil, urea fertilizer, and rice (from World Bank 1980).**

| | Price | | |
|---|---|---|---|
| | Oil[a] ($/barrel) | Urea ($/t) | Rice ($/t) |
| 1960 | 1.5 | – | 125 |
| 1965 | 1.3 | 96 | 136 |
| 1970 | 1.3 | 48 | 144 |
| 1971 | 1.7 | – | 129 |
| 1972 | 2.1 | – | 147 |
| 1973 | 2.9 | 95 | 350 |
| 1974 | 11.2 | 316 | 542 |
| 1975 | 10.9 | 198 | 363 |
| 1976 | 11.7 | 112 | 255 |
| 1977 | 12.8 | 127 | 272 |
| 1978 | 12.9 | 145 | 368 |
| 1979 | 20.0 | 173 | 331 |
| 1980 | 28.0 | 207[b] | 464 |
| 1981 | 32.0 | 280[b] | 511 |
| 1982 | 35.7 | – | 589 |
| 1985 | 47.3 | 368 | 764 |
| 1990 | 73.6 | 518 | 1,056 |

[a]1960 to 1971 prices are for Saudi Arabian light. Post-1971 prices are average OPEC petroleum prices. [b]Actual prices from *Bulletin Today,* Manila, Philippines, 23 July 1981.

In 1979, oil prices once again rose sharply to $20/barrel from $12.90 in 1978. The price of urea fertilizer increased to $173/t, and rice declined slightly to $331/t.

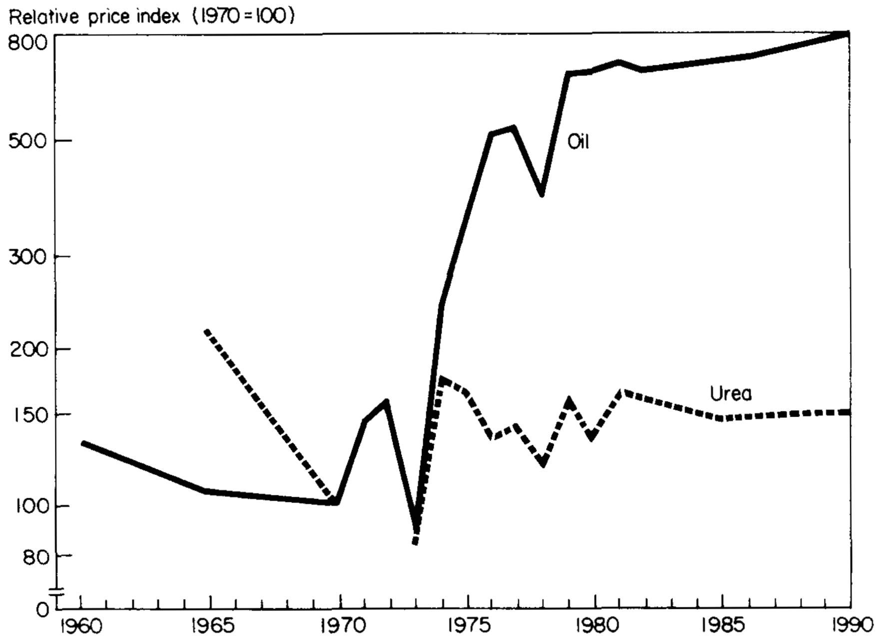
World Bank projections indicate continued increases in the prices of oil, urea, and rice. The Bank estimates that by 1990 the price of crude oil will be almost four times its 1979 level. Rice and urea prices are both predicted to increase around threefold between 1979 and 1990. As a result, the price of urea relative to the price of rice is expected to remain almost unchanged through the 1980s, and that of oil will show only a slight increase during the same period (Fig. 1). The price projections in Table 2 suggest, then, that the worsening trends in the prices of oil and urea relative to that of rice during the 1970s may ease over the next decade.

## CURRENT INPUT AND LABOR USE IN RICE PRODUCTION AND CHANGES IN RELATIVE PRICE STRUCTURE

Irrigated and transplanted rice regimes are the most important methods of rice production in most parts of Asia, but practices vary. The incidence of weeds and the need for weed control differ significantly between rice production regimes. Different conditions imply different costs.

### Japan

Japanese rice farming has been characterized by intensive use of labor and fertilizer. In the past two decades, however, there has been a major change: mechanization. With the introduction of the transplanting machine in the early 1970s, mechaniza-




**1.** Prices of oil and urea relative to rice price in world markets.

tion of all tasks in rice production from land preparation to postharvest activities was completed. The process of mechanization in Japanese rice production is reflected in changes in current input structure and labor use.

The current input ratio (the ratio of current input costs to total output) remained around 13% between 1962 and 1978 (Table 3). The cost of fertilizer has been the largest component of current input costs. Its share, however, has been declining. The cost of fertilizer was more than 9% of total output and almost 70% of total current input costs in 1962, but declined to 6% and 45% in 1978, respectively. This was due partly to the absolute decline in the real costs (nominal cost deflated by output price) of fertilizer and partly to the increases in other current inputs such as herbicides and power. The use of gasoline and other oils for operating farm machinery increased almost threefold between 1962 and 1970 and by another 40% over the period 1970 to 1978, keeping pace with rapid mechanization.

Another current input which has shown a steady increase, both absolutely and relatively, is herbicide. The share of herbicide cost, which had been only 0.4% of total output and about 3% of total current inputs in 1962, increased to 1.5% and 11% in 1978, respectively. Although its share is still much smaller than that of fertilizer, the herbicide cost has increased more rapidly than that of other current inputs.

In contrast with increased mechanization and herbicide use, there has been rapid reduction of labor required for rice production (Table 4). The 1978 level of weeding labor was about one-third of that in 1962. As a result, the total labor input per hectare was reduced from 192 man-days in 1962 to 90 man-days in 1978.

Much of the adjustment in current input structure and labor use in Japanese rice

**Table 3. Changes in current input structure of rice production per hectare in Japan, 1962-78[a] (from Japan Ministry of Agriculture and Forestry [n.d.]).**

| | Unit | 1962 | | | 1970 | | | 1978 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Quantity | Paddy equivalent (kg/ha) | % | Quantity | Paddy equivalent (kg/ha) | % | Quantity | Paddy equivalent (kg/ha) | % |
| Total paddy production | kg | 5620 | 5620 | 100.0 | 6050 | 6050 | 100.0 | 6650 | 6650 | 100.0 |
| Paddy price | ¥/kg | 66.5 | | | 11.5 | | | 235.6 | | |
| Current inputs: | | | | | | | | | | |
| Seed | kg | 37 | 42 | 0.7 | 39 | 56 | 0.9 | 42 | 99 | 1.5 |
| Fertilizer | | | | | | | | | | |
| Ammonium sulfate | kg | 82 | 26 | 0.5 | 40 | 7 | 0.1 | 36 | 5 | 0.1 |
| Compound (low) | kg | 262 | 85 | 1.5 | 128 | 26 | 0.4 | 57 | 12 | 0.2 |
| Compound (high) | kg | 115 | 58 | 1.0 | 479 | 153 | 2.5 | 599 | 189 | 2.8 |
| Other purchased | – | – | 146 | 2.6 | – | 95 | 1.6 | – | 114 | 1.7 |
| Self-supplied | kg | 7058 | 209 | 3.7 | 5127 | 127 | 2.1 | 2503 | 90 | 1.4 |
| Total | – | – | 524 | 9.3 | – | 408 | 6.7 | – | 410 | 6.2 |
| Total nitrogen applied | kg | 117 | | | 120 | | | 119 | | |
| Insecticide and pesticide | | | | | | | | | | |
| Mercury, powder | kg | 14 | 12 | 0.2 | – | – | – | – | – | – |
| BHC 3%, powder | kg | 8 | 7 | 0.1 | 3 | 2 | 0.0 | – | – | – |
| IBP, powder | kg | – | – | – | 3 | 2 | 0.0 | 5 | 5 | 0.1 |
| Kasugamycin, dust | kg | – | – | – | 7 | 5 | 0.1 | 2 | 1 | 0.0 |
| BPMC, powder | kg | – | – | – | – | – | – | 7 | 4 | 0.1 |
| Others | – | – | 53 | 0.1 | – | 66 | 1.1 | – | 112 | 1.7 |
| Total | – | – | 72 | 1.3 | – | 75 | 1.2 | – | 122 | 1.9 |

Continued on opposite page

**Table 3** continued

| | Unit | 1962 | | | 1970 | | | 1978 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Quantity | Paddy equivalent (kg/ha) | % | Quantity | Paddy equivalent (kg/ha) | % | Quantity | Paddy equivalent (kg/ha) | % |
| Herbicide | | | | | | | | | | |
| 2,4-D, liquid | kg | 0 | 2 | 0.0 | 2 | 1 | 0.0 | – | – | – |
| PCP, granular | kg | 5 | 11 | 0.2 | 8 | 7 | 0.1 | – | – | – |
| CNP, granular | kg | – | – | – | 7 | 7 | 0.1 | 14 | 12 | 0.2 |
| Thiobencarb simetryn, granular | kg | – | – | – | – | – | – | 8 | 14 | 0.2 |
| Others | – | – | 12 | 0.2 | – | 43 | 0.1 | – | 77 | 1.2 |
| Total | – | – | 25 | 0.4 | – | 58 | 1.0 | – | 103 | 1.5 |
| Power | | | | | | | | | | |
| Gasoline and other oil | liter | 69 | 38 | 0.7 | 188 | 62 | 1.0 | 262 | 82 | 1.2 |
| Electricity and others | – | – | 11 | 0.2 | – | 13 | 0.2 | – | 21 | 0.3 |
| Total | – | – | 49 | 0.9 | – | 75 | 1.2 | – | 103 | 1.5 |
| Others [b] | – | – | 52 | 0.9 | – | 72 | 1.2 | – | 62 | 0.9 |
| Total | – | – | 164 | 13.6 | – | 744 | 12.3 | – | 899 | 13.5 |

[a] Paddy equivalent costs are derived by dividing each cost value by the price of paddy. The dash (–) stands for none or not applicable. [b] Other material inputs such as rope and vinyl. Cost for irrigation is not included.

**Table 4. Changes in labor input for rice production per hectare by task in Japan, 1962-78 (from Japan Ministry of Agriculture and Forestry [n.d.]).**

| | Labor [a] (man-days/ha) | | | Change (%) | |
|---|---|---|---|---|---|
| | 1962 | 1970 | 1978 | 1970-62 | 1978-70 |
| Land preparation | 17 | 14 | 11 | -18 | -21 |
| Transplanting | 31 | 29 | 12 | -6 | -41 |
| Weeding | 26 | 16 | 9 | -38 | -44 |
| Harvesting and threshing | 66 | 44 | 21 | -33 | -52 |
| Others | 52 | 43 | 31 | -17 | -14 |
| Total | 192 | 146 | 90 | -24 | -38 |
| % of total labor that is hired | 11 | 11 | 3 | | |

[a] 1 man-day = 8 hours.

production has been induced by changes in the relative price structure. The wage rate in agriculture has shown an almost steady increase relative to the price of rice throughout the past two decades (Fig. 2). The agricultural wage rate relative to the prices of other inputs has also risen, except for fertilizer and power prices during the two “oil crisis” periods. The rising price of labor relative to those of other inputs has provided strong incentives for Japanese rice farmers to save labor by mechanization and by applying more herbicide. The prices of agricultural chemicals and machinery relative to rice have not altered significantly, even after the oil crisis of 1973-74. Their prices have declined relative to the wage rate, although they have shown a rising trend since 1978 relative to the price of rice.

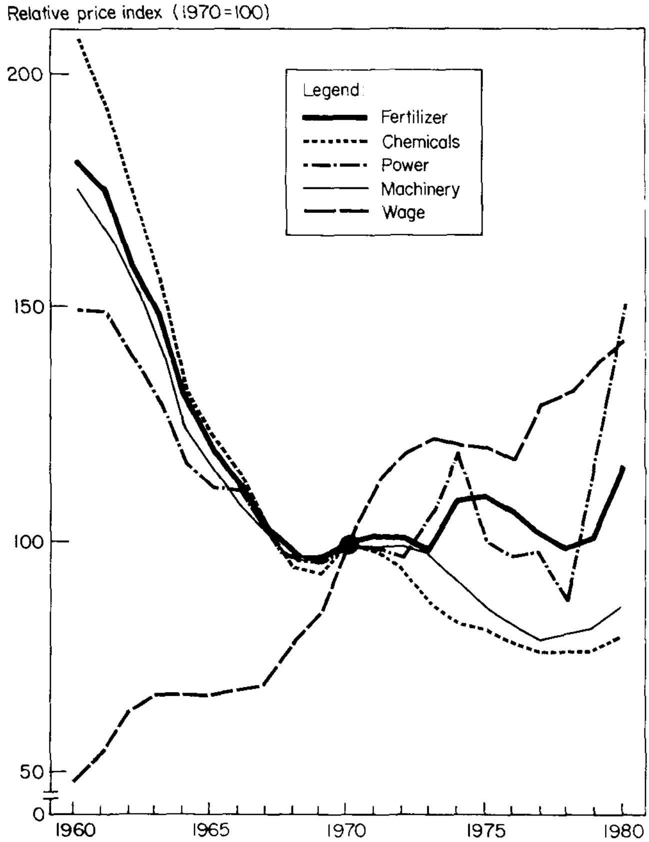
The price of power has oscillated since the first oil crisis, and the price of fertilizer seems to have followed the power price (Fig. 2). The trend of declining fertilizer price relative to rice price came to an end in the late 1960s because of a leveling off in rice price due to overproduction. The oil crisis of 1973-74 resulted in a reversal of the trend in the relative price of fertilizer. During the subsequent period, the average quantity of fertilizer applied by Japanese rice farmers did not increase.

In contrast, a declining relative price of herbicides was accompanied by increased rates of herbicides application, even after the oil crisis. There was increased substitution of chemicals for manual weed control. As a result, the real cost of direct weed control (herbicide cost plus labor cost for weeding) remained at about 4% of total output throughout the 1962-78 period.

Continued increases in the price of fertilizer could have serious impact on Japanese rice farmers, as fertilizer is the largest component of current inputs. Rising fuel prices could also seriously affect Japanese rice production in the future, given the high degree of mechanization that has been introduced over the past two decades.

## Laguna, Philippines

The data on the adjustments in rice farming to changing price levels for the Philippine case are from Laguna Province, where rice production is characterized by a high degree of technological development. The diffusion of modern cultivars has been rapid and thorough, and has been accompanied by increasing application of fertilizer and pesticides and by the adoption of improved cultural practices such as




**2.** Indices of input prices relative to rice price, Japan.

intensive weeding and straight row planting. The mechanization of land preparation by hand tractors, which began in the mid-1960s prior to the diffusion of modern cultivars and was completed by the mid-1970s, was another major technological change. With the introduction of portable threshers, the method of rice farming in Laguna became one of the most progressive in Southeast Asia.

An increase in rice yields due to the introduction of modern cultivars has been supported by the increased use ofcurrent inputs, especially nitrogen fertilizers (Table 5). The share of curent input cost in total production cost increased from 5% in 1966 to over 16% in the 1970s. A significant increase in the value added (total output less paddy equivalent cost of current input) was due to the large increase in total output after modern cultivars were adopted. But the increase in the value added has not been as great since 1970, despite a steady increase in rice yield. From 1970 to 1975 it remained constant. The real (paddy equivalent) cost of fertilizer declined from 1975 to 1978, although its share in total output and total current input costs was still the

**Table 5. Changes in current input structure of rice production per hectare, Laguna, Philippines, 1966-78 wet seasons.**

| | 1966 | | 1970 | | 1975 | | 1978 | |
|---|---|---|---|---|---|---|---|---|
| | kg/ha | % | kg/ha | % | kg/ha | % | kg/ha | % |
| Paddy production | 2540 | 100.0 | 3530 | 100.0 | 3661 | 100.0 | 3984 | 100.0 |
| Current input:[a] | | | | | | | | |
| Seed | 44 | 1.7 | 67 | 1.9 | 83[b] | 2.3 | 83[b] | 2.1 |
| Fertilizer[c] | 61 (17) | 2.4 | 186 (59) | 5.3 | 357 (81) | 9.8 | 312 (77) | 7.8 |
| Insecticide | 1 | 0.0 | 35 | 1.0 | 75 | 2.0 | 74 | 1.9 |
| Herbicide | 9 | 0.4 | 21 | 0.6 | 22 | 0.6 | 33 | 0.8 |
| Others | 11 | 0.5 | 54 | 1.5 | 80 | 2.2 | 144 | 3.6 |
| Total | 126 | 5.0 | 363 | 10.3 | 617 | 16.9 | 646 | 16.2 |
| Value added | 2416 | 95.0 | 3167 | 89.7 | 3044 | 83.1 | 3338 | 83.8 |
| (modern cultivar adoption, %) | (0) | | (96) | | (100) | | (100) | |

[a]Costs in paddy equivalent. [b]Estimated values. [c]Total nitrogen applied is indicated in parentheses.

**Table 6. Changes in labor inputs for rice production per hectare by task, Laguna, Philippines, 1966-78 wet seasons (from Smith and Gascon 1979).**

| | 1966 | 1970 | 1975 | 1978 |
|---|---|---|---|---|
| | *Man-days/ha* | | | |
| Land preparation | 19 | 11 | 11 | 9 |
| Transplanting | 10 | 11 | 11 | 10 |
| Weeding | 11 | 19 | 32 | 27 |
| Harvesting and threshing | 36 | 37 | 36 | 28 |
| Others | 10 | 16 | 22 | 12 |
| Total | 86 | 94 | 112 | 86 |
| | *Percent* | | | |
| Portion of total labor that is hired | | | | |
| Weeding | 19 | 63 | 81 | 82 |
| Total | 60 | 70 | 80 | 79 |

largest. In contrast, the cost of herbicide showed a steady increase, even after 1975.

As the new rice technology was adopted, the total labor used per hectare in rice production increased by 30% between 1966 and 1975 (Table 6). During this period, the labor requirement for land preparation decreased substantially because hand tractors were substituted for draft animals. This decrease, however, was more than compensated for by the almost threefold increase in the level of hand weeding labor.

In contrast to the labor use in Japanese rice farming, that in Laguna is characterized by a high dependency on hired labor (Tables 4 and 6). The percent of total labor that was hired in Laguna was 60% in 1966, and it increased after the adoption of the new rice production technology. Especially distinct has been the increased use of hired labor for weeding. In Laguna, the increased need for hand and rotary weeding has been met mainly by hired landless workers or near-landless small farmers who do weeding without receiving a cash wage but who operate under a labor hiring arrangement called the *gama* system (Barker and Hayami, this volume). Although weeding labor increased more than the other categories of labor between 1966 and 1975, it has decreased since 1975. The total labor use in 1978 was as low as that in 1966, due mainly to reductions in weeding, harvesting, and threshing labor.

The changes in input use levels for rice production from 1966 to 1970 can be explained largely by the introduction of new rice technology, which required increased rates of fertilizer, pesticides, and labor to obtain the higher potential yields. The changes in input structure since 1970 have been due less to the impact of changing technology and more as a response to changing relative prices.[1]

As was the case in Japan, the declining trend of fertilizer price relative to rice, which had encouraged increased use of fertilizer during the initial modern cultivar adoption period, was reversed after the first oil crisis. This trend in the relative price of fertilizer was probably the major reason why the increasing trend in fertilizer application has eased since 1975.

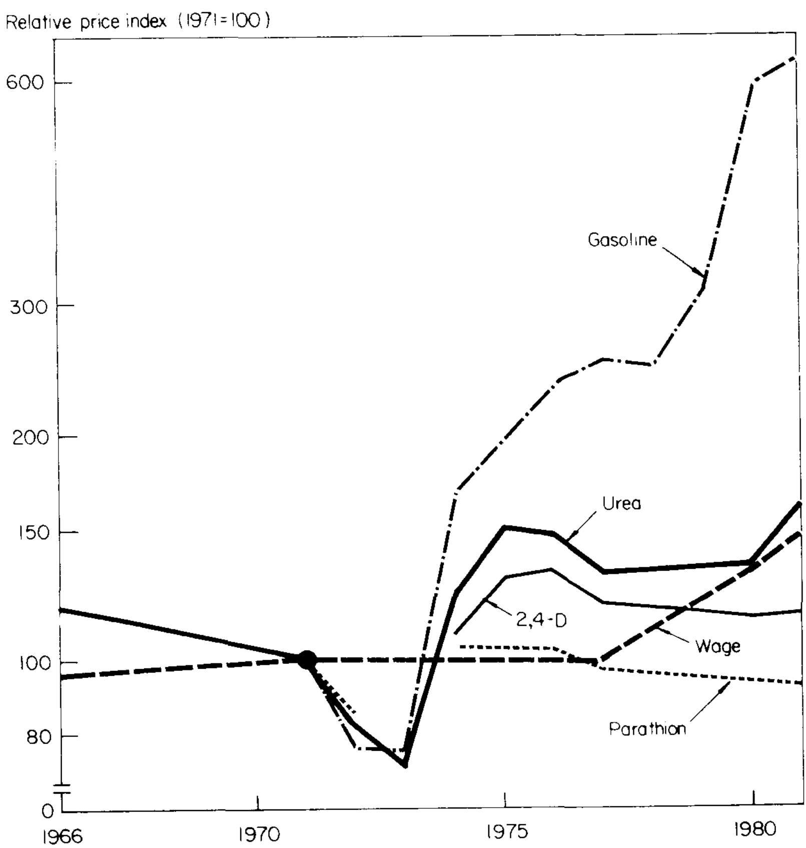
[1]The adoption of the mechanical thresher and the introduction of butachlor are two technologies that affected rice production and labor use levels during the 1970s.

The price of gasoline in 1981 was more than 16 times higher than it was in 1971, and the price of gasoline relative to the price of rice was 6.5 times higher. Faced with this rapid increase in the relative price of power, farmers in Laguna lowered their power consumption levels. For land preparation some farmers shifted back from the use of hand tractors to use of animal power.

The relative price of herbicide (2,4-D) also rose toward 1976. The increase in the price relative to rice and labor, however, was the smallest of all current inputs except insecticide (parathion). The relative price of both chemicals declined toward 1980 (Fig. 3).

In 1966, prior to the introduction of modern rice cultivars, 88% of surveyed farmers were using a herbicide in combination with hand weeding or rotary weeding, or both (Table 7). By 1970, the percentage had increased to 98%, partly due to the increased need for weed control with the introduction of the less competitive modern rice cultivars. The percentage decreased to 91% by 1975 and remained at that level through 1978.

Among the farmers that used herbicides, the rate of application has remained low and relatively constant. Butachlor has been applied preemergence at an average rate




**3.** Indices of input prices relative to rice price, Laguna, Philippines.

of 0.5 kg/ ha, and 2,4-D has been applied at 0.3 kg/ha. The most significant change in herbicide use by Laguna rice farmers over the period has been in the shift from the use of postemergence application of 2,4-D to preemergence application of butachlor.

The wage rate relative to the price of rice, which had stayed constant until 1976, has increased substantially since then. The real wage rate has risen more rapidly than the herbicide price. This change in the herbicide price relative to the wage rate has been partly responsible for the substitution of herbicide for weeding labor. As a result, the total cost for weed control (herbicide plus weeding labor) has declined since 1975, even though the prices of herbicide and weeding labor have been increasing (Table 7).

The changing energy situation appears to have affected, through changes in the relative price structure, the levels of fertilizer and power used by rice farmers in Laguna. The effect of rising fertilizer prices on fertilizer use could be serious because the cost of fertilizer is the largest component of current input cost (about 50% of total current input costs), and because alternatives to purchased chemical fertilizers do not presently exist.

**Java, Indonesia**

Rice farming in Indonesia, especially in Java, is very different from that in Laguna, Philippines, in terms of changes in the input structure of rice production in response to the changing energy situation. The data examined in this section are from a village study conducted in the Regency of Subang in West Java. The population pressure against land in this area, although it is not as severe as in Central and East Java, is much more serious than in Laguna.

While the rice fields in the village are well irrigated, technology is stagnant. The traditional system of double cropping rice is still practiced, and more than 80% of the farmers are still planting traditional cultivars.

Current input structures in the villageare much simpler than those in Japan or the Philippines (Table 8). Farmers do not apply any herbicide or use farm machinery. Fertilizer is the major item in current inputs. The real cost of fertilizer is around 80% of the total current input cost and 6 to 8% of total production. The level of fertilizer

**Table 7. Methods and cost of weed control of Laguna (Philippines) farmers, 1966-78 wet seasons.**

| | 1966 | 1970 | 1975 | 1978 |
|---|---|---|---|---|
| % farmers using herbicides | 88 | 98 | 91 | 91 |
| % farmers using preemergence herbicides | 0 | 10[a] | 17[b] | 47[b] |
| Cost of herbicides[c] (kg/ha):(l) | 9 | 21 | 22 | 33 |
| % in total output | 0.4 | 0.6 | 0.6 | 0.8 |
| Cost of weeding labor[c] (kg/ha):(2) | 83 | 149 | 249 | 229 |
| % in total output | 3.3 | 4.2 | 6.8 | 5.7 |
| Total cost for weed control[c] (kg/ha):(1)+(2) | 92 | 170 | 271 | 262 |
| % in total output | (3.7) | (4.8) | (7.4) | (6.5) |

[a]Liquid 2,4-D applied at the preweed-emergence stage. [b]Butachlor applied at the preemergence stage. [c]In paddy equivalent (cost deflated by paddy price).

**Table 8. Changes in current input structure of rice production per hectare, Subang, West Java, Indonesia, 1968-71 to 1978[a] (from Kikuchi et al 1980a).**

| | 1968-71[b] | | | 1978 dry | | |
|---|---|---|---|---|---|---|
| | Quantity (kg) | Paddy equivalent | | Quantity (kg) | Paddy equivalent | |
| | | kg/ha | % | | kg/ha | % |
| Total paddy production[c] | 2600 | 2600 | 100.0 | 2944 | 2944 | 100.0 |
| Current inputs | | | | | | |
| Seed | 37 | 37 | 1.4 | 43 | 43 | 1.5 |
| Fertilizer | | | | | | |
| Urea | --- | --- | – | 198 | 210 | 7.1 |
| Triple superphosphate | --- | --- | – | 31 | 33 | 1.1 |
| Total[d] | 190 | 279 | 10.7 | 229 | 243 | 8.2 |
| Insecticide and pesticide | – | 29 | 1.1 | – | 8 | 0.3 |
| Herbicide | – | – | – | – | – | – |
| Power | – | – | – | – | – | – |
| Total | – | 345 | 13.3 | – | 294 | 10.0 |

[a] Paddy equivalent costs are derived by dividing each cost value by the price of paddy. – stands for none or not applicable and --- for unknown. The current inputs do not include an irrigation fee. [b] Average for wet and dry seasons. [c] Paddy price is Rp 19.4/kg in 1968-71 and Rp 65/kg in 1978. [d] Total nitrogen applied was not known in 1968-71, and 89 kg in 1978.

application was high in 1968-71 and it increased further through 1978. In spite of the increase in rate, the real cost of fertilizer declined absolutely, resulting in a higher value added ratio in 1978 than in 1968-71.

The amounts of labor used by rice farmers per hectare in Subang are higher than in Laguna (Tables 6 and 9). The average labor used per hectare was 134 mandays in Subang in 1968-71 and 156 man-days in 1978, the major labor task being land preparation. While draft animals were used for land preparation, human labor with hoes was increasingly substituted for animal land preparation. This resulted in an increase in land preparation labor over the period 1968-71 to 1978.

**Table 9. Changes in labor inputs for rice production per hectare by task, Subang, West Java, Indonesia, 1968-71 to 1978 (from Kikuchi et al 1980a.b).**

| Item | Labor input (man-days/ha) | | |
|---|---|---|---|
| | 1968-71[a] | 1978 dry | % change |
| Land preparation | 53 | 64 | 21 |
| Transplanting | | 18 | |
| Weeding | 40 | 25 | 28 |
| Other crop care | | 8 | |
| Harvesting and threshing | 41 | 41 | 0 |
| Total | 134 | 156 | 16 |
| % of labor that is hired | | | |
| Weeding | – | 67 | |
| Total | – | 79 | |

[a] Av of dry and wet seasons. – = data not available.

**Table 10. Changes in input prices for rice production, Subang, West Java, Indonesia. 1968-71 to 1978 (from Kikuchi et al 1980a).**

| | 1968-71[a] | 1978 dry | % change |
|---|---|---|---|
| Paddy price (Rp/kg) | 19.4 | 65.0 | 235 |
| Nominal input price | | | |
| Fertilizer (Rp/kg) | 28 | 69 | 146 |
| Wage rate[b] (Rp/h) | 20 | 60 | 200 |
| Animal rental (Rp/day) | 120 | 620 | 416 |
| Real input price[c] | | | |
| Fertilizer (kg/kg) | 1.4 | 1.1 | –21 |
| Wage rate[b] (kg/h) | 1.0 | 0.9 | –10 |
| Animal rental (kg/day) | 6.2 | 9.5 | 53 |

[a]Av for wet and dry seasons. [b]Wage for weeding. [c]Nominal price deflated by paddy price.

Hand weeding and use of a rotary weeder-like tool made of wood with curved nails on the bottom were the sole methods of direct weed control in the village. The level of weeding labor for 1968-71 is not available; however, the data indicate an increase in labor absorption for weeding from around 1970 to the late 1970s. As in Laguna, hand weeding was done mainly by hired labor.

Changes in input structure in the village occurred mainly in response to changes in the relative price structure. The relative price of fertilizer declined over the 10-year period (Table 10), largely as a result of the heavy government subsidy on fertilizer. It appears that this sharp decline in the price of fertilizer relative to that of rice induced the increase in fertilizer application.

The real wage rate for weeding in the village also declined. Without increased demand for labor, the wage rate would be expected to decline as the labor force increased. This decline in the real wage rate induced more intensive manual weeding in the village.

## CHANGES IN RELATIVE PRICES AND CHOICE OF WEED CONTROL METHODS

A simple economic evaluation is presented in Table 11 to examine the possible effects of different price structures on the cost of alternative weed control methods in rice.[2]

Three systems of weed control are considered: system 1 — labor only, assuming 40 man-days of weeding labor per hectare; system 2 — the weed control method adopted by the *average Laguna farmer* in a 1980 IRRI study, using both labor and herbicides (preemergence application of butachlor followed by postemergence application of 2,4-D and some hand weeding); and system 3 — herbicides only in two alternative methods: one uses thiobencarb - 2,4-D, and the other butachlor and 2,4–D.

Under the price structures for Laguna in 1971 and 1974 there is no change in the

[2]If rice yields are assumed to be the same for each method of weed control, the least cost method of weed control is also the one that maximizes net return.

**Table 11. Comparison of real weeding cost among alternative weeding methods under different price conditions.**[a]

| Weeding methods and level of inputs | Real weeding cost (kg/ha) | | | | | | |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G |
| | 1971 prices | 1974 prices | 1980 prices | Japan 1980 wage | Java 1978 wage | High chemical price (1) | High chemical price (2) |
| System 1. Labor only | | | | | | | |
| For 40 mandays | 314 | 308 | 417 | 656 | 288 | 417 | 417 |
| System 2. Laguna, 1980 | | | | | | | |
| Butachlor 0.38 liter | 50 | 41 | 20 | 20 | 20 | 23 | 118 |
| 2,4-D 0.38 liter | 8 | 9 | 9 | 9 | 9 | 10 | 53 |
| Labor 17 mandays | 133 | 131 | 177 | 279 | 122 | 177 | 177 |
| Total | 191 | 181 | 206 | 308 | 151 | 210 | 348 |
| System 3. Herbicides only | | | | | | | |
| a. Thiobencarb - 2,4-D 30 kg | – | – | 150 | 150 | 150 | 173 | 885 |
| Labor 5 mandays | – | – | 52 | 82 | 36 | 52 | 52 |
| Total | – | – | 202 | 232 | 186 | 225 | 937 |
| b. Butachlor 1.42 liters | 188 | 153 | 75 | 75 | 75 | 87 | 442 |
| 2,4-D 1.42 liters | 30 | 33 | 34 | 34 | 34 | 39 | 201 |
| Labor 5 mandays | 39 | 39 | 52 | 82 | 36 | 52 | 52 |
| Total | 251 | 225 | 161 | 191 | 145 | 178 | 695 |

[a]Real cost in terms of paddy equivalent (nominal cost deflated by paddy price). Note that capital cost for rotary weeder and sprayer is not included. — = not known.

least cost method of weed control. The Laguna 1980 method is the least cost alternative both before and after the energy crisis (cases A and B). With prices of herbicides relative to labor declining in 1980 (case C), the herbicide-only methods (system 3) emerge as economically viable for weed control. The costs of the herbicide-only system are almost equivalent to, or even lower than, the cost of the Laguna 1980 method (system 2). This suggests that if the 1980 price structure were to continue, or if herbicide prices were to decline further relative to labor, the labor for weeding would continue to decline.

Cases D to G provide weeding cost estimates for each system under different assumptions about the wage rate and herbicide prices. In case D, a high wage rate for weeding, as in Japan, is assumed. It shows the definite advantage of the herbicide-only method over the other two weed control systems. In case E, the wage rate in West Java, which is the lowest of those in the three countries, is assumed. The result is similar to that of case C. This suggests that a manual-chemical method of weed control like the Laguna 1980 system might be adopted, even in Java, if herbicides were to become available and farmers to become acquainted with herbicide application techniques.

In case F, estimates of the weeding cost assume that the price of herbicides relative to rice will rise in the future as fast as the World Bank's projected increase in the world price of oil (Table 2). It can be seen that if this assumption is made, the cost of weed control does not increase markedly from that when 1980 prices are assumed. The choice of weeding method is unaltered from that when 1980 prices are assumed, i.e., the Laguna 1980 method is the least cost alternative.

Case G represents an extreme case in which the relative price of herbicide is assumed to rise as rapidly as that of gasoline in Laguna between 1971 and 1980. Under this condition, the herbicide-only method is most expensive, and the difference in the cost between the labor-only and Laguna 1980 methods becomes insignificant. This would induce a shift back in weeding method from the labor-herbicide mixture method of Laguna 1980 to a more labor-intensive system of weed control.

## WEED CONTROL UNDER DIFFERENT RICE PRODUCTION REGIMES

It is generally recognized that the incidence of weeds is more serious in rice production regimes other than the irrigated, transplanted one.

The costs of weed control under different rice production regimes in the Philippines are compared in Table 12. The data show that the cost of weed control under nonirrigated regimes is not more than that under the irrigated, transplanted regime of Laguna. Weed control cost for rainfed, dry-seeded rice is 50% less than for irrigated, transplanted rice. It appears that the general conclusions arrived at in the previous sections are applicable, to some extent, to other rice production regimes.

The lower weeding costs of the systems shown in Table 12 do not imply that the incidence of weeds and the need for water control under the nonirrigated rice production regimes are less than those under the irrigated transplanted. They do, however, indicate that the return from more intensive weed control is lower than the increase in cost under the adverse conditions of these rice production regimes.

**Table 12. Comparison of real weeding cost[a] per hectare among different rice production regimes, Philippines.**

| | Herbicide | Labor | Total |
|---|---|---|---|
| *Irrigated, transplanted[b]* | | | |
| 1974 quantity | 0.89 liter (2,4-D) | 32[c] man-days | – |
| Real cost | 21 kg | 246 kg | 267 kg |
| % in total output | 0.7% | 7.9% | 8.6% |
| 1980 quantity | 0.44 liter (2,4-D)<br>0.38 liter | 17 mandays | – |
| Real cost | 32 kg | 188 kg | 220 kg |
| % in total output | 0.8% | 4.9% | 5.7% |
| *Rainfed, transplanted[d]* | | | |
| 1970 real cost | 4 kg | – | – |
| % in total output | 0.3% | – | – |
| 1974 real cost | 27 kg | – | – |
| %in total output | 1.8% | – | – |
| 1977 real cost | 24 kg | – | – |
| % in total output | 1.1% | – | – |
| *Rainfed, wet-seeded[e]* | | | |
| 1975-80 real cost | 28 kg | 28 kg | 56 kg |
| % in total output | 1.1% | 1.1% | 2.2% |
| *Rainfed, dry-seeded[f]* | | | |
| 1975-80 real cost | 12 kg | 98 kg | 110 kg |
| % in total output | 0.8% | 6.8% | 7.7% |

[a]Real cost in paddy equivalent. [b]For Laguna. The data are from a Laguna village studied by the Agricultural Economics Department, IRRI. [c]As of 1975. [d]For 12 villages in Bulacan and Nueva Ecija. Estimated from Bogahawatte (1978) and Gascon et al (1978). [e]For Iloilo. Wet-seeded rice with modem cultivars, av of first and second crops. The data are from the Cropping System Project, Agricultural Economics Department, IRRI. [f]For Iloilo. Dry-seeded rice with modern cultivars, av of first crop. Data source is the same as in *e.*

## TECHNOLOGICAL ALTERNATIVES

If the costs of indirect methods of weed control (water management, cultivation, fertilizer, etc.) are considered, the total cost of controlling weeds has risen significantly since 1973. Whether considered in terms of the cost of “weed control” or in terms of “total production costs”, the impact of rising petroleum prices on the cost of rice production is cause for concern to farmers, research organizations, and government policy makers.

There are several possible areas of research and development in weed control that will reduce the effects of rising petrochemical prices, besides the most evident one of developing more effective and less costly herbicides.

### Factor substitution

Determination of the interrelationships between direct methods of weed control (herbicides and manual and mechanical weeding) and indirect methods (fertilizer, water management, etc.), and of their effects on rice yield are essential if estimates of the most economic uses of inputs are to be obtained. An understanding of these technical relationships is especially important in a situation where input and product prices are changing rapidly.

**Low volume spraying or controlled droplet application**

Several advantages of controlled droplet herbicide application exist; they may become more important as herbicide prices continue to increase (Lavers 1980): a) application of a lower volume of herbicide speeds application and facilitates more timely and effective weed control, and may result in higher yields; b) the lower volume saves fuel and labor; if different chemicals can be mixed in a tank and applied at once, further fuel and labor savings will be realized; c) the need for fewer trips through the field reduces crop damage; and d) with further attention to droplet size, reduced loss of spray, and more effective application to the plant or soil surface, it may be possible to decrease the amount of active ingredient applied.

**Placement of chemicals**

Banded application of herbicides and fertilizer, if feasible in rice, would reduce the quantities applied and result in cost savings. Deep placement of fertilizer would increase the productivity of applied fertilizer. The effect on net revenue, however, would depend on the crop yield and costs associated with the different application techniques relative to those obtained with the conventional methods of application.

**Organic alternatives**

Rising prices of petrochemicals may make the use of natural and synthetic mulches and systems of reduced tillage more attractive. These techniques reduce the dependence of a production system on petrochemical-based inputs.

**Crop rotation**

The use of crop rotation systems to control weeds may become more important in areas that are in rice monoculture, as the direct costs of controlling weeds in rice increase. The use of crop rotation systems that include a leguminous crop to provide nitrogen may also become more attractive as fertilizer prices continue to increase. The profitability of a monoculture system with its high cost of weed control and of applied fertilizer relative to a multiple cropping system should be considered.

**Rice cultivars**

The Green Revolution in rice production has been based on the use of rice cultivars that are responsive to high levels of fertilizer and weed and insect control. It has also occurred primarily on irrigated land. Increasing prices of fuel and chemical inputs have implications for the appropriate rice cultivars to be grown in the future. If the prices of inputs continue to rise and the price of rice does not increase sufficiently, farmers may be better off using the traditional cultivars that compete better with weeds, are less susceptible to pest damage, and give higher yields than using modern cultivars at low rates of fertilizer.

An alternative to returning to the traditional rice cultivars instead of persisting with the existing modern cultivars is to develop new cultivars that give higher yields at lower input levels.

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## DISCUSSION

BAKER: If a man is faced with limited credit, he has to make a decision: do I cut back on fertilizer and do something else or do I cut back on water and increase something else? I would like to know if there is any computer modeling which could assist the extension people or others who advise farmers what adjustments to make in the light of the volatile changing input prices.

*O'BRIEN:* There is no shortage of models that look at the farm adjustment process, but they are often riddled with assumptions and inadequate data, and therefore their relevance to the work of extension people is often limited. Perhaps even more simple types of analysis — budgeting types of approaches — are more appropriate.

WIRJAHARDJA: From your slides it seems that to increase rice production per unit area two times, the required energy input is five times. What is your suggestion to overcome this imbalance?

*O'BRIEN:* In view of the rising prices of inputs (fertilizer, fuel, labor, and herbicides) and the changes in prices of inputs relative to each other and to the price of rice, an important first step is to clearly establish the interrelationships between the inputs in the rice production process. From this basis (i.e., production function), the economically optimum strategies under changing price levels can be determined and research efforts can be directed towards those components of the production system where the greatest payoff will be obtained.

Other areas of research and development are outlined in the last section of the paper.

DE DATTA (comment): I think collecting survey data in the Laguna area is overdone. I would strongly urge economists to collect data in the heart of Central Luzon, Nueva Ecija, and even in the Bicol region, where some important changes are taking place. I would say that we are already saturated with survey information from Laguna, which, because of the *gama* system, is a typical of the country.

# HERBICIDES AND THE ENVIRONMENT

Y. L. Chen

The effects on herbicides of temperature, photodecomposition, microbial degradation, and soil properties, and the effects of herbicides on fish, mussel, seaweed. and *Chlorella* are reviewed. A model rice paddy ecosystem is examined. More attention must be paid to the effects of herbicides on environmental quality. The relation between herbicides and soil in paddy fields is emphasized. Regional and international cooperation or collaborative research programs on herbicide problems should be strengthened.

Pesticides play an important role in rice fields in many countries. For example, about 60% of the total cultivated land in Taiwan is paddy field but 80% of all pesticides used are in paddy fields. Currently, 84 herbicide compounds are registered in Taiwan. Of these chemicals, 29 are registered for use in rice fields, either as single components or as components in mixed herbicides (Chen 1980) (Table 1). The primary herbicides currently used in rice fields all over the world are molinate, thiobencarb, butachlor, oxadiazon, propanil, and chlomethoxynil (Chen 1981). Butachlor, thiobencarb, and chlomethoxynil are the herbicides used most in Taiwan both as a single component and mixed with other herbicides.

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**Table 1. Herbicides registered for use in rice fields in Taiwan.**

| Chemical type | Common name | Chemical name | Registration Year |
|---|---|---|---|
| Phenoxy | Allyl-MCPA[a] | Allyl-4-chloro-2-methylphenoxyacetate | 1967 |
| | Ethyl-MCPB[a] | Ethyl-4-chloro-2-methylphenoxybutylate | 1969 |
| | MCPA[a] | 4-Chloro-2-methylphenoxyacetic acid | 1970 |
| | – | 4-Chloro-2-methylphenoxyacetohydrazide | 1970 |
| | Phenothiol[a] | S-Ethyl-4-chloro-2-methylphenoxythioacetate | 1971 |
| | Naproanilide[a] | a-(ß-Naphthoxy) propionanilide | 1976 |
| Amide | Propanil | 3’,4’-Dichloropropionanilide | 1966 |
| | Butachlor | 2-Chloro-2’,6’-diethyl-*N*-(butoxymethyl) acetanilide | 1971 |
| Toluidine | Pendimethalin | 3,4-Dimethyl-2,6dinitro-*N*-1-ethylpropylaniline | 1976 |
| Urea | Fluothiuron[a] | 3-[3-Chloro-4-(chlorodifluoromethylthio)pheny1]-1, 1-dimethylurea | 1977 |
| | Dymron[a] | 1-(a ,a-Dimethylbenzyl)-3-(4-methylphenyl) urea | 1979 |
| Carbamate | Molinate | *S*-Ethyl-*N,N*-hexamethylenethiocarbamate | 1967 |
| | Benthiocarb | S-(4-Chlorobenzyl)*N,N*-diethylthiocarbamate | 1971 |
| | – | 2,4-Dichlorophenyl-*N,N*-tetramethylene-carbamate | 1973 |
| Phenol | PCP | Pentachlorophenol | 1967 |

Continued on opposite page

**Table 1** continued

| | | | |
|---|---|---|---|
| Diphenyl ether | Nitrofen | 2,4-Dichlorophenyl 4'-nitrophenyl ether | 1965 |
| | Chloronitrofen | 2,4,6-Trichloropheny1 4'-nitrophenyl ether | 1971 |
| | Chlomethoxynil | 2,4-Dichlorophenyl 4'-nitro-3'-methoxyphenyl ether | 1972 |
| | Bifenox | 2,4-Dichloropheny1 3'-methoxycarbonyl 4'-nitrophenyl ether | 1976 |
| | Oxyfluorfen [a] | 2-Chloro-4-trifluoromethylpheny1 3'-ethoxy-4'-nitrophenyl ether | 1980 |
| Nitrile | Dichlobenil | 2,6-Dichlorobenzonitrile | 1965 |
| Diazine | Oxadiazon | 5-*tert*-Butyl-3-(2,4-dichloro-5-isopropoxyphenyl)-1,3,4-oxadiazol-2-one | 1972 |
| | Bentazon | 3-Isopropy1-1*H*-2,1,3-benzothiadiazin-4-one 2,2-dioxide | 1976 |
| Pyridazine | Credazine [a] | 3-(2-Methylphenoxy)-pyridazine | 1971 |
| Triazine | Dimethametryn [a] | 2-(1,2-Dimethylpropylamino)-4-ethylamino-6-methylthio-1,3,5-triazine | 1974 |
| Organophosphorus | Piperophos [a] | *S*-2-Methylpiperidinocarbonylmethyl *O,O*-dipropyl phosphorodithioate | 1974 |
| | Bensulide [a] | *O,O*-Diisopropyl *S*-phenylsulphonylamioethyl phosphorodithioate | 1976 |
| Acetophenone | Methoxyphenone | 3,3'-Dimethyl-4-methoxybenzophenone | 1977 |
| Cyclohexanone | | 2-(a–Cyclohexenyl)cyclohexanone [a] | 1969 |

[a] Used as a component of mixed herbicide only.

## FACTORS IN HERBICIDE DEGRADATION

Almost all herbicides are applied to the soil, making understanding of the relationship between herbicides and soil indispensable. But in spite of this important fact, studies on the behavior of herbicides in rice fields are new and somewhat shallow. Only a few studies on the degradation of herbicides in paddy fields have been reported and most of these were done by Japanese investigators, especially Kuwatsuka and his coworkers at Nagoya University. They reviewed the behavior of herbicides in the soil environment, with special emphasis on the fate of principal paddy herbicides in flooded soils (Kuwatsuka and Niki 1976).

Many factors may affect the behavior of herbicides in the environment. Climatic condition and soil properties seem to be the most important. The quantity of herbicide residue that can accumulate in soil depends on such factors as the nature of the chemical, the soil type, and the texture, moisture, soil microbes, cation exchange capacity, content and nature of organic matter and clay minerals, and pH of the soil. Photodecomposition also is an important phenomenon related to dissipation of residue.

All herbicides decompose and metabolize in soils to a varying degree. The extent and nature of the degradation vary with environmental condition and chemical. Certain herbicides are metabolized or degraded completely in a matter of hours; other chemicals require weeks or months. Some complex herbicides are readily metabolized by soil microorganisms; some relatively simple ones are amazingly resistant to biodegradation. Degradation results from biotransformation by different enzymatic actions or by normal chemical reactions.

Some factors related to the degradation and dissipation of herbicides after application include temperature, photodecomposition, microbial degradation, and soil properties.

### Temperature

Some herbicides are very sensitive to temperature. For example, simetryn combined with other herbicides such as thiobencarb, MCPB, molinate, MCPA-thioethyl, or bentazon is used in Japan to control weeds in rice fields. But because of the higher temperatures in Taiwan, serious injuries to rice were found even after the application rate was reduced to minimum amounts when these combined herbicides were officially tested in Taiwan. Other examples are the phenoxy-type herbicides such as 2,4-D, MCPA, and MCPB extensively used in Japan and in the Philippines. Because of the unusual low temperatures in early spring in southern Taiwan, occasional cases of such injury as onion-leaves phenomenon were observed in the first crop when mixed herbicides containing these phenoxy-type compounds were used.

In laboratory tests, the volatilization of butachlor from aqueous solution and its adsorption in soil were significantly influenced by temperature. The loss of butachlor by volatilization from a 0.05 *M* $CaCl_2$ solution was demonstrated to be 4.5% at 21.5° C, and 30% at 40° C. Raising the temperature from 20 to 40° C usually resulted in decreased soil adsorption (Chen and Chen 1979a). In field experiments, some differences were observed between the first (March) and second (August) rice crops

(Table 2). Degradation and dissipation of butachlor were more rapid in the second paddy crop (Chen and Chen 1979a).

**Photodecomposition**

Work on the photodecomposition of herbicides has only been done during the past two decades. Since photodecomposition is an important route of the degradation and dissipation of herbicides from crops and soils, such studies are useful in establishing residue tolerances and the residue levels considered to be negligible. These studies also may lead to establishing no-effect levels and waiting periods for crops.

The photodegradation products of nitrofen were found to be 2,4-dichlorophenol, *p*-nitrophenol, 2,4-dichlorophenyl 4'-aminophenyl ether, and 2,4-dichlorophenyl 4'-hydroxyphenyl ether (Crosby et al 1972).

Photodecomposition products of PCP were isolated and identified as 2,4,5,6-tetrachlororesorcinol, chloranilic acid, 2,5-dichloro-3-hydroxy-6-pentachlorophenoxy-*p*-benzoquinone, 2,5-dichloro-3-hydroxy-6-(2',4',5',6'-tetrachloro-3'-hydroxyphenoxy)-*p*-benzoquinone, 3,4,5-trichloro-6-(2',3',4',5',-tetrachloro-6'-hydroxyphenoxy)-*o*-benzoquinone, and 3,5-dichlor-4-(2',3',5',6'-tetrachlor-4'-hydroxy)-6-(3, 4,5,6-tetrachloro-2-hydroxyphenoxy)-*o*-benzoquinone (Kuwahara et al 1965, 1966a, 1966b, 1969). Octachlorodibenzo-*p*-dioxin was identified as an additional photodecomposed product (Crosby et al 1972).

Desethylthiobencarb, *p*-chlorobenzaldehyde, *p*-chlorobenzylalcohol, *p*-chlorobenzoic acid, *N*-*p*-chlorobenzyl *N*,*N*-diethylamine, and *p*-chlorobenzyl mono- and di-sulfide were identified as the photodegradate products of thiobencarb (Y. L. Chen et al 1976, Ishikawa et al 1977b). Recently, thiobencarb sulfoxide was also identified as a photodecomposition product of thiobencarb when this unstable sulfoxide was reduced to thiobencarb by irradiation with UV light (Ishikawa et a1 1980a).

Butachlor as thin film on glass photodecomposed rapidly under UV light. Its half-life was found to be about 1.5 hours. At least 7 photodecomposed products were observed in gas chromatographic analysis. 2-chloro-2', 6'-diethylacetanilide, 2-hydroxy-2', 6'-diethyl-*N*-(butoxymethyl) acetanilide, 1-chloroacetyl-2,3-dihydro-7-ethylindole, and *N*-2',6'-diethylpheny1-2,5-dihydrooxazol-4-one were identified as the photodecomposed products (Chen and Chen 1978). Photodecomposition of butachlor was more rapid and more complicated in aqueous solution than as a thin film on glass. Half-life periods were about 0.8 hour under the UV light and 5.4 hours under sunlight irradiation. As many as 24 compounds were detected by gas chromatography. The partial pathways involved in the photodecomposition of butachlor in aqueous solution in paddy fields was proposed (Fig. 1) (Y. L. Chen et al 1981c).

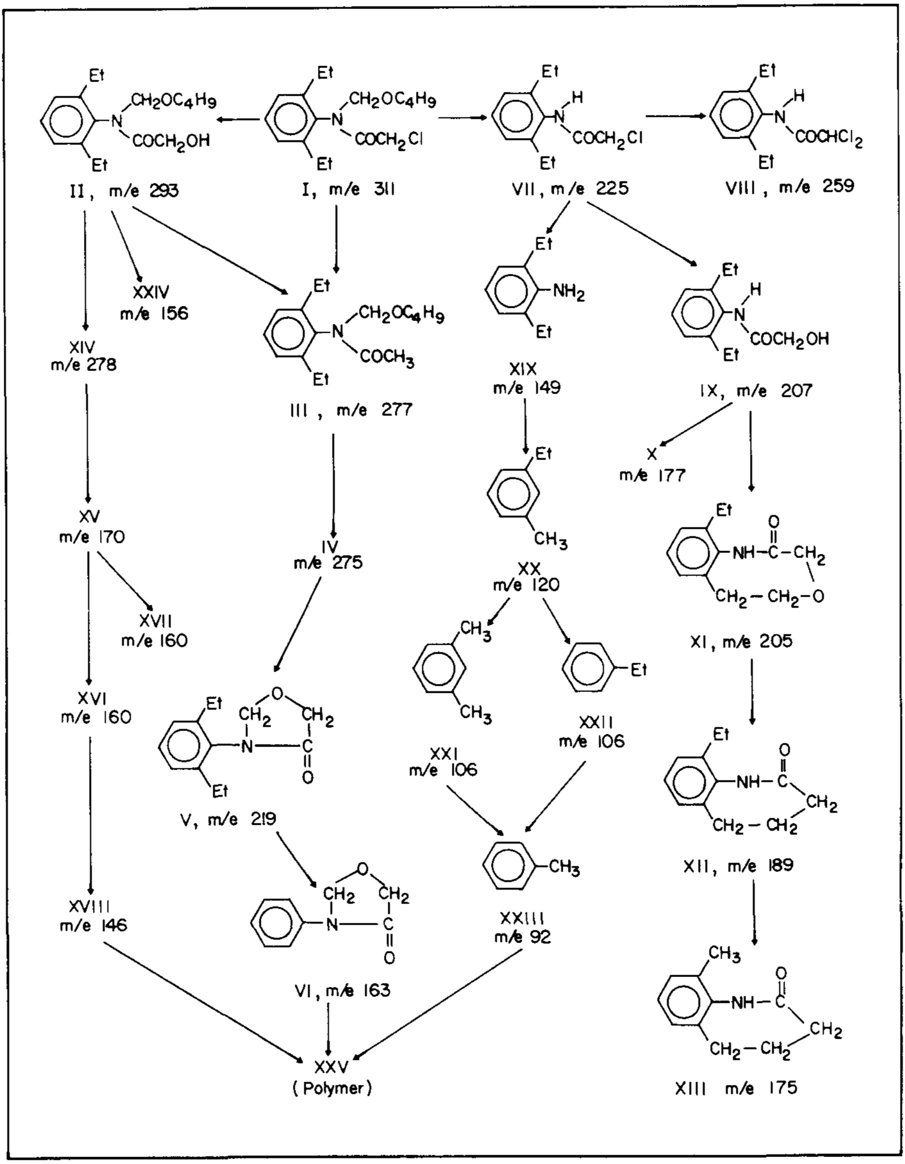
The photodecompostion of bifenox in aqueous solution was reported by Ohyama and Kuwatsuka (1976). Cleavage of the ether linkage, hydrolysis, reduction, and hydroxylation of the benzene rings occurred. A small amount of nitrofen also was detected.

Laboratory experiments have indicated that molinate in dilute aqueous solution is rather stable under sunlight. Irradiation in the presence of tryptophan resulted in decomposition, primarily to 1-[(ethylsulfinyl) carbonyl] hexahydro-1 *H*-azepine, S-

**Table 2. Residues of butachlor in rice fields.**

| Date | Time (day) | In water (ppm) | Water pH | In soil[a] (ppm) 0-3 cm | 3-6 cm | 0-6 cm | Soil pH | In rice plant[b] (ppm) Shoot | Root | Dried wt (g/Plant) |
|---|---|---|---|---|---|---|---|---|---|---|
| 2d crop (1977) | | | | | | | | | | |
| Aug 2 | -1 | <0.001 | 7.4 | <0.001 | <0.001 | <0.001 | 6.0 | <0.001 | <0.001 | 0.05 |
| 3 | 0 | 2.16 | 7.6 | 9.17 | 0.58 | 4.59 | 6.5 | 31.20 | <0.001 | 0.05 |
| 4 | 1 | 0.46 | 7.8 | 2.00 | 0.15 | 3.44 | 6.5 | 12.74 | 0.81 | 0.09 |
| 5 | 2 | 0.24 | 8.3 | 0.87 | 0.10 | 2.38 | 6.3 | 0.46 | 0.46 | 0.10 |
| 7 | 4 | 0.09 | 7.7 | 0.44 | 0.06 | 0.23 | 6.6 | <0.001 | <0.001 | 0.09 |
| 11 | 8 | 0.02 | 8.4 | 0.23 | 0.12 | 0.45 | 6.4 | <0.001 | <0.001 | 0.11 |
| 19 | 16 | 0.02 | 7.4 | 0.17 | 0.05 | 0.07 | 6.9 | <0.001 | <0.001 | 1.11 |
| Sep 4 | 32 | 0.02 | 7.6 | 0.30 | 0.06 | 0.07 | 6.5 | <0.001 | <0.001 | 3.95 |
| 1st crop (1978) | | | | | | | | | | |
| Mar 3 | -1 | <0.001 | 6.8 | <0.001 | <0.001 | <0.001 | 6.6 | <0.001 | <0.001 | 0.03 |
| 4 | 0 | 0.29 | 6.7 | 4.00 | 0.51 | 0.76 | 6.1 | 2.03 | 1.62 | 0.03 |
| 5 | 1 | 0.30 | 6.6 | 2.76 | 0.24 | 1.07 | 6.0 | 2.54 | 2.88 | 0.03 |
| 6 | 2 | 0.25 | 6.5 | 1.72 | 0.06 | 0.33 | 6.0 | 3.43 | 2.86 | 0.03 |
| 8 | 4 | 0.19 | 6.3 | 1.17 | 0.06 | 0.38 | 6.0 | 2.98 | 2.37 | 0.03 |
| 12 | 8 | 0.11 | 7.0 | 2.23 | 0.48 | 2.43 | 6.7 | 0.44 | 5.98 | 0.04 |
| 20 | 16 | 0.04 | 7.1 | 0.53 | 0.06 | 1.09 | 6.4 | 0.74 | 0.93 | 0.07 |
| Apr 5 | 32 | 0.01 | 7.0 | 1.25 | <0.001 | 0.50 | 6.4 | <0.001 | <0.001 | 0.22 |

[a]Oven-dried weight. [b]Air-dried weight.




**1.** Partial pathway scheme of the photodecomposition of butachlor in an aqueous solution.

ethyl hexahydro-2-oxo-1*H*-azepine-1-carbothioate, and hexamethyleneimine (Soderquist et al 1977).

When credazine was photodecomposed in aqueous solution at pH 9.0, 3-pyridazinone-(2*H*) and *o*-cresol were identified as the major products of photodegradation. Others included 3-(2-methylphenoxy) pyridazine-1-oxide, hydroxylated credazine, and salicylic acid (Nakagawa and Tamari 1974).

**Table 3. The half-life periods of some herbicides used in rice fields, determined by laboratory experiments.**

| Herbicide[a] | Concentration (ppm) | Average half-life (days) | | References |
|---|---|---|---|---|
| | | Wetland condition | Dryland condition | |
| PCP | 100 | 30 | 50 | Matsunaka and Kuwatsuka (1975) |
| | 10 | 5 | | ” |
| Chloronitrofen | 10 | 15 | 50 | ” |
| Nitrofen | 10 | 11 | 50 | ” |
| Chlomethoxynil | 10 | 15 | 50 | ” |
| Benthiocarb | 20 | 40 | 26 | ” |
| | 50 | 50 | 30 | Y. L. Chen et al (1976) |
| Swep | 25 | 7 | 2 | Matsunaka and Kuwatsuka (1975) |
| Propanil | 50 | 1 | 1 | ” |
| Butachlor | | | 11 | Beestman and Demming (1974) |
| | 100 | 25 | | Chen and Chen (1977) |
| | 100 | 11 | | Chen and Wu (1978) |
| Bifenox | 10 | 3 | 6 | Ohyama and Kuwatsuka (1976) |
| Simetryn | 1 | 53 | | Izawa et al (1981) |
| Ethyl-MCPB | 0.3 | 1 | | ” |
| Methoxyphenone | 2 | 8 | | ” |
| | 4 | 9 | 27 | Izawa and Asaka (1979) |
| | 20 | 10 | | Kurozumi et al (1980) |

[a]Chemical names of the herbicides are shown in Table 1, except that of swep, which is methyl 3,4-dichlorocarbanilate.

The photodegradation of propanil was studied by Moilanen and Crosby (1972). The major pathways were the replacement of chlorine atoms by hydroxylgroups or hydrogen, the formulation of propionamide, and the hydrolysis of the amide.

Exposure of methoxyphenone to UV light in aqueous solution resulted in rapid decomposition. Methoxyphenone was decomposed predominantly by cleavage at the carbonyl group to *m*-toluic acid and 4-methoxy-3-methylbenzoic acid. Other photodecomposition reactions were progressive oxidation of the 3- or 3'-methyl group, reduction of the carbonyl group and demethylation of the methoxyl group. When exposed to sunlight, methoxyphenone rapidly decomposed on both glass and silica gel plates. In aqueous solution, it decomposed in the same way as when exposed to UV light. Virtually no difference was observed between the photodecomposed products obtained by sunlight and by UV light. Methoxyphenone acts as an effective photosensitizer, similar to benzophenone (Fujii et al 1979).

## Microbial degradation

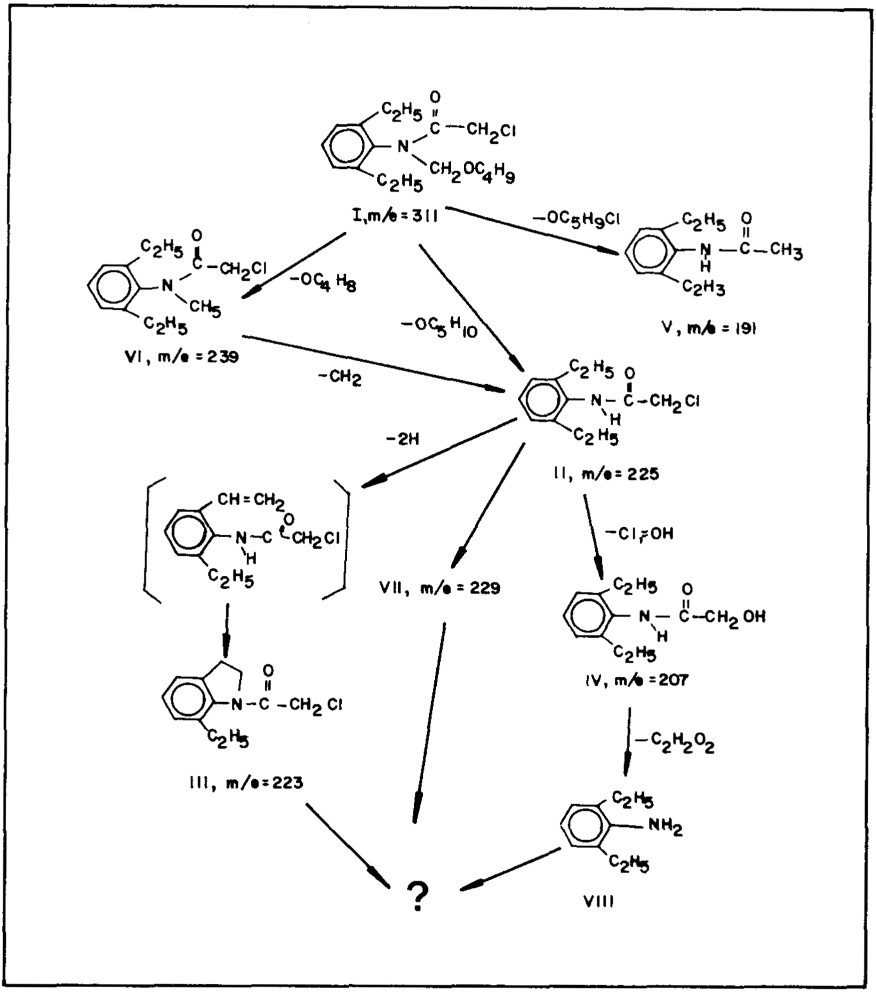
The average annual temperature of Taiwan is around 28° C. The average temperature for the coldest month is about 19° C. These high temperatures favor herbicide degradation in rice fields. The activities of soil microbes always seem to be positive throughout the year in tropical and subtropical zones such as Taiwan. The approximate half-life periods of some herbicides used in rice fields are shown in Table 3. Values vary with different soil types and with experimental conditions. Soil microbes undoubtedly play an important role in the degradation and dissipation of these herbicides in soil.

Chen and Wu (1978) found several soil microbes that effectively degrade butachlor. One of the most effective, *Mucor sufui* NTU-358, produced at least 8 to 12 metabolites. Some of these metabolites were identified and partial pathways involved in the degradation of butachlor were proposed (Fig. 2). Lee (1978), in his study of the degradation of butachlor by soil fungus *Chaetomium globosum,* isolated more than 10 metabolites and characterized some.

Populations of fungi, actinomycetes, and bacteria increased 1 week after the addition of butachlor to the soil (Y. L. Chen et al 1981a). Higher doses of butachlor kept the population of soil microbes higher than that in the control up to 4 weeks after incubation.

About 20 metabolites were detected products of thiobencarb degradation by soil microbes (Ishikawa et al 1976). *S*-benzyl *N,N*-diethylthiocarbamate, the dechlorination product of thiobencarb, identified in paddy field soil also seemed to be the product of thiobencarb degradation by soil microbes (Ishikawa et al 1980b). Deschlorthiobencarb is associated with the phytotoxic action and is believed to be the cause of rice plant dwarfing in paddy fields.

Degradation of PCP in soil was studied by Kuwatsuka and Igarashi (1975). Three tetrachlorophenols, 4 or 5 trichlorophenols, and PCP methyl ether were detected. PCP methyl ether and 2,3,4,5-tetrachlorophenol were the major products of degradation by soil microbes. The effect of PCP on bacterial flora in reductive layers of waterlogged soil was studied by Kato et al (1981a, b, c). PCP was applied to the surface water of waterlogged soil at the recommended rate and at 100 times the recommended rate. Changes in total numbers of aerobic bacteria were not clear.




**2.** Partial pathway scheme of the degradation of butachlor by *Mucor sufui.*

However, the effects on the changes in numbers of PCP-tolerant bacteria and gram-negative bacteria were clear.

Studies on the degradation of bifenox in flooded and dryland fields showed that the hydrolysis was caused by microbial reaction (Ohyama and Kuwatsuka 1976, 1978). Under flooded conditions, nitrofen, chloronitrofen, and chlormethoxynil were degraded by soil microbes and chemical processes to their amino derivatives (Niki and Kuwatsuka 1976a, Oyamada and Kuwatsuka 1979). Chlormethoxynil degraded rapidly in soil. Degradation products of chlormethoxynil in flooded soil were identified as the amino, dimethyl, formylamino, acetylamino and propionyl-amino derivatives and as 2,4-dichlorophenol (Niki and Kuwatsuka 1976b).

The degradation of naproanilide in three different soils was studied under oxidative- and reductive-flooded conditions (Oyamada et al 1980). 1-(2-Naphthoxy) propionic acid was identified as the major product; methyl 1-(2-naphthoxy) prop ionate, 2-naphthol, 2-hydroxy-l,4-naphthoquinone, and 2,3,-,2,6-, and 2,7-dihydroxynaphthalene were the minor products.

Recently, degradation of ethyl-MCPB, simetryn, and methoxyphenone in reductive flooded soils was compared with degradation in normally prepared flooded soils (Izawa et al 1981). Ethyl-MCPB was degraded in the reductive soils as rapidly as in the normally prepared ones, with a half-life of less than 1 day. The free acid of MCPB formed also degraded rapidly under both soil conditions. MCPA was formed in the normally prepared soils but was not detected in the reductive soils. The half-life period of simetryn in the 2 soils was 37 and 63 days under reductive conditions and 48 and 58 days under normally prepared conditions. Methoxyphenone degraded rapidly at almost the same rate under both soil conditions. The major degradation product was 3,3’-dimethyl-4-hydroxybenzophenone.

Methoxyphenone disappeared rapidly under anaerobic flooded conditions, with a half-life of about 10 days. The major degradation product was 3,3’-dimethyl-4-hydroxybenzophenone. Oxidative products of the 3- or 3'-methyl group and reductive products of the carbonyl group of methoxyphenone also were detected. The products metabolized by an insolated microorganism coincided with those found in the soil except for 3,3’-dimethyl-4-methoxy-benzhydrol (Kurozumi et al 1980).

**Soil properties**

Flooded soils differ from dryland soils in physicochemical and biological properties. Therefore, the herbicides applied to paddy fields should behave differently from those applied to dryland fields. For example, the half-life periods of PCP ranged from 12 to 70 days under flooded conditions and from 12 to 120 days under dryland conditions (Kuwatsuka and Igarashi 1975). This also was reported for nitrofen, chloronitrofen, and chlomethoxynil (Niki and Kuwatsuka 1976a), and for thiobencarb (Nakamura et al 1977).

Herbicide degradation is affected by such physicochemical properties of the soil as organic matter, clay minerals, clay content, cation exchange capacity, pH, redox potential, moisture content, structure, and texture of soil (Kuwatsuka and Niki 1976). The effects of organic matter and chemical fertilizer on degradation of thiobencarb and MCPA under different soil conditions were reported by Duah-Yentumi and Kuwatsuka (1980). The degradation of thiobencarb was different among three soil types under flooded conditions (Y. L. Chen et al 1976).

The adsorption of piperophos by paddy field soils was studied by the slurry method (Hata and Isozaki 1980). The amounts of herbicide adsorbed vaned depending on soil properties. The extent of adsorption correlated with cation exchange capacity, phosphate absorption coefficient, and hygroscopic water content, but did not correlate with total carbon content, clay content, and pH.

Cucumber plants in the vicinity of herbicide-treated paddy fields in northern Japan have showed phytotoxic symptoms since 1976. It was believed that the evaporation of herbicides from paddy water caused the injury. The amount of herbicide evaporated at 30° C from an aqueous solution at concentrations of 0.2 to 5 ppm was determined. Herbicides with higher vapor pressure and lower solubilities in water showed higher volatility (Yukimoto et al 1979). Dichlobenil evaporated the most, followed by molinate, thiobencarb, nitrofen, butachlor, and simetryn. Ishikawa et al (1977a) demonstrated that the volatilization of benthiocarb from an aqueous solution was reduced by adding more soil.

Butachlor applied at the normal rate stimulated soil respiration for about 1 week; but at 10 and 50 times the recommended rate, inhibitory effects were observed only in the first 3 days. These inhibitory effects seemed to be transitory. The cation exchange capacity after 7 weeks was not affected significantly by different amounts of butachlor applied at 30° C under waterlogged conditions (Chen 1979).

## SAFETY TO FISH, MUSSEL, SEAWEED, AND *CHLORELLA*

Generally, acute toxicities to mammals of most of the herbicides are relatively low. But some herbicides are highly poisonous to fishes and mussels. An example is PCP, once very popular as a single compound or as a component of mixed herbicides in Japan and in Taiwan to control weeds in paddy fields. It has a TLm value around 0.1 ppm. This very serious adverse effect limited its continued use in paddy fields and now this relatively inexpensive, locally producible herbicide has been almost completely replaced by other chemicals.

Some species of seaweeds and *Chlorella* also may he affected by herbicides which act as photosynthetic inhibitors in plants. Although butachlor has not been reported to inhibit-photosynthesis, in our recent experiments with rice and *Echinochloa crus-galli* Beauv. var. *oryzicola* Ohwi, crude protein, amino acids, and nitrate reductase activity differed suggesting that butachlor may act as an inhibitor of protein synthesis (Y. L. Chen et al 1981c). Chlorophyll, sugar, and starch did not differ. Butachlor at a concentration of 0.1 ppm also was found to inhibit the growth of Chlorella vulgaris (Chen and Chen 1979).

## STUDIES OF MODEL RICE PADDY ECOSYSTEMS

Studies on the biotransformation and bioaccumulation of herbicides using a model ecosystem are a new approach to understanding the behavior of chemicals in the environment. A model rice paddy ecosystem was introduced by Lee et al (1976). The fate of three diphenyl ether-type herbicides — nitrofen, chlomethoxynil, and bifenox — was studied. Nitrofen was found to be relatively stable under the model ecosystem conditions. It was bioconcentrated and stored over a 33-day period in the tissues of alga, snail, mosquito larva, and fish. When the carbomethoxy group of bifenox was used as a degradophore, tissue storage of the parent compound was minimal. The methoxy group of chlomethoxynil was not an effective degradophore.

More recently, S. V. Chen et al (1981) studied the fate of thiobencarb using a modified model ecosystem that used a $^{14}C$-labeled compound. They found that the ecological magnification in fish is 13.83 and the biodegradability index is 0.47, indicating that this herbicide seemed to be safe for the environment.

A laboratory model rice paddy ecosystem is useful for evaluating the environmental effects and fate of pesticides before using them in rice culture.

## CONCLUSION

It has not been my intention to review all of the literature on the behavior of herbicides used in rice fields. But because the consumption of herbicides is increasing, the effects of chemical herbicides on the environment should be carefully considered before their use. More attention should be paid to the effects of herbicides on environmental quality. Investigations of the relationships between herbicides and soil should be emphasized, especially in tropical and subtropical paddy fields. Regional and international cooperation and collaborative research projects would be helpful.

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## DISCUSSION

YEH: Some farmers apply 2,4-D at 2-3 weeks after flowering, then harvest 1 month later. What is the degradation or decomposition of 2,4-D in rice grain?

*CHEN:* I have not been able to find any information on degradation or dissipation in rice grain. Usually, we do not recommend 2,4-D at this stage, but I know some farmers use this treatment.

YEH: Do the farmers use 2,4-D as an anti-lodging chemical?

*CHEN:* This is not recommended.

YEH: But it is very popular. They apply 2,4-D in the second crop season at 60-70 days after transplanting. The hills open up a little and this prevents sheath blight infection.

MATSUNAKA: Japanese farmers are also using 2,4-D for this purpose.

MERCADO: You did not include a diagram of your model rice paddy system.

*CHEN:* This will be. published elsewhere.

BAKER: I was interested in your model but soil was missing, if I interpreted it correctly.

*CHEN:* I used sterilized sand because soil includes microbes. If you use soil, most of the chemical will be absorbed and decomposed. I wanted to simplify and make the relationships more clear.

BAKER: I recognize that this is very important to get the herbicide into other organisms. But if you try to extrapolate to the real world, this important component (soil) is missing.

*CHEN:* Also, if you use soil the many different soil properties have control.

# REGULATORY, ENVIRONMENTAL, AND GENERAL CONSTRAINTS TO DEVELOPMENT OF WEED SCIENCE TECHNOLOGY

K. P. Dorschner

Increasing regulatory requirements for herbicides result in higher product development costs and in some instances impede research. Variations in regulatory requirements among countries complicate the development of weed control technology for international markets. Costly delays in the introduction of new products result from the lack of guidelines for the development of research data to support product registration. Environmental constraints result from inadequate knowledge of the complexity of agroecosystems and the intricacy of the basic biology of weeds. Organizational rigidity and disciplinary isolation often result in research protocols that fail to provide data suitable for regulatory processes. Solutions to the regulatory, environmental, and general constraints are proposed.

The technology of weed control and the discipline of weed science have made remarkable progress over the past 40 years. Some important accomplishments are the discovery of new classes of selective herbicides and novel plant-growth regula-

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tors, refinement of herbicide application techniques, the use of insects and plant pathogens as biological weed control agents, and the improvement of cultural and mechanical weed control practices. This progress has been achieved despite a continuing shortage of specialists trained in weed science. Present control technology needs modification to provide control over a wider range of geographical and climatic variations. Despite the significant progress in chemical, cultural, and biological weed control, it is estimated that weeds still cause losses in excess of 10% of agricultural production each year.

An important mission of weed scientists is to provide weed control technology that is not only effective but safe to man and the environment. While this mission is feasible, it is often affected by real or perceived regulatory, environmental, or general constraints. These constraints are often serious impediments to progress, and warrant identification and continual assessment.

Scientists generally recognize that they must develop a more thorough understanding of the basic biology of weeds. Studies are needed on biochemistry, ecology, population dynamics, and allelopathy; competition threshold calculations are required for specific weeds and crops. The residual properties of herbicides in soil and water require attention and their degradative and metabolitic products need to be identified. The general indictment has been made that only a narrow range of control tactics is available for weed control. This is particularly true where perennial, deep rooted weeds are involved, or where control of aquatic weeds is desired. An important technological area requiring additional research emphasis is the adverse effects on nontarget environmental components of volatility, drift, and misuse of herbicides.

These are just a few of the areas where research is needed to strengthen, diversify, or develop new weed control technology. The regulatory, environmental, and general constraints to accomplishing them need to be identified and resolved.

## REGULATORY CONSTRAINTS

Regulatory constraints to the development of weed control technology are procedures, practices, or regulations of governmental agencies that delay the registration process excessively or that hinder research.

Weed control technology is a major manipulation of the environment. It is reasonable to delineate and regulate the possible environmental and human health effects of that technology. The policies of such control should be predicated on the relative benefits of the technology to society and the risks to man and the environment.

In many instances present regulatory requirements inhibit the development of new or improved weed science technology. Increasing regulatory demands are generally reflected in higher costs for product development that, in many cases, result in decisions not to participate in new ventures. For example, many pesticide manufacturers are reluctant to register their products for use on minor specialty crops. Many of these crops are highly important as food, feed, and fiber. In the U.S. the regulatory constraint is addressed through an Interregional Research Program (IR-4). It is a nationwide cooperative effort of the federal government, state agricultural experiment stations, and industry. They share the costs and expertise in developing data to support product registration for minor crops. An approach such as the IR4 minor use program is not a complete solution. Such programs can be effective and responsive, but they suffer from limited resources and budgetary constraints.

The development of weed control products for international markets presents special problems because product registration requirements vary from country to country. In some cases, a product sponsor may be required to provide data other than those obtained in the country of origin. Sometimes all testing procedures may need to be modified to conform with local requirements. The additional testing is costly and delays product introduction. International organizations concerned with weed control are actively working to standardize international registration requirements.

Recently several important herbicides have become suspect as potential environmental pollutants hazardous to man or nontarget organisms. Some of these products already have been removed from the market; others may be discontinued. The diversion of university, government, and industry research from long-term weed science technology needs to the reevaluation of previously approved products is, in many cases, counterproductive.

Another regulatory constraint is the length of time from registration application to approval. This interim period often excessively interrupts the critical path of development. Administrative difficulties in this area continue to frustrate researchers and technology advancement. By the time new teehnology is approved for use, it may be obsolete or require considerable modification.

Data submitted by weed scientists to support product registrations often are insufficient according to regulatory agencies. But in many cases the agencies have not promulgated guidelines and test protocols for the registration of herbicides and plant-growth regulators. Such guidelines and test protocols are critical for environmental chemistry, toxicology, aquatic biology, and metabolism.

Cultural, mechanical, and biological weed control methods are still important in vegetation management systems. But most weed scientists agree that these techniques alone are not adequate for modern, high production agriculture. Chemical herbicides used in conjunction with good farm practices are needed to maintain satisfactory weed control. Herbicides are subject to regulatory scrutiny and evaluation of their toxicology, efficacy, environmental chemistry, and other characteristics. These evaluations are essential, but they must be applied in a common sense, uniform manner. Currently, there is no uniform regulatory policy on potential carcinogens. Chemical manufacturers view the present decision process as unpredictable. Research initiatives are delayed and new herbicides and plant-growth regulators do not reach the market.

Preventive weed control is another deficient regulatory program that concerns weed scientists. Adequate protection from importation and redistribution of weeds or their precursors does not exist; extant protective measures are actually ineffective. This hinders the making of long-term research commitments to develop new weed control technology, which may become ineffective because of the encroachment of new weed species.

Existing governmental regulatory requirements should be continually evaluated and updated to meet changing needs brought about by new technology. The ultimate payoff would be in more agricultural productivity and better environmental quality.

## ENVIRONMENTAL AND GENERAL CONSTRAINTS

Environmental constraints to the development of weed control technology are those that, because of a lack of fundamental scientific knowledge, do not permit effective research planning, or that are so complex that they are finite barriers to research. They may be characteristic of the environment, of agroecosystems, or of native stands of weeds. A quality environment is a finely tuned system in which competition among ecological components is a continuous and natural occurrence. The challenge before weed scientists is to develop, as a component of agroecosystems, new technology that does not adversely affect the total system.

A major void in the design and conduct of experiments to reveal the environmental impacts of new technology is the lack of understanding of the diversity of ecosystems under which crops are grown. More basic information is needed on the prevalence and importance of native beneficial organisms and how they relate to each other and to their pest hosts. Knowledge about the interactions within pest complexes and between host and pest populations is urgently needed. Satisfying these basic ecological information needs would provide a much stronger foundation upon which to develop research programs that would yield acceptable data on environmental impacts.

Our knowledge of the biochemistry, morphology, physiology, and phenology of weeds is inadequate. We must develop a better comprehension of the life cycles and growth stages of weeds, particularly of perennial and biennial species. A more thorough understanding of plant metabolism is needed to study translocation of herbicides and growth regulators, and to evaluate the resistant and reactive sites of herbicides. Plant and seed dormancy and their impacts on the efficacy of weed control tactics require more attention. The perennial plant *Euphorbia esula,* for example, has the ability to become dormant upon experiencing adverse effects on its top growth.

Well-structured weed control programs, as well as other compatible pest management programs, should include accurate information on economic thresholds. Determination of economic thresholds for infestation of weeds in specific crops seems a rather short-term, straightforward research task, but it is not quite so simple. There are three research approaches in this area:

1. Single tactic, single objective approach — use of a herbicide to control *Amaranthus retroflexus* in maize fields;
2. Multiple tactic, single objective approach — use of herbicides, biological organisms, and cultural practices to control *A. retroflexus* in maize fields; and
3. Multiple tactic, multiple objective approach — use of herbicides, insecticides, and fungicides to control weeds, insects, and diseases in maize fields.

Research on economic thresholds of weeds generally has been done on interactions of a single pest (a weed) and a host, but the management of several pest populations in a cropping area is highly complex. Economic threshold determinations are required for whole systems.

There is a shortage of data that accurately define the extent and nature of crop losses due to weed competition. In some cases, we must rely on estimates, but these usually understate the seriousness of the problems and often negate the need for research. Accurate data on crop yields and crop quality are needed to develop economic thresholds.

There are constraints that are implicit in government regulations to protect endangered species. While weed scientists and regulatory agencies agree on this environmental issue, procedural conflicts that arise must be resolved intelligently.

Organizational rigidity and disciplinary isolation often are general constraints to the development of weed science technology. Lack of communication and cooperation among weed scientists, production horticulturists and agronomists, soil scientists, economists, agricultural engineers, and others can result in research protocols that fail to provide suitable data for regulatory processes. These data may not be useful for developing weed control measures in agroecosystems in which a total farm approach to pest management is desired. Organizational rigidity focusing only on a narrow range of research possibilities is fostered by training. Resistance to change is inherent in an inflexible system. The weed science community must avoid this situation or, when it exists, resolve it for the benefit of the discipline.

Innovative research most often is a random event. Weed scientists must remain continually cognizant of this and strive to resolve the constraints to the development of new weed control technology. The constraints should be viewed as opportunities for achievement, because only in this framework will a truly positive focus on research result.

# WORKSHOP RECOMMENDATIONS

## STATUS OF TRAINING OPPORTUNITIES AND TRAINING NEEDS

L. J. Matthews and L. C. Burrill

No effort was made to restrict the discussion on the status of training opportunities and training needs to rice. The suggestions made here are presented with the full realization that there is a wide range in the level of educational opportunities in the countries of the world. Most of the suggestions apply to a country or region where weed control training programs do not exist or are in their infancy. Nevertheless, many of the comments presented will also be applicable to countries with established weed training programs. A weed control training program, whether in a training center, a university, or in a farmer's field, cannot be effective unless necessary support programs are available and improved at the same time.

Most of the suggestions are aimed to guide administrators, donors, or weed control specialists in establishing or upgrading their training programs. We suggest the following steps to establish or improve a weed control program through training.

1. Where there are no weed scientists, bring in one or more expatriate weed control specialists to:

- teach weed science principles at the BS level if a university teaching agriculture exists,
- identify and train people to help conduct weed control research,
- help identify and assign priorities to weed problems,
- assist in conducting weed control research, and
- assist in procuring basic research equipment when needed.

2. Identify, at an appropriate time, one or more candidates for advanced training in weed science and assist in identifying a site and providing funding for training.

It is important for advisers to be involved in planning the educational programs of students. The first group of students sent for degree training should concentrate on gaining expertise in conducting field research. Later groups can specialize in areas such as physiology and toxicology, which are required to support a complete weed science program.

Advisers should consider having students do their course work at a university and their research at sites more similar to their home countries. The scarcity of training sites in the tropics is acknowledged. Sponsors should consider the advantages to students of visits by their major professors to review thesis research and students' research programs after a suitable time.

Every effort should be made to assure that returning students work in weed science for at least 5 years.

3. Identify crop production researchers with the bachelors degree to participate in short course training in weed science principles, weed identification, and research techniques. All planned short courses should be budgeted for and have follow-up support and contacts as part of the program. Short courses are best conducted in the trainees' home country, but opportunities in a second country should not be overlooked.

4. Strengthen the ability of extension agents to transfer weed control technology to farmers. Publications and short-term training to emphasize weed control principles as well as detailed recommendations should be provided to selected extension agents.

5. Donors should assist weed control programs in acquiring existing publications on weed science and weed identification and in preparing new publications. That may be one of the most useful and lasting contributions a donor organization can make.

6. Donor organizations should provide travel assistance for weed specialists to attend conferences and visit research centers. It is vital for scientists to remain up-to-date and to keep their enthusiasm high. Membership and active participation in appropriate weed science societies should be encouraged.

7. We recognize the important role that the chemical industry is now playing in education and encourage greater levels of cooperation among government researchers, extension personnel, and industry representatives on educational programs of mutual interest.

8. We encourage the international agricultural research centers to maintain or establish weed control training programs for production specialists as well as for weed control specialists.

# WORKSHOP RECOMMENDATIONS

## RESEARCH PRIORITIES AND OPPORTUNITIES FOR COLLABORATION

D. L. Plucknett and M. M. Schreiber

### WEED BIOLOGY

The discussion of the working group centered on needs and problems in weed biology and on ways collaboration could be achieved. There was general concern about the need to know more about specific problem weeds in each country, to learn the life cycles of each, and to share information. The discussion also took note of the wide differences in weed information available in the countries represented:

- developed and developing countries with widely different systems of rice culture — irrigated, rainfed, and deepwater rice.
- capital-intensive systems with heavy herbicide use in contrast with labor-intensive systems where hand labor is the main system of weed control, and
- countries with many weed scientists and well-developed programs in contrast with countries just beginning weed research.

Observations and recommendations made by the working group are as follows:

1. Weed identification and taxonomy are important to understand the plants and facilitate information exchange. For scientists who do not have access to taxonomic help, it would be useful to have a list of taxonomists or institutions that would assist in identifying plants. We suggest that an institution, perhaps IRRI, should keep a herbarium of important weeds of rice-producing areas.

2. Each country should conduct its own survey of important weeds of rice and share such information.

3. Population shifts from annual to perennial species with continued use of herbicides are significant. Vegetation analyses are necessary to understand the direction of weed population movement with time and as management practices change. A series of experiments should be started to follow changes in weed populations under different conditions. There is a real need to find reliable but less time-consuming methods of studying weed vegetation trends. No consensus was reached on the amount of information to be recorded and the possible benefits such detailed studies would have for actual weed control. Perhaps IWSS, IRRI, or some other organizations could be persuaded to prepare a manual on methods of vegetation analysis for weed workers. *This appears to be a possible area for collaboration.*

4. It was agreed that studies of the life cycle are useful and even essential for establishing weed control practices, but no agreement was reached on details that may be necessary. As in the vegetation analysis question, there are methodology matters in life cycle studies that need consideration. The discussion group agreed that a manual of procedures and methods in weed biology would be useful.

5. Weed biology studies should include studies to determine the competitiveness of individual weeds with rice. Weed density and duration of competition, and crop and weed competition for nutrients and light would be important components of such studies.

6. Considerable discussion centered on the choice of individual problem weeds that require study. One suggestion was that studies should be made on $C_4$ plants, but all collaborators could not concentrate on $C_4$ plants because some important rice weeds are $C_3$. *Echinochloa* species and perennial sedges were mentioned frequently as possible candidates for more intensive biology studies.

7. We recommend that an international network be established to monitor weed problems. Cooperating countries could study their individual weed problems and share their information in a network forum. A range of environmental measurements should be made and reported to ensure wider understanding of results.

## WEED CONTROL

Research inputs on the control of weeds in diverse rice cultures can increase the production of rice to the benefit of mankind. For the greatest benefits, research in weed control must be integrated with research in other disciplines including agronomy, entomology, plant pathology, nematology, agricultural engineering, economics, and sociology. The principal objective of weed science research for rice is to develop and integrate weed control practices and systems for maximum yields and economic returns under the various rice cultures. But weed scientists must be aware of environmental abuse and pollution; damage to nontarget organisms; and conservation of energy, fertilizer, and other resources.

One research priority that applies to all rice cultures is research on substituting fertilizers for weed control inputs. Given that broad research priority, we developed major research directions for various kinds of rice culture and assigned priorities to them as follows:

**Irrigated, transplanted**

- Develop more efficient weed control systems, including herbicides, for hard-to-kill weeds (particularly perennials).
- Improve crop establishment (crop injury, weed control, timing) by minimizing possible herbicide injury to young rice seedlings.

**Irrigated, direct-seeded**

1. Dry-seeded
   - Develop more effective programs for hard-to-control weeds, including herbicide programs and cropping systems.

2. Wet-seeded
   - Develop effective programs for hard-to-control weeds, include herbicide programs and cropping systems.
   - Reduce crop injury by developing methods to minimize herbicide injury to the crop.

**Rainfed, wetland** (includes transplanted, wet-seeded, and dry-seeded cultures)
- Compare efficacy of present technology: hand weeding vs rotary weeding vs herbicides vs combinations.
- Develop new weed control technology:
  1. More efficient mechanical methods for weed control.
  2. Techniques to control algae.
  3. Techniques to protect young seedlings from herbicides.
  4. Herbicide programs, including herbicide antidotes.
  5. Techniques for evaluating cultivar tolerance for herbicide.
  6. Techniques for evaluating rice cultivars' competitiveness with weeds.

**Rainfed, dryland** (dry-seeded, unbunded)
- Develop new weed control technology:
  1. Nonchemical weed control practices, including cropping systems, competitive cultivars, and improved crop rotations.
  2. Chemical weed control practices integrated with nonchemical methods.
- Improve crop establishment by developing seeding methods to control weeds and improve stands.
- Develop effective weed control systems for hard-to-control weeds such as grasses and sedges.

**Deepwater** (dry-seeded)
- Develop improved technology for weed control before flooding the crop.

# APPENDICES

**Appendix 1. Weeds and weed synonyms.**

## Weeds

*Acalypha ciliata* Forsk.
*Acanthospermum hispidum* DC.
*Aeschynomene aspera* L.
*A. indica* L.
*A. sensitiva* Sw. var *hispidula* (H.B.K.) Rudd
*A. virginica* (L.) B. S. P.
*Ageratum conyzoides* L.
*Alisma canaliculatum* A. Br. & Bouche
*A. lanceolatum* With.
*A. plantago-aquatica* L.
*A. plantago-aquatica* L. var. *orientale* G. Sam
*A. triviale* Pursh
*Alopecurus aequalis* Sobol. var. *amurensis* (Komarov) Ohwi
*Altemanthera philoxeroides* (Mart.) Griseb
*A. sessilis* (L.) DC.
*Alysicarpus rugosus* (Willd.) DC.
*Amaranthus lividus* L.
*A. retroflexus* L.
*A. spinosus* L.
*A. viridis* L.
*Amischophacelus axillaris* (L.) Rolla Rao & Kammathy
*Ammannia auriculata* Willd.
*A. baccifera* L.
*A. coccinea* Rottb.
*A. latifolia* L.
*A. multiflora* Roxb.
*Aneilema japonica* (Thunb.) Kunth
*Aspilia bussei* O. Hoffm. & Muschler
*A. helianthoides* Burth. & Hook.f.

*Bacopa eisenii* (Kell.) Pennell
*B. rotundifolia* Wettst.
*Bergia capensis* L.
*Bidens pilosa* L.
*Blyxa japonica* Maxim. ex Archers & Gurcke
*Boerhavia diffusa* L.
*B. erecta* L.
*Bolhoschoenus compactus* Drabov.
*Brachiaria deflexa* (Schum.) C. E. Hubb.
*B. lata* (Schum.) C. E. Hubb.
*B. mutica* (Forsk.) Stapf
*B. plantaginea* (Link) Hitchc.
*B. platyphylla* (Griseb.) Nash
*B. ramosa* (L.) Stapf
*B. reptans* (L.) Gard. & C. E. Hubb.
*Butomus umbellatus* L.

*Caesulia axillaris* Roxb.
*Callitriche stagnalis* Scop.
*Calopogonium mucunoides* Desv.
*Caperonia castanaefolia* (L.) St. Hil.
*Cassia occidentalis* L.
*C. rotundifolia* Pers.
*C. tora* L.
*Celosia argentea* L.
*C. trigyna* L.
*Cenchrus echinatus* L.
*Chara foetida* A. Br.
*C. zeylanica* Willd.
*Chenopodium album* L.
*Chlorella vulgaris* Beij
*Chloris pilosa* Schum.
*Commelina benghalensis* L.
*C. communis* L.
*C. diffusa* Burm. f.
*C. erecta* L.
*C. jacobi* Fischer
*Corchorus aestuans* L.
*C. echinatus* Benth.
*C. fascicularis* Lam.
*C. olitorius* L.
*C. tridens* L.
*Croton lobatus* L.
*Cyanotis axillaris* (L.) D. Don
*Cynodon dactylon* (L.) Pers.
*Cyperus amuricus* Maxim.
*C. articulatus* L.
*C. compressus* L.
*C. difformis* L.
*C. diffusus* Vahl.
*C. eragrostis* Vahl.
*C. erythrorhizos* Muhl.
*C. esculentus* L.
*C. fuscus* L.
*C. glomeratus* L.
*C. imbricatus* Retz.
*C. iria* L.
*C. laetus* J.&C. Presl.
*C. luzulae* Rottb. ex Willd.
*C. monti* L.
*C. odoratus* L.
*C. pulcherrimus* Willd. ex Kunth
*C. rotundus* L.
*C. spharelatus* Rottb.
*C. strigosus* L.

*Dactyloctenium aegyptium* (L.) Willd.
*Damasonium australe* Salisb.
*Dichromena pubera* Vahl.
*Digiraria ciliaris* (Retz.) Koel.
*D. microbachne* (Presl) Henr.
*D. sanguinalis* (L.) Scop.
*D. violascens* Link
*Diodia scandens* Sw.
*Diplachne fusca* (L.) Beauv.
*Dopairium junceum* (Roxb.) Hamilt.

*Echinochloa colona* (L.) Link
*E. crus-galli* (L.) Beauv.
*E. crus-galli* (L.) Beauv. ssp. *crus-galli* var. *crus-galli*
*E. crus-galli* (L.) Beauv. ssp. *crus-galli* var. *praticola* Ohwi
*E. crus-galli* (L.) Beauv. ssp. *hispidula* (Retz.) Honda var. *hispidula*
*E. crus-pavonis* (H.B.K.) Schult.

*E. frumentacea* Link
*E. glabrescens* Munro ex Hook.f.
*E. haploclada* (Stapf) Stapf
*E. obtusifora* Stapf
*E. oryzoides* (Ard.) Fritsch
*E. phyllopogon* (Stapf) Koss.
*E. picta* (Koen.) Michael
*E. pyramidalis* (Lam.) Hitch. & Chase
*E. stagnina* (Retz.) Beauv.
*E. utilis* Ohwi & Yabuno
*Echinodorus cordifolius* (L.) Griseb.
*Eclipta prostrata* (L.) L.
*Eichhomia crassipes* (Mart.) Solms
*Elatine triandra* Schk.
*Eleocharis acicularis* (L.) Roem. & Schult.
*E. acicularis* (L.) Roem. & Schult. var. *longiseta* Svenson
*E. dulcis* (Burm.f.) Henschel
*E. geniculata* (L.) Roem. & Schult.
E. kuroguwai Ohwi
*E. ovata* (Roth) Roem. & Schult.
*E. palustris* (L.) R.Br.
*E. parvula* (Roem. & Schult.) Link
*E. quadrangulata* (Mich x.) Roem. & Schult.
*E. tuberosa* Schult.
*Eleusine indica* (L.) Gaertn.
*Emilia sonchifolia* (L.) DC.
*Eragrostis aspera* (Jacq.) Nees
*E. japonica* (Thunb.) Trin.
*E. pilosa* (L.) Beauv.
*Erigeron floribundus* (H.B.K.) Sch.-Bip.
*Eriocaulon sexangulare* L.
*Eriochloa punctata* (L.) Desv.
*Euphorbia esula* L.
*E. heterophylla* L.
*E. hirta* L.
*E. hyssopifolia* L.

***F**imbristylis autumnalis* (L.) Roem. & Schult.
*F. dichotoma* (L.) Vahl.
*F. littoralis* Gaud.

***G**alinsogaparviflora* Cav.

***H**ackelochloa granularis* (L.) O. Ktze.
*Hedyotis corymbosa* (L.) Lam.
*H. herbacea* L.
*Heliotropium indicum* L.
*Heteranthera limosa* (Sw.) Willd.
*H. reniformis* Ruiz & Pav.
*Hibiscus cannabinus* L.
*Hydrilla verticillata* (L.f.) Royle
*Hygroryza aristata* (Retz.) Nees
*Hymenachne acutigluma* (Steud.) Gilliland

***I**mperata brasiliensis* Trin.
*I. cylindrica* (L.) Beauv.
*Indigofera dendroides* Jacq.
*Ipomoea aquatica* Forsk.
*I. eriocarpa* R.Br.
*I. heterotricha* F. Didr.
*I. purpurea* (L.) Roth
*I. triloba* L.
*Ischaemurn barbatum* Retz.
*I. rugosum* Salisb.
*Ixophorus unisetus* (Presl.) Schlecht.

***J**uncus bufonius* L.

***L**apsana apogonoides* Maxim.
*Leersia hemndra* Sw.
*L. japonica* Honda
*L. oryzoides* (L.) Sw.
*L. perrieri* A. Camus
*L. tisseranti* A. Chev.
*Lemna minor* L.
*Leonurus sibiricus* L.
*Leptochloa chinensis* (L.) Nees
*L. fascicularis* (Lam.) A. Gray
*L. panicea* (Retz.) Ohwi
*L. panicoides* (Presl) Hitchc.
*L. uninervia* (Presl.) Hitchc. & A. Chase
*Leucas martinicensis* R.Br.
*Limnocharis flava* (L.) Buch.
*Lindemia anagallidea* (Michx.) Penn.
*L. anagallis* (Burm.f.) Pennell
*L. crustacea* (L.) F. Muell.
*L. procumbens* (Krock.) Philcox
*Lobelia chinensis* Lour.
*Ludwigia adrcendens* (L.) Hara
*L. decurrens* Walt.
*L. erecta* (L.) Hara
*L. hyssopifolia* (G. Don) Exell
*L. leptocarpa* (Nutt.) Hara
*L. octovalvis* (Jacq.) Raven
*L. perennis* L.
*L. prostrata* Roxb.

***M**ariscus cylindristachyus* Steud.
*M. mutisii* H.B.K.
*Marsilea minuta* L.
*M. quadrifolia* L.
*Melochia concatenata* L.
*Mimosa invisa* Mart.
*M. pudica* L.
*Mimulus orbicularis* Wall.
*Mitracarpus scaber* Zucc.
*Mollugo nudicaulis* Lam.
*Monechma ciliatum* Hochst ex Nees
*Monochoria vaginalis* (Burmf.) Presl

***N**ajas guadelupensis* (Spring) Magnus
*N. minor* All.
*Nymphaea nouchali* Burm.f.

***O**enantha javanica* (Bl.) Dc.
*Oryza alta* Swallen
*O. australiensis* Domin.
*O. barthii* A. Chev.
*O. brachyantha* A. Chev. & Roehr.
*O. eichingeri* Peter.
*O. glaberrima* Steud.
*O. grandiglumis* (Doell) Prod.
*O. latifolio* Desv.
*O. longistaminata* A. Chev. & Roehr.
*O. minuta* J. S. Presl ex. C. B. Presl
*O. nivara* Sham & Shastry

*O. officinalis* Wall. ex Watt
*O. perennis* Moench.
*O. punctata* Kotschy ex Steud.
*O. ridleyi* Hook.f.
*O. rufipogon* Gnff.
*O. sativa* L. (red rice)
*O. sativa* L.f. spontanea Roschev.
*O. sativa* cv. *silvatica*
***P****anicum cambogiense* Balansa
*P. fasciculatum* Sw.
*P. maximum* Jacq.
*P. repens* L.
*Paspalum conjugatum* Berg.
*P. dilatatum* Poir.
*P. notatum* Fluegge
*P. paspalodes* (Michx.) Scribn.
*P. scrobiculatum* L.
*Pennisetum polystachyon* (L.) Schult.
*Pentapetes phoenicia* L.
*Phragmites communis* Trin.
*Phyllanthus amarus* Schum. & Thonn.
*P. niruri* L.
*Physalis angulata* L.
*P. micrantha* Link
*P. minima* L.
*Plantago lanceolata* L.
*Polygonum acre* H.B.K.
*P. acuminatum* H.B.K.
*P. coccineum* Muhl.
*P. hydropiper* L.
*P. hydropiperoides* Michx.
*P. lapathifolium* L.
*P. punctatum* Ell.
*Polypogon monspeliensis* (L.) Desf.
*Portulaca oleracea* L.
*P. quadrifida* L.
*Potamogeron crispus* L.
*P. distinctus* A. Benn.
*P. natans* L.
*P. nodosus* Poir.
***R****hynchoryza subulata* (Nees) Baillon
*Rhynchospora corniculata* (Lam.) A. Gray
*Richardia scabra* L.
*Rotala indica* (Willd.) Koehne
*Rotala indica* (Willd.) Koehne var. *uliginosa* (Miq.) Koehne
*R. rotundifolia* Koehne
*Rottboellia exaltata* L.f.
*Rumex dentatus* L.
***S****agirtaria chilensis* Cham. & Schlecht.
*S. guyanensis* H.B.K.
*S. longiloba* Engelm.
*S. montevidensis* Cham. & Schlecht.
*S. montevidensis* Cham. & Schlecht. ssp. *calycina* Engelm. Bogin.
*S. pygmaea* Miq.
*S. sagittifolia* L.
S. *trifolia* L.
*Salvinia molesta* D. S. Mitchell
*S. natans* (L.) All.
*Schwenkia americana* L.
*Scirpus articularus* L.
*S. fluviatilis* (Torr.) A. Gray
*S. juncoides* Roxb.
S. *juncoides* Roxb. var. *juncoides*
*S. juncoides* Mr. *hotarui* (Ohwi) Ohwi
*S. maritimus* L.
*S. mucronatus* L.
*S. planiculmis* F. Schmidt
*S. supinus* L.
*Sesamum orientale* L.
*S. radiatum* Schum. & Thonn.
*Sesbania exaltata* (Raf.) Cory
*Setaria barbata* (Lam.) Kunth
*S. geniculata* (Lam.) Beauv.
*S. glauca* (L.) Beauv.
*S. pallide-fusca* (Schumach.) Stapf & Hubb.
*Sida alba* L.
*S. linifolia* Cav.
*S. rhombifolia* L.
*S. stipulata* Cav.
*S. urens* L.
*Solanum nigrum* L.
*S. paniculatum* L.
*Sorghum halepense* (L.) Pers.
*Sparganium erectum* L.
*Spermacoce stachydea* DC
*S. verticillata* L.
*Sphaeranthus indicus* L.
*Sphenoclea zeylanica* Gaertn.
*Spigelia anthelmia* L.
*Spirodela polyrhiza* (L.) Schleid.
*Spirogyra nitida* (Dillwyn) Link
*Stachytarpheta angustifolia* Vahl.
*Striga hermonthica* (Del.) Benth.
*Synedrella nodiflora* (L.) Gaertn.
***T****alinum triangulare* (Jacq.) Willd.
*Tonina fluviatilis* Aubl.
*Trianthema portulacastrum* L.
*Tridax procumbens* L.
*Tripogandra multiflora* (Sw.) Raf.
*Typha angustifolia* L.
*T. latfolia* L.
*T. laxmanni* Lepechin

*Utricularia aurea* Lour.

***V****allisneria spiralis* L.
*Veronica anagallis-aquatica* L.
*V. galamensis* (Cass.) Less.
*V. perrotteti* Sch. Bip.

***Z****annichellia palustris* L.
*Zizania aquatica* L.

# Weed synonyms

*Aeschynomene rudis* see *A. sensitiva* var. *hispidula*
*Alisma orientale* see *A. plantago-aquatica* var. *orientale*
*A. plantago* see *A. plantago-aquatica*
*Bergia aquatica* see *B. capensis*
*Bolboschoenus maritimus* see *Scirpus maritimus*
*Cassia obtusifolia* L. see *C. tora*
*Corchorus acutangulus* see *C. aestuans*
*Cyperus fexax* see *C. odoratus*
*C. mutisii* see *Mariscus mutisii*
*C. serotinus* see *C. monti*
*Damasonium minus* see *D. australe*
*Digitaria adscendens* see *D. ciliaris*
*D. horizontalis* see *D. microbachne*
*Echinochloa crus-galli* var. *formosensis* see *E. glabrescens*
*E. crus-galli var. oryzicola* see *E. phyllopogon*
*E. erecta* see *E. phyllopogon*
*E. oryzicola* see *E. phyllopogon*
*E. seratina* see *E. crus-galli*
*Echinodorus berteroi* see *E. cordifolius*
*Eclipta alba* see *E. prostrata*
*Elencharis equisetina* see *E. dulcis*
*E. obtusa* see *E. ovata*
*E. yokoscensis* see *E. acicularis* var. *longiseta*
*Eriocaulon sieholdianum* see *E. sexangulare*
*Fimbristylis annua* see *F. dichotoma*
*F. miliacea* see *F. littoralis*
*Hibiscus aspera* see *H. cannabinus*
*Hymenachne pseudointerrupta* see *H. acutigluma*
*Ipomoea reptans* see *I. aquatica*
*Juncellus serotinus* see *Cyperus monti*
*Jussiaea decurrens* see *Ludwigia decurrens*
*J. erecta* see *Ludwigia erecta*
*J. leptocarpa* see *Ludwigia leptocarpa*
*J. linfolia* see *Ludwigia hyssopifolia*
*J. prostrata* see *Ludwigia prostrata*
*J. repens* see *Ludwigia adscendens*
*Leptochloa filiformis* see *L. panicea*
*Lindernia pyxidaria* see *L. procumbens*
*Marsilea crenata* see *M. minuta*
*Melochia corchorifolia* see *M. concatenata*
*Monochoria vaginalis* var. *plantaginea* see *Monochoria vaginalis*
*Nymphaea stellata* see *N. nouchali*
*Oldenlandia corynbosa* see *Hedyotis corymbosa*
*O. herbacea* see *Hedyotis herbacea*
*Oryza breviligulata* see *O. barthii*
*O. perrieri* see *Leersia perrieri*
*O. subulata* see *Rhynchoryza subulata*
*O. tisseranti* see *Leersia tisseranti*
*Panicum purpurascens* see *Brachiaria mutica*
*P. reptans* see *Brachiaria reptans*
*Paspalum distichum* see *P. paspalodes*
*Potamogeton franchetti P. distinctus*
*Salvinia auriculata* see *S. molesta*
*Scirpus hotarui* see *S. juncoides var. hotarui*
*S. juncoides* ssp. *Juncoides* see *S. juncoides*
*Setaria lutescens* see *S. glauca*
*Veronica anagallis* see *V. anagallis-aquatica*

**Appendix 2. Cultivated crops other than rice.**

| Common name | Scientific name | Common name | Scientific name |
|---|---|---|---|
| Barley | *Hordeum vulgare* L. | Mungbean | *Vigna radiata* (L.) Wilczek |
| Black gram | *Vigna mungo* (L.) Hepper | Onion | *Allium cepa* L. |
| Cassava | *Manihot esculenta* Crantz. | Peanut | *Arachis hypogaea* L. |
| Chickpea | *Cicer arietinum* L. | Pigeonpea | *Cajanus cajan* (L.) Millsp. |
| Chili | *Capsicum annuum* L. | Ramie | *Boehmeria nivea* (L.) Gaud. |
| Coconut | *Cocos nucifera* L. | Rubber | *Hevea brasiliensis* Muell. Arg. |
| Cotton | *Gossypium hirsutum* L. | Sesame | *Sesamum indicum* L. |
| Cucumber | *Cucumis sativus* L. | Sorghum | *Sorghum bicolor* (L.) Moench. |
| “Dhaincha” | *Sesbania aculeata* Poir | Soybean | *Glycine max* (L.) Merr. |
| Garlic | *Allium sativum* L. | Sugarcane | *Soccharum officinarum* L. |
| Grass pea | *Lathyrus sativus* L. | Sweet potato | *Ipomoea batatas* (L.) Lam. |
| Hemp sesbania | *Sesbania exaltata* (Raf.) Rydb. | Tobacco | *Nicotiana tabacum* L. |
| Jute | *Corchorus capsularis* L. | Watermelon | *Citrullus lanatus* (Thunb.) Mansf. |
| Kenaf | *Hibiscus cannabinus* L. | Wheat | *Triticum aestivum* L. |
| Lentil | *Lens culinaris* Medik. | | |
| Linseed | *Linum usitarissimum* L. | | |
| Maize | *Zea mays* L. | | |

**Appendix 3. Diseases of crops and weeds.**

| Common name | Scientific name |
|---|---|
| **Crop diseases** | |
| Bakanae | *Fusarium moniliforme* Sheldon |
| Basal node rot | *Fusarium oxysporum* |
| Blast | *Pyricularia oryzae* Cav. |
| Brown spot | *Helminthosporium oryzae* Breda de Haan |
| Glume blight | *Phyllosticta glumarum* (Ell. & Tr.) Miyake |
| Leaf scald | *Rhynchosporium oryzae* Hashioka et Yokogi |
| Narrow brown leaf spot | *Cercospora oryzae* Miyake |
| Seedling blight | *Sclerotium rolfsii* Sacc. |
| Sheath blight | *Rhizoctonia solani* Kuhn |
| Stem rot | *Sclerotium oryzae* Cattaneo |
| **Weed diseases** | |
| (not known) | *Colletotrichum gloeosporioides* (Penz.) Sacc. f. ssp. *aeschynomene* |
| (not known) | *Colletotrichum gloeosporioides* (Penz.) Sacc. f. ssp. *jussiaea* |
| (not known) | *Cercospora rodmanii* Conway |

**Appendix 4. Insects and nematodes.**

| Common name | Scientific name |
|---|---|
| **Insects** | |
| China mark moth | *Nymphula nymphaeata* (L.) |
| Chironomid fly | *Chiranomus cavazzai* Kieff. |
| Chironomid fly | *Cricotopus trifasciatus* (Panz.) |
| Fall armyworm | *Spodoptera figiperda* (J. E. Smith) |
| Grass spittle bugs | *Deois flavopicta* (Stal.)<br>*Zulia entreriana* Berg |
| Lesser corn stalk borer | *Elasmopalpus lignosellus* (Zell.) |
| Pyralid moth | *Calamotropha shichito* (Mats.) |
| Rice gall midge | *Orseolia oryzae* (Wood-Mason) |
| Rice leaf miner | *Hydrellia griseola* (Fallen) |
| Rice stem borer | *Diatraea saccharalis* (Fabr.) |
| Rice stink bugs | *Oebalus* sp.<br>*Tibraca limbativentris* Stal. |
| Rice water weevils | *Lissorhoptrus philus* Kush.<br>*Oryzophilus oryzae* (Lima.) |
| **Nematodes** | |
| Ring nematode | *Macroposthonia onoensis* (Luc) De Grisse |
| Root-knot nematode | *Meloidogyne graminicola* Golden and Birchfield |
| Root-knot nematode | *Meloidogyne javanica* (Treub) Chitwood |
| White-tip nematode | *Aphelenchoides besseyi* Christie |

**Appendix 5. Pesticides.**

| Common name/ trade code number/trade name | Chemical name |
|---|---|
| **Herbicides** | |
| Acifluorfen | sodium 5-(2-chlor-4-trifluorornethyl) phenoxy-2-nitrobenzoate |
| ACR 1207 | 6–amino-*o*-toluic acid |
| Alachlor | a -2',6'-diethyl-*N*-methoxymethylaceranitide) |
| Amiprofos-methyl | *O*-methyl *O*–2-nitro-*p*-tolyl isopropylphosphomnidothioate |

Continued on next page

**Appendix 5** continued

| Common name/ trade code number/trade name | Chemical name |
|---|---|
| Bensulide | *OO*-di-isopropyl *S*-2-phenylsulphonyl-amino-ethyl phosphorodithioate |
| Bentazone | 3-isopropyl–(1*H*)-benzo-2,1,3-thiadiazin-4-one 2,2-dioxide |
| Bifenox | methyl 5–(2,4dichlorophenoxy)-2-nitrobenzoate |
| Butachlor | *N*-butoxymethyl-a-chloro-2',6'-diethylacetanilide |
| Butralin | 4-(1,1-dimethylethyl)-*N*-(1-methylpropyl)-2,6-dinitrobenzene amine |
| Byram (R4574) | *S*-l-ethyl-propyl- *N,N*-hexamethylene thiocarbamate |
| Chlomethoxynil | 2,4-dichlorophenyl 3-methoxy-4-nitrophenyl ether |
| Chlornitrofen | 4-nitrophenyl 2,4,6-trichlorophenyl ether |
| Chloroxuron | 3-[4–(4-chlorophenoxy)phenyl]-1,1-dimethylurea |
| Credazine | 3-*o*-tolyloxypyridazine |
| Cyperquat | 1-methyl-4-phenylpyridinium |
| 2,4-D | 2,4-dichlorophenoxy acetic acid |
| 3,4-D | 3,4-dichlorophenoxy acetic acid |
| Dalapon | 2,2-dichloropropionic acid |
| Dichlobenil | 2,6-dichlorobenzonitrile |
| Dichlorprop | (±)-2–(2,4-dichlorophenoxy) propionic acid |
| Dimethametryn | 2-(1,2-dimethylpropylamino)-4-ethylamino-6-methylthio-1,3,5-triazine |
| Dinitramine | *N'N'*-diethyl-2,6-dinitro-4-trifluoromethyl- *m*-phenylenediamine |
| Diuron | 3-(3,4-dichlorophenyl)-1,1-dimethylurea |
| Dymrone | *N*-( a ,a -dimethylbezyl)-*N'p*-tolylurea |
| Endothal | 7-oxabicyclo [2,2,1]heptane-2,3-dicarboxylic acid |
| EPTC | *S*-ethyl dipropylthiocarbamate |
| EXP 3316 | Chemistry not disclosed |
| Fenoprop | (±)-2-(2,4,5-trichlorophenoxy)propionic acid |
| Fluchloralin | *N*-(2-chloroethyl)-2,6-dinitro-*N*-propyl-4-trifluoromethylaniline |
| Fluorodifen | 4-nitrophenyl 2-nitro-4-trifluoromethylphenyl ether |
| Fluothiuron | 3-(3-chloro-4-chlorodifluoromethyl-thiophenyl)-1,1-dimethylurea |
| Glyphosate | *N*-(phosphonomethyl)glycine |
| KCO23 | Chemistry not disclosed |
| KCO25 | Chemistry not disclosed |
| MCPA | 4-chlorc–2-methylphenoxy acetic acid |
| MCPB | 4-(4-chloro-2-methylphenoxy)butyric acid |
| Mecoprop | (±)-2-(4–chloro-2-methylphenoxy) propionic acid |
| Methiocarb | 4-methylthio-3,5-xylyl methylarbamate |
| Methoxydymrone | 1-( a , a -dimethylbenzyl)-3-methoxy-3-phenylurea |
| Methoxyphenone | 3,3\-dimethyl-4-methoxybenzophenone |
| Methyldymrone | 1-( a , a dimethylbenzyl)-3-methyl-3-phenylurea |
| Metolachlor | 2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-6-methoxy-1-methylethylacetamide |
| Molinate | *S*-ethyl *NN*-hexamethylenethiorbamate |
| Naproanilide | a -( ß -naphthoxy) propionanilide |
| Nitrofen | 2,4-dichloro-4'-nitrodiphenyl ether |
| Oxadiazon | 5-*tert*-butyl-3(2,4-dichloro-5-isopropoxyphenyl)-1,3,4-oxadiazol-2-one |
| Oxyfluorfen | 2-chloro–1-(3)-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl) benzene |
| Paraquat | 1,1'-dimethyl-4,4'-bipyridylium ion |
| PCP | pentachlorophenol |
| Pendimethalin | *N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine |
| Pentanochlor | 3'-chloro-4'-methyl-a -methylvaleranilide |

Continued on opposite page

**Appendix 5** continued

| Common name/ trade code number/ trade name | Chemical name |
|---|---|
| Perfluidone | 1,1,1-trifluoro-*N*-2-methyl4(phenylsulphonyl) phenylmethane sulphonamide |
| Phenothiol | *S*-ethyl 4-chloro-2-methyl-phenoxythloacetate |
| Piperophos | *S*-2-methyl-piperidinocarbonylmethyl *OO* -dipropyl phosphordithioate |
| Pretilachlor | a -chloro-2',6'diethyl- *N* -(2-propoxyethyl acetanilide) |
| Prodiamine | 2, 4dinitro-$N^3$,$N^3$dipropyl-6-(trifluormethyl)-l,3-benzenediamine |
| Prometryn | 2,4-di(isopropylamino)-6-methylthio-1,3,5-triazine |
| Propanil | 3',4'-dichloropropionanilide |
| Propazine | 2-chloro-4,6-di(isopropylamine) 1,3,5-triazine |
| Pyrazolate | 4–(2,4-dichlorobenzoyl)-1,3-dimethylpyrazol-5-yl- *p* -toluene-sulphonate |
| Pyridate | 6-chloro-3-phenylpyridazin4-yl *S*- octyl thiocarbonate |
| R 22523 | *S*-benzyl-isobutylethyl-thioarbamate |
| Simazine | 2-chloro-4,6-di(ethylamino)-1,3,5-triazine |
| Simetryn | *N,N'*-diethyl-6-(methylthio)-1,3,5-triazine-2,4-diamine |
| Swep | methyl 3,4-dichlorophenylcarbamte |
| 2,4,5- T | 2,4,5-trichlorophenoxyacetic acid |
| TCA | trichloroacetic acid |
| TCE-styrene | a -2,2,2-trichloroethylstyrene |
| Terbuchlor | *N*-butoxymethyl-6'-terr-butyl-a- chloroacet+-toluidide |
| Thiobencarb | *S*-4-chlorobenzyl diethylthocarbamate |
| Tiocarbazil | *S*-benzyl *N,N*-di-*sec* butyl thiolcarbamate |
| W L9385 | 2-azido-4-ethylamino-6-*teri*-butylamino-s-triazine |
| | **Insecticides** |
| BHC | 1,2,3,4,5,6-hexachlorocyclohexane |
| BPMC | 2-sec-butylphenyl-N-methylcarbamate |
| Carbaryl | 1-naphthyl N-methylcarbamate |
| Carbofuran | 2,3dihydro-2,2dimethyl-7-benzofuranyl methyl-carbamate |
| Chlorpyrifos | *O,O*-diethyl *O* -(3,5,6-trichloro-2-pyridyl)-phosphorothioate |
| DDT | Dichloro diphenyl trichloroethane |
| Dieldrin | Hexachloroepoxy-octahydroendo, exo-dimethanonaphthalene |
| Fenitrothion | *O,O*-dimethyl *O*- (3-methyl-4-nitrophenyl) phosphorothioate |
| Isoprocarb | 2-isopropyl-phenyl-N-methylarbamate |
| Methyl parathion | *O,O*-dimethyl-*O*-p-nitrophenyl phosphorothioate |
| Parathion | *O,O*-diethyl *O* -p-nitrophenyl phosphorothioate |
| | **Fungicides** |
| Benomyl | methyl1-(butylcarbamoyl)-2-benzimidazole-carbamate |
| Captafol | cis-N[(l,l,2,2,-tetrachloroethyl)thio]-4-cyclohexene-l,2dicarboximide |
| IBP | *O,O*- diisopropyl-S-benzyl thiophosphate |
| Kasugamycin | D-3-0-[2-amino-4-(l-carboxyiminomethyl) amino-2,3,4,6-tetradeoxy- a -D-arabinohexo-pyranosyl)-D-chiro-inositoll |

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