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Major Agricultural Problems and Research Priorities in the Eastern-Africa Region

Nairobi, Kenya
19-22 July 1983

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and
The Australian Centre for International Agricultural Research
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Coordinators

J.G. Ryan and F.J. Wang'ati

Scientific Editor

J.G. Ryan

Publication Editor

J.V. Mertin

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The Australian Centre for International Agricultural Research (ACIAR) was established in June, 1982 by an Act of the Australian Parliament. Its mandate is to help identify agricultural problems in developing countries and to commission collaborative research between Australian and developing country researchers in fields where Australia has a special research competence.

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Foreword

Australia has been called a 'lucky country'. In many respects this is true, but in one sense it is not. It is no ready-made 'Garden of Eden'. On the contrary, it shares with much of Africa extensive areas with harsh arid and semi-arid conditions used both for agricultural and pastoral activities. In these areas it has made considerable technological advances – assisted greatly by research activities in the Universities, in the Commonwealth Scientific and Industrial Research Organization (CSIRO), and in the State Departments of Agriculture. It is these research techniques and results that Australia is offering to share with developing countries.

The instrument for this activity is the Australian Centre for International Agricultural Research (ACIAR). ACIAR is charged with making available its experience by establishing collaborative arrangements with developing country research organizations – where that seems to promise a fruitful outcome and is requested by the country concerned.

One of the methods of establishing contacts and of determining the relevance or otherwise of Australian experience is the 'Workshop'. This not only establishes personal contacts between scientists but does determine whether or not Australian experience is relevant to the specific developing country problems under review. The Consultation held in Nairobi in collaboration with the National Council for Science and Technology was one such case. The clear lead given by the Hon. K.N.K. Biwott, Minister for Regional Development, Science, and Technology, in Kenya set the tone for discussions now likely to lead to a more fruitful relationship between agricultural scientists in Eastern Africa and Australia. These Proceedings will serve as a basic document in the development of that relationship.

J.G. Crawford
Chairman, Board of Management
The Australian Centre for International
Agricultural Research
Canberra, Australia

Preface

The Australian Centre for International Agricultural Research (ACIAR) and the National Council for Science and Technology (NCST) of Kenya jointly sponsored the Eastern Africa-ACIAR Consultation on Agricultural Research in Nairobi from 18-22 July 1983. The purpose of the Consultation was to bring together senior scientists from six Eastern African countries and their Australian counterparts to identify major agricultural problems and priorities in Eastern Africa where Australian agricultural research capacity might be effectively applied in collaborative programs.

The highly successful Consultation was attended by 70 delegates. They comprised 27 scientists from the national research programs of Ethiopia, Kenya, Somalia, the Sudan, Tanzania, and Uganda, who were meeting together for the first time in many years, 26 observers from international research and development organizations, and 17 scientists from Australia. A list of participants is contained in an Appendix to the Proceedings. The papers and deliberations focused primarily on the problems and potentials of the semi-arid tropical regions of Eastern Africa.

These Proceedings of the Consultation are significant for several reasons. Firstly, they contain papers from senior scientists and research administrators from six Eastern African countries that describe their major agricultural problems and the research priorities they have established in order to overcome them. These perspectives are supplemented by papers by eminent scientists from a number of international agencies, who have had extensive experience in Eastern Africa. Particular emphasis is placed on the semi-arid tropical regions in the countries and on the crops, livestock, and forestry enterprises that are most important in them. The farming systems in which these enterprises appear are also described, as are the socio-economic constraints to the improvement of their productivity.

The second feature of the Proceedings volume is the papers by a number of Australian scientists that describe the research that has been conducted in Australia on the same types of technical problems that farmers face in the semi-arid tropical regions of Eastern Africa. Australia's semi-arid tropics offer many similarities to Eastern Africa and the comparative experience was an important reason for conducting the Consultation. Indeed the major achievement of the Consultation was identification of several research topics that could form the basis of collaboration between Eastern Africa and Australia in the future. These are described in the concluding sections of the Proceedings.

The success of the Consultation was due to many people. The Government of Kenya was gracious in agreeing to host it through the good office of its National Council for Science and Technology. His Excellency the Australian High Commissioner, Mr A.G.D. White, took an active interest in the Consultation and was responsible for facilitating the contacts with the Government of Kenya. Thanks are especially due to Dr (Mrs) R.N. Oduwo, Assistant Science Secretary in the NCST who was responsible for the co-ordination of the local arrangements. She was ably supported by Mr A. Neylan, a consultant with ACIAR, who oversaw the general preparations and organization of the Consultation. Dr R. Gray, Director-General of the International Laboratory for Research on Animal Diseases (ILRAD) kindly agreed to make his facilities at Kabete available for the conduct of the Consultation. Our thanks are due to him and to Mr J. Lenehan and Mr M. Craig and their colleagues in ILRAD for ensuring that all the conference and catering arrangements were first class. Mr M. Mbogua and his staff at the Nairobi Serena Hotel made the visiting delegates most welcome and we are grateful to them for their hospitality.

Mr J.J. Ondieki, Dr J.A. Odera, and Dr J.D. Wachira were most competent rapporteurs for the various sessions and their contributions are appreciated. Mr S. Arnott of the Australian High Commission and Mrs Z. Smith gave invaluable assistance to us in the organization and conduct of the Consultation.

Mr P. Kusewa, Officer-in-Charge of Katumani Research Station, Dr B.N. Majisu, Director of the Kenya Agricultural Research Institute, and their staff provided the delegates with overviews and field visits to their institutions. This was especially appreciated by the Australian delegates, a number of whom had not visited the region before.

The staff of ACIAR in Canberra must be thanked for their contribution to the success of the Consultation. Particular mention should be made of Dr D. Blight, Ms W. Cuskelly, Mr A. Satrapa, and Ms J. Elliott. Finally, we must express our gratitude to all the delegates for giving the Consultation the benefit of their time and expertise. Without them and the thorough and patient attention of the Publication Editor Jack Mertin, this Proceedings volume would not have been possible.

J.G. Ryan and F.J. Wang'ati
Co-ordinators

Inauguration

The opening ceremony of the Consultation. From the left: His Excellency Mr A. G. D. White, Australian High Commissioner for Kenya; Professor J.R. McWilliam, Director, ACIAR, Australia; Professor P. Gacii, then Permanent Secretary, Ministry of Regional Development, Science and Technology, Kenya; and Dr F.J. Wang'ati, Acting Deputy Secretary, National Council for Science and Technology, Kenya.

Welcoming Address

The Hon. K.N.K. Biwott, E.G.H., M.P., Minister for Regional Development, Science and Technology, Kenya. On behalf of the Minister, this speech was delivered by Professor P. Gacii, then Permanent Secretary, Ministry of Regional Development, Science and Technology, and now Permanent Secretary, Ministry of Lands and Settlement.

Your Excellency, the Australian High Commissioner to Kenya, the Director of the Australian Centre for International Agricultural Research, Distinguished Scientists, Ladies and Gentlemen:

It gives me great pleasure to be with you this morning on this important occasion. I would like to start by expressing my sincere thanks to the Australian Centre for International Agricultural Research (ACIAR), the Kenya National Council for Science and Technology, and the Australian High Commission here in Nairobi, for organizing this meeting.

It is indeed a great honour for Kenya to host this meeting and on behalf of the Government and the people of Kenya, I would like to take this opportunity to welcome all the participants, especially those who have come from outside Kenya. I hope that during your brief stay here, you will have an opportunity to see some of our agricultural research activities which have already made a major contribution to agriculture in Kenya. Kenya is primarily an agricultural country. Agricultural research is, therefore, the most developed scientific activity in the country.

The Government continues to place emphasis on agricultural research and has recently established the Kenya Agricultural Research Institute which, it is hoped, will facilitate better coordination of research in the wide field of agricultural sciences. We, therefore, heartily welcome the possibility of ACIAR joining the other international organizations in support of agricultural research in Kenya and the Eastern Africa Region as a whole.

I will now turn briefly to some issues that will no doubt be of interest to you in your discussions over the next few days.

I understand that one of the objectives at this forum is to help Australians have a better understanding of the main problems affecting agricultural production in the Eastern Africa Region that could be alleviated through research. The other objective is to inform agricultural scientists of the areas in which Australia has developed relevant expertise that could be made available to Eastern Africa.

Implicit in these objectives is the need to develop lasting interpersonal relationships that would be an invaluable aid to the development and successful implementation of joint research projects. I am aware that a number of scientists from the Eastern Africa Region have studied in Australia and that some Australian scientists have visited or worked in this Region.

What needs to be done now is to develop a more coordinated program through which a larger number of scientists from the Eastern African Region can visit and work in Australian research institutions to enable them to learn new techniques. At the same time, a number of Australian scientists could be seconded to our research institutions to enable them to appreciate the difficulties that limit our capacity to develop agriculture. Through such efforts, the benefits of the collaborative research projects will become longer lasting while also strengthening our agricultural research capability.

Next, I would like to highlight the issues of food production and the threat of desertification through loss of vegetative cover and top soil. Although in recorded history severe droughts have occurred throughout the Eastern Africa Region with varying frequency, the increase in population, the changing ecosystem and eating habits have reduced the Region's resilience to adverse weather. This means that whenever droughts occur these days, they rapidly develop into emergency famine situations. The drought situation is further aggravated by the deterioration of soil resource through erosion and improper tillage methods. Our ability to produce enough food in the future will, therefore, depend on the acquisition and application of appropriate farming technologies, especially in the arid and semi-arid areas, which constitute the bulk of the land resource in the Region.

Australia has coped well with this problem and we look forward to your assisting us in our efforts to adopt the technology that has enabled you to do this rapidly. Kenya has already made considerable progress in this direction as evidenced by the establishment of a permanent Presidential Commission for Soil Conservation and Afforestation, and the current vigorous national effort to mobilize the entire population to take measures to conserve the soil. A better use of the soil, particularly in the more fragile ecosystems is, however, the only way to sustain long-term productivity and I believe the application of science and technology can make a major impact on the development of these regions. Any technology that ACIAR can provide in the field of soil and water conservation would, therefore, be most welcome.

The other issue I would like to highlight is that of renewable sources of energy, particularly wood fuel. The majority of our population depends on wood fuel in rural areas, and on charcoal in urban areas for their domestic use. Our wood fuel resources have, however, not kept pace with the rising demand. The *Eucalyptus* species, which I understand were introduced from Australia, have served us well in the high rainfall areas where their rate of growth and capacity for regeneration has been outstandingly beneficial.

We have, however, still to identify suitable species of trees that can help alleviate the situation in the drier areas of our countries. The local *Acacia* species, although well adapted, have such a low regenerative capacity that in several areas they have not survived intensive harvesting. It is our hope, therefore, that some of the research activities that will be supported by ACIAR will be directed to methods of improving the fuelwood resource, particularly in the dryland areas.

Finally, Mr. Chairman, I would like to commend highly the initiative taken by ACIAR early in its existence to familiarize itself and the Australian scientists with the problems of agriculture in Africa. Also, I would like to caution that in Africa, the agricultural problems, which appear to be simple and straightforward, are at times very complex. This is largely because they are tied up with socio-cultural values and practices which cannot be modified overnight. Many projects have, therefore, failed to produce the required benefits to the population simply because their planners ignored this important parameter. I hope the free exchange of views, which will take place at this forum, will only be a beginning and that a constant dialogue through consultative meetings of this kind will be established in the course of the implementation of the agreed projects.

I am further pleased to note that in your discussions you will be covering the important fields of socio-economics and farming systems. To the majority of farmers in the Eastern Africa Region agriculture in the broadest sense, which includes livestock production, is more a way of life, a livelihood, than a purely economic enterprise. The motivating factors for agricultural production are therefore complex and will require a careful study in each environment in order to develop appropriate agricultural research stategies.

I am keenly aware, Mr. Chairman, that your time is limited by the very busy schedule of this consultative meeting. Therefore, with these brief remarks, it is my pleasant duty to declare this Eastern Africa-ACIAR Consultation on Agricultural Research, officially open. I wish the participants an enjoyable stay in Kenya and success in their deliberations. My ministry, and I believe that the whole of the Eastern Africa Region will look forward to your recommendations and the opportunity to initiate, as early as possible, bilateral research programs with ACIAR. Thank you.

Response to Welcoming Address

J.R. McWilliam*

Thank you Professor Gacii for your remarks on behalf of the Minister and for your generous welcome to Nairobi.

ACIAR is very grateful for the opportunity to participate in this Consultation, which has brought together this distinguished group of agricultural scientists to focus on the question of how Australia, through the support provided by ACIAR, can develop an effective collaborative research program to assist in increasing the agricultural productivity of the Eastern African Region.

In coming to Kenya to talk about cooperation we realize that we are only one of a large number of donor agencies looking for opportunities to provide assistance for the Region. A recent estimate indicated that some 40 aid agencies are providing funds and technical support in Africa. Australia is one of these donors and through its official aid agency, the Australian Development Assistance Bureau, is supporting a number of development projects in Eastern Africa, including a major project here in Kenya.

ACIAR, the Australian Centre for International Agricultural Research, is a new independent aid organization, established by the Australian government to administer aid in the broad field of agricultural research.

In brief, ACIAR's task is to help identify and solve problems in developing countries through collaborative research activities, and in the process, strengthen the indigenous research capacity of those countries with which it works.

We have come to talk about opportunities for collaborative research in Africa because we are one of the few Western developed countries that share similar agricultural environments in the tropics and subtropics. Also, we are engaged in research on problems that have a great deal in common with those in East and West Africa. We believe we can exploit this comparative advantage and that our experience and research capabilities can be of value in Africa.

We have come hoping to develop an effective partnership in research to help in the solution of particular problems of importance to Kenya, and to Africa generally. In saying this, I must caution against raising unrealistic expectations. Our resources, both in funds and in the availability of agricultural scientists, are limited and thus to be effective in any collaboration in Africa we will have to focus our efforts and work wherever possible on problems of broad regional significance.

To help us in this task of finding the best focus for future collaboration, we have gathered together a distinguished group of advisers, including the most important component, i.e. a selection of the best informed local agricultural authorities from six countries in Eastern Africa. To this, we have added a cross section of experienced international scientists and donor representatives with considerable understanding of the Region. To complete the group, a selected sample of Australian scientists with considerable expertise in those areas of research that are most likely to form the basis of future collaboration are included.

With this mix of highly experienced people and with the format of the meeting, I believe that we will arrive at a very useful synthesis at the conclusion of this Consultation. In coming to this meeting, ACIAR and its team have tried to avoid developing any preconceived ideas about the agricultural research needs of Africa, although it is difficult not to come without some impressions of the major issues. It is clear that the food problems facing sub-Saharan Africa are serious and that population growth will continue to press hard on food supplies, both crops and livestock, and on other resources including land, water, and energy supplies through to the end of the century.

We would agree with those African analysts such as Carl Eicher, who suggest (Foreign Affairs, Fall issue, 1982, p. 151) that given the necessary policy reforms, the long range solution to the food problems in Africa will depend to a large degree on the achievements of agricultural research. Of particular relevance in this regard is

* Director, ACIAR, Canberra, A.C.T., Australia.

the need to increase expenditure on dryland farming systems, with emphasis on the integration of food crops, forage, and livestock production. In saying this, it is appreciated that African farming systems are extremely complex and the development of suitable technical packages will require location specific research by multidisciplinary teams. There is no easy short cut solution to this problem.

In these and other research and development problems, there is a great need for the many donor agencies that support activities in Africa and in this Region, to attempt a greater coordination of their efforts. It is critical that ACIAR knows what has been achieved by other projects, what is in progress, and also for us to link together with donors in a joint effort with national scientists whenever this seems to be appropriate.

The other criteria that I believe will be essential if we are to have any success in a joint research effort are that:

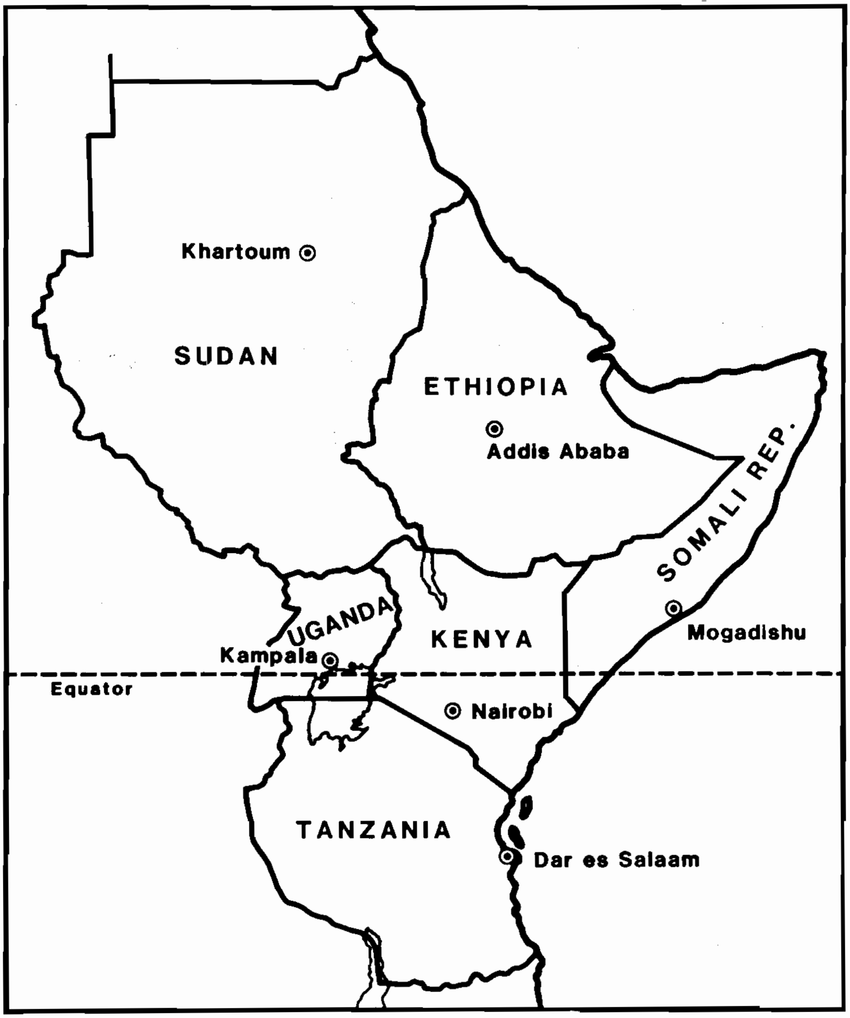
* We must respond to the research priorities of those we are trying to help and not attempt to impose our own sense of priorities on them.
* In any partnership in research, both parties must derive a benefit from our collaboration; it will not succeed if it is a one sided affair.
* Both parties must want to be involved and both must share in the planning and conduct of the research.
* The support must be secure and sustained for a sufficient period of time to have a real chance of success.

This then is what our visit to Africa is about.

ACIAR would like to thank the Government of Kenya for this opportunity to hold the Eastern Africa/ACIAR Consultation on Agricultural Research here in Nairobi, and also the Minister for his sound advice in his opening remarks. Our special thanks are extended to Dr. Wang'ati and the National Council for Science and Technology for co-sponsoring the Consultaton, and finally to Dr. Gray and his team for providing the support and the excellent venue for our meeting here at ILRAD.

Our colleagues in Australia were quick to describe our visit to Kenya as ACIAR's African safari. They are right, as it is a safari, but one with a difference and one that I hope will have a more constructive impact than most. In coming here we believe that we have something to offer Africa and also something to gain in return. If we can begin our discussions with this philosophy then our efforts have a very good chance of success.

Session 1
Eastern Africa: Country Perspectives



This map shows the location in Eastern Africa of the six countries, i.e. Sudan, Ethiopia, Somalia, Uganda, Kenya, and Tanzania whose representatives attended the Consultation.

Status of Agricultural Research in Ethiopia

M. Abebe, M. Mekuria, and T. Gebremeskel*

Ethiopia has a total land area of 122 million ha. Agriculture is the mainstay of the Ethiopian economy and provides about 60% of the gross national product, despite the fact that only 16% of the cultivable land is presently under cultivation. Consequently, 90% of the population lives in the rural areas with 85% of the labour force deriving its income from a subsistence oriented mixed farming system geared mainly to local consumption. In spite of this, agricultural exports primarily coffee, hides, and grains provide most of the foreign exchange and make up about 60% of the total export. However until recently, little inroads were made to promote research backed agricultural development.

This paper attempts to assess the status of agricultural research in Ethiopia as an integral component of its effect on agricultural development and hence increasing productivity. Such an assessment calls for an *a priori* understanding about its agro-ecology. It is only in such a setting that the diverse conditions prevailing in the country and research needs thereof can best be understood and tackled.

Physiography, Climate and Cropping Patterns

Ethiopia manifests a great contrast in physiographical conditions. The interior highlands rise rapidly to over 2 000 m (Ras Dashen Mountain is 4 620 m) and the coastal lowlands with a huge depression sink to more than 100 m below sea level.

The climate is very diverse. The Ethiopian highlands have an almost temperate climate with maximum temperatures rarely rising above 25-28°C. This region receives high rainfall (1 200-1 300 mm/yr) from July-September and contrasts with the plains of Ogaden and Danakil, which are very dry and desert-like. The transition zone towards the Somalian coast is semi-arid to arid with erratic rainfall totalling 250-500 mm/yr. The coastal strip along the Red Sea receives less than 100 mm/yr and is extremely hot.

As a consequence of the climate, most of the cultivated land and the peasant population are found in the rainfall-abound highlands. Here the environment is conducive for a number of tropical and temperate zone crops. Barley and wheat dominate the highlands while maize, sorghum, cotton, and groundnuts grow in the lowlands. Teff, flax, oil, and pulse crops grow in between. Coffee, the most important cash crop, grows in the northwestern and eastern plateaux. Livestock production is mainly in the lowlands which, although sparsely populated, consist of large grazing areas with good pasture lands scattered in various places.

With the above setting, it would not be difficult to realize that agricultural research should be given due priority to answer pressing problems in the different agro-ecological zones. Yet, the systematic study of agriculture in these zones has not received due attention. However in recent years, efforts have been made to rectify part of the situation and this paper attempts to review some of the findings, identify the bottlenecks, and suggest alternatives on what should be done.

Organization of Research

Prior to the formation of the Institute of Agricultural Research (IAR), different organizations were conducting agricultural research, e.g. the College of Agriculture, the Debre Zeit Experiment Station, etc. Agricultural research in Ethiopia was institutionalized in 1966 by the establishment of the IAR, which has subsequently been supported by four successive phases of a UNDP/FAO Project. It has been given a national mandate to sponsor and coordinate all agricultural research.

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* Soil Scientist, Agric-Economist, Institute of Agricultural Research, Addis Ababa, Ethiopia; and Animal Scientist, Ministry of Agriculture, Addis Ababa, Ethiopia, respectively.

When the IAR was established, it was estimated that approximately 140 professional research staff would be required. At June 1982, the IAR employed 143 graduate and postgraduate staff, consisting of Ph.D. 10 (Breeding/ Agronomy 7, Soil Science 2, Veterinary Medicine 1), M.Sc. 35, and B.Sc. 98.

In global terms this number might appear sufficient but certain research disciplines remain under-staffed. While field crops and crop protection departments are well staffed, the livestock, horticulture, soil and water conservation, agricultural engineering, and the socio-economics departments need to be strengthened. Despite this, a number of reliable research findings have been determined during the short time since the IAR was established and some are highlighted below.

Since its inception, IAR has maintained links with most of the appropriate regional and international agencies. Within Ethiopia it has links with Addis Ababa University, in particular the College of Agriculture at Alemaya, Awasa and Debre Zeit Junior Colleges, the Ministry of Agriculture, the Ministry of State Farms Development, the Ministry of Coffee and Tea Development, Relief and Rehabilitation, the Arsi Rural Development Unit, and the Soviet Phytobiological Laboratory.

The above institutions conduct a varying degree of research because at this stage the IAR cannot totally address itself to the research needs of the country. However, the work of all these institutions are linked to a varying extent with the IAR, either within the IAR team program or in collaborative research programs.

Internationally, the IAR has collaborative research links with CIMMYT, IITA, ICRISAT, ICARDA, CIP, and ILCA.

Research in Soil Science

The Soil Science Department includes soil fertility, soil surveys, soil and water conservation, irrigation and drainage, and laboratory services. The weakest points are (1), the lack of applied research on soil and water conservation and (2), the management of irrigated lands especially drainage requirements and soil salinity control, which already has caused serious damage.

Soil Fertility

Studies have been conducted by different institutions on different occasions on soils and fertilizers, including an assessment of the nutrient status of different soils and investigations on the amount, kind, method, and time of fertilizer application. Findings from the above, though meager due to trained manpower constraints and facilities, have been made available to users. However, because of inadequate linkage between research and extension, very limited innovations have reached the small farmer. That the transfer of this technology is not high is evidenced by the fact that more than 70% of the Ethiopian farmers do not use fertilizers. Even when such information is readily available, there is a disregard of the natural conditions of soils in relation to crops that restrict responses to fertilizers. Among the prevalent conditions are high acidity, alkalinity, excessive erosion etc. Consequently, fertilizer application both by the traditional and the state farms sector is nothing but arbitrary.

Where fertilizers are used, the absence of a concomitant use of good quality seeds with high genetic potentials and the use of the oxen pulled local plough, which does not result in a deep seed-bed, are other factors that limit fertilizer efficiency.

There is inadequate manpower training and this is reflected in a total absence of basic research in soil and plant nutrition, soil physics, soil chemistry, soil microbiology, and biochemistry etc.

Soil Survey

Soils found in Ethiopia range from the slightly weathered Entisols to the highly weathered Oxisols. Weathering of intermediate intensities are represented by the Inceptisols, Alfisols, Utisols, Vertisols etc. Yet, the extent and economic significance of these and other soils are not fully documented.

In a country with a total area of 122 million ha, only 44.8% has been surveyed. Of this, only 0.33% is detailed while the rest is a reconnaissance or semi-detailed nature. Thus, a great portion of the surveyed areas was done on a scale that has little practical value in agriculture.

In general it can be said that the correlation and coordination of various systems of soil classification have been unsatisfactory, and when conducted, have been done in the broadest categories. Much more needs to be done at detailed levels of classification in order to provide better extrapolation of research investigation, especially in soil management. Among these are pedological surveys, pedogenic studies, soil classification, and the broadening of soil survey work into land use surveys.

Soil Conservation

The general landscape, unique topography, heavy deforestation, very low levels of soil management, and intensive rainfall have resulted in heavy erosion losses. To-day, soil erosion is one of the most serious problems facing agriculture in Ethiopia.

More than 4 million ha of land are said to be very badly degraded already. In addition, the country continues to lose over one billion metric tons of soil yearly. Unless urgent preventive and mitigative measures are taken to arrest this trend soon, the agricultural resources base itself will be irreparably damaged.

Fortunately, there is a growing awareness of the problem, though perhaps not of its magnitude. The Soil and Water Conservation Department of the Ministry of Agriculture is conducting conservation programs involving the introduction of improved agricultural practices, physical conservation measures, re-afforestation, water resources development, and extension education in soil and water conservation among peasant associations.

Irrigation, Drainage and Salinity

Increased emphasis has been placed on irrigated agriculture in recent years. Thus, in 1978 about 15 major potential irrigation schemes were identified and pre-feasibility studies were conducted for the Valley Agricultural Development Authority (VADA) with the objective of implementing them in the near future. Currently, about 50 000 ha are irrigated.

Incorrect irrigation practice, lack of proper drainage facilities and in some cases, poor designs have led to the degradation of a significant area by salinization, alkalinization, and build-up of the water table. This has rendered the land completely or partially unproductive.

Research on irrigation and related fields have been conducted at an IAR station for the past ten years. However, research on irrigation methods and criteria, water management, and particularly salinity and drainage have not received adequate attention. This is not so much due to the failure to recognize the need for such research as due to the lack of properly trained staff and inadequate facilities. Hence, a strong program of research in irrigation, drainage, and salinity control would pay ample dividends not only by helping to reclaim salinized land but by providing the knowledge required to maintain sustained productivity on land to be brought under irrigation in the future.

Miscellaneous

Specific attention should be given to the large areas of land that are idle or under-utilized under present management conditions. A case in point is the Vertisols with their inherent poor interval drainage thus limiting farming in places.

To partly overcome this problem, soil burning is a common practice in the central highlands of Ethiopia. The practice is carried out in order to make the land productive for only 2 or 3 years. The field would then be left fallow for a period ranging from 10 to 20 years, and the cycle is repeated again. Such soils and the practice itself merit serious research efforts.

Crops Research

In regional terms, the present distribution of crops gives a rough assessment of crop adaptability to the main climatic regions.

Where adequate moisture is available during the growing season (500-700 mm), maize, teff, haricot, and lima beans are most suited to the upper lowlands (1 000-1 500 m a.s.l.) and intermediate highlands (1 500-2 000 m a.s.l.).

Wheat, sorghum, food barley, and linseed are well adapted to the intermediate highlands (1 500-2 000 m a.s.l.). Barley, field peas, and faba beans are particulary well suited to the high altitude areas of about 2 500 m a.s.l.

Adapted vegetables and fodder crops are available for all three ranges of elevations. Above

3 500 m a.s.l. the frost hazard becomes critical and the absence of a proper dry period for harvesting precludes any useful agriculture.

The lowlands, where the low rainfall limits cropping, can only be used under irrigation. Suitable crops here are cotton, kenaf, groundnut, sesame, and vegetables.

Cereals

In decreasing order of importance, i.e. in terms of area and total production, the major cereals in Ethiopia are teff, maize, sorghum, barley, and wheat. The national yield averages are far lower than those of many countries. Therefore, research is aimed at producing varieties that yield better than those that are currently being grown by farmers.

Much improvement over the yield of land-races is being achieved through selection, introduction, and crossbreeding of exotic varieties of the above mentioned crops.

From the cereals, pulses and oil crops, high yielding and well adapted varieties have been selected. The best planting time, spacing, and seeding rate have been tested. Rates and types of fertilizers to be used, and pest control measures to be applied have been established.

In addition to breeding, the selection and adaptation of cultural practices for the various crops and agro-ecological conditions of the country must remain a priority. Equally, research on the nature of diseases, insects, and weeds, i.e. their biology, mode of dissemination, attack, control, etc need to be conducted.

Horticulture

The department has been responsible for investigations on variety screening for performance and disease resistance under local conditions. Cultural techniques including fertilizer and in some cases, water requirement and pest control studies, are being conducted.

Crops involved are fruits and nuts (mainly citrus and banana), vegetables (chili, sweet pepper, tomatoes, onions, garlic, and shallots), roots and tubers (potato, sweet potato), herbs and spices (black pepper, ginger, turmeric and cardamon). On the whole, horticultural research has lagged behind mainly as a result of the lack of sufficient qualified staff.

Coffee

Work so far has concentrated on the selection and distribution of Coffee Berry Disease (CBD) resistant varieties. In addition, research is undertaken on weed contol, stumping cycle, intercropping of coffee with cereals and pulses, and fertilizer trials.

Emphasis is needed on hybridization, research on the physiology of arabica coffee, determination of economic fertilizer rates for the major soil types, and on management techniques to increase productivity of forest coffee, which still produces 60% of the total GDP output.

Fibre Crops

Research on fibre crops has concentrated on cotton and kenaf. A number of high yielding cotton varieties have been developed for irrigated and rainfed areas. As a consequence, invariably all planting material used by the State farms are products of IAR research. Equally, a number of high yielding kenaf varieties have been developed. However, until the rating problem is solved, it is unlikely that the hectarage under kenaf will increase.

Crop Protection

Investigation and pioneer work on pest and pathogen indentification and screening of pesticides have resulted in the publication of preliminary recommendations for pest and weed control in Ethiopia.

Besides CBD study on coffee, work has concentrated on rust in wheat, maize, groundnut, sesame, and cotton; bacterial blight on cotton; late blight on potato; stalk borers on sorghum etc.

Research in Animal Sciences

Ethiopia has the largest livestock population in Africa and the tenth largest in the world. The Ministry of Agriculture estimates the present size of this population at 27 million cattle, 24 million sheep, 18 million goats, 7 million equines, 1 million camels, and 52 million poultry.

Livestock and livestock products contribute about 35% of the agricultural output and also supply the power to cultivate virtually the total country's crop land. The contribution of livestock towards rural transport under the conditions of a limited road network cannot be over-emphasized.

In spite of the rich livestock wealth, the contribution of this subsector to the national economy has been generally low. This is mainly due to health hazards, feed, and water constraints.

Grazing is about the only feeding method practised, but in many parts of the country grazing conditions are unfavourable for more than half of the year. Natural pastures are severely overgrazed, particularly in the highlands and around permanent water points. On the other hand, extensive range areas in the lowlands are under-utilized for lack of permanent water.

Livestock in mixed-farming highlands depend on fallow land grazing, some hay production, and crop residue feeding practises. These in themselves are inadequate. In general, then, poor nutrition is a major factor limiting productivity.

Disease constitutes another serious constraint. Up to 50% of calves die from disease and/or starvation. Finally, trailing animals for slaughter over long distances, without adequate feeding or watering results in considerable loss of body weight and meat quality.

In spite of the above contentions, various research stations, educational institutions and development agencies have come up with high milk-yielding dairy cows, beef cattle, and poultry. However, the findings have not yet fully reached the farmer due to inadequate trained manpower and necessary facilities, and uncoordinated research.

Presently research is carried out on:

1. Cattle with emphasis on milk production through crossbreeding with exotic cattle, with an additional consideration being the production of a heavier and more efficient draught animal.
2. Sheep and goats——aimed at milk and meat production, mainly through cross-breeding and secondly, through selection of native breeds.
3. Pasture and forage crops——with a view to their improvement and conservation.
4. Nutrition——which involves the analysis of feeds and formulation of rations for different animals etc.

Since livestock improvement is a long-term undertaking and because the research program was launched only in 1973, the impact on production has been low so far.

Health

Animal health activities are a function of the Animal Resource Development Department of the Ministry of Agriculture. The Veterinary Service Division and the National Veterinary Research Institute (NVRI) are the two major units responsible for the National Animal Health Service. Staff consist of 85 veterinarians (of whom 40 are Ethiopian nationals), 270 animal health assistants, 126 upper and middle level technicians, and 672 vaccinators.

Important diseases of economic importance are rinderpest, contagious bovine pleuro-pneumonia, foot-and-mouth disease, anthrax, blackleg, pasteurellosis, trypanosomiasis, sheep pox, rabies, tick-borne diseases, and internal and external parasites. Trypanosomiasis has made impossible the development of some 98 000 km^2 of potential agricultural and grazing lands.

Organization of Livestock Research

The major institutions involved are the IAR, NVRI, and ILCA.

In the IAR, there is the Department of Animal Science, Forage, Pasture, and Range Management with sections for cattle, sheep, and goats; animal nutrition; pasture and forage; and an animal health advisory section. There are four field stations for research in the following agro-climatic zones——highland, mid-highland, arid, and semi-arid.

The NVRI, a semi-autonomous unit, is located 45 km from Addis Ababa. It is an overall coordinator for four regional laboratories. The Institute undertakes basic research and diagnostic work, but its main activity is vaccine production to meet the national demand. A total of 44 million doses of viral and bacterial vaccines are produced annually, of which about 50% is used against rinderpest and contagious bovine pleuro-pneumonia.

ILCA, which is part of the CGIAR network, became operational in 1977 and *inter alia*, is concerned with livestock production systems.

Major Problems

Matters of concern relate to feed, health, productivity, marketing, and manpower.

A major problem is the supply of feed on a year-round basis. In recent years, feed supplies have further deteriorated due to an expansion of sedentary farming in the highlands and the encroachment of crop production into traditional grazing areas in the lowlands.

Contagious, infectious, and parasitic diseases are among the major constraints to the development and fuller utilization of the vast livestock resources. As a result of this and poor nutrition, there is high mortality——cattle 8.5%, sheep 14.5%, and goats 11.6%.

The marketing system is traditional, unorganized and inefficient. Coupled with uncontrolled livestock movements, the present marketing situation is a constraint limiting the improvement program.

Because of the feed, health and marketing factors, productivity in indigenous stock is significantly low in the highlands and the lowlands.

The lack of adequately trained personnel for research and extension is also a major problem.

Research Priorities

1. Priority must be given to improving the productivity of native breeds of cattle, sheep, and goats.
2. Because the largest concentrations of human and animal populations are in the highlands, research priorities should be given to this zone in respect of pastures, forage, and management in mixed farming systems.
3. There should be dryland farming studies in the lowlands, which cover 50% of the land area of Ethiopia, and from which the commercial off-take of cattle occurs.
4. The economic impact of internal and external parasites should be investigated.
5. Indigenous grasses and legumes should be identified and studied.
6. Existing accumulated data on different farms in the country should be analysed and interpreted.

Socio-Economics and Farm Management Studies

The research programs of the Department of Socio-Economics and Farm Management Studies started with straightforward studies in the field of agricultural economics, with particular emphasis on farm-recording systems development, production cost studies, and farm management studies on private commercial farms. Due to the need for basic farm level (micro-level) information on resource use, organization, farm income and expenditure the focus was on economic studies of small-holder income. Subsequently nationwide farm management surveys in co-operation with other development agencies were launched.

Presently the major emphasis is on:

Farming Systems Research

The multidisciplinary approach is intended to bring to the attention of the researchers those problems faced by the farming community and is designed to test and evaluate technologies developed at the research stations under actual conditions prevailing on the farm. The choice of recommendation hence requires the socio-economic assessment of innovations. In light of this rationale, farming systems research focuses on:

1. Problem identification through multidisciplinary surveys.
2. Development of simple and viable whole-farm packages based on the problems identified.
3. Testing of the packages on farmers' fields and subjecting them to both technical and economic evaluation.

As a result, surveys were conducted in nine locations and package testing for different crops on seven sites have been conducted. In general, the results reflected the success of the recommended packages. However, the packages lacked the other most important subcomponents of the farming system such as livestock and improved implements. With regard to innovation adoption, farmers were reluctant to accept the higher levels of fertilizer recommendations, some cereal varieties that have specific problems (threshability, colour, and low market demand compared with existing varieties), and hand weeding recommendations.

Large Scale Farm Management Research

Due to the rapid speed under which large scale State farms are being established in the different agro-ecological zones, immediate attention is required to tackle the managerial organizational and technical problems. Hence economic-based research efforts are essential to investigate;

1. Range, size of enterprises, and their combinations.
2. Level of mechanization.
3. Efficiency of resource use on the State farms.
4. Means of devising farm-recording, planning, and controlling systems.

Presently case studies are underway in four divergent locations that represent cereal and horticultural farms.

Field Scale Trials of Recommended Practices on Research Station Farms

The Department of Socio-Economics and Farm Management Studies runs the farms of the research stations for basic and breeder seed multiplication. Farm record-keeping systems have been maintained over many years.

The objectives of this project are to develop input/output norms for various crops on different stations and to test different forms of recording information for a comprehensive development of a farm record-keeping system. These activities are underway on six major stations and 14 crops are produced annually.

Economic Evaluation of Fertilizer and Herbicide Use

The crop improvement packages so far have been dominated by improved seeds and fertilizer recommendations. Farmers are becoming reluctant to apply recommended rates due to the skyrocketing fertilizer prices and the stable grain price they are paid. Hence a study on the economics of fertilizer use is being conducted on major crops in selected areas.

Since different herbicides are recommended, an economic evaluation on the type and rate of herbicide application is being conducted. Further comparative studies are being made between chemical control of weeds and hand weeding.

Economics of Sheep Rearing

Since IAR is engaged in sheep and goats research, introducing improved rams and/or ewes to peasant associations or producer cooperatives in order to assess their performance under peasant farm management situations has been found necessary. This is being done particularly in areas that have high potential for sheep production. Data on management practices and input/output information are being collected. Pasture improvement practices to be recommended in the area will be included soon.

Research Capabilities

Socio-economics and farm management research activities presently do not cover all the major agro-ecological zones of the country, but are limited around IAR stations and substations. This is due to constraints in trained manpower, transportation facilities and in uncoordinated research efforts with different agencies involved in similar endeavours.

Hence if agricultural research is to be goal oriented and is to generate technologies that will accelerate agricultural productivity, then a strengthening of the socio-economic and farm management studies should be given due priority.

Conclusion

In the Ethiopian setting, the need for strengthening agricultural research becomes paramount when one is cognizant of the agricultural development objectives of the government. These include:-

1. Alleviating the existing food shortage.
2. Increasing the production of raw materials for industrial use.
3. Expanding export earnings and producing import- substituting products.

To attain these objectives, developing the scientific and technological capability of the country in order to generate innovations that would solve production problems is vital.

Status of Agricultural Research in Somalia

M.A. Noor, M. Abdullahi, and A.N. Alio*

Somalia, which is located between 12° N and 2° S latitudes in the Horn of Africa, has an area of 638 000 km^2. The population is estimated at 5 million of which 80% are engaged in agriculture; 60% are pastoral nomads and 20% are settled farmers.

Climate and Soils

Climatically, Somalia is classified as arid to semi-arid, and can be divided into three zones, viz. the Northern Mountain Zone with a semi-Mediterranean climate and average annual rainfall from 50-750 mm in different areas; the Northern and Central Coast Zone with an arid climate and annual rainfall of 50-100 mm; and the Southern Inland and Coastal Zone with an equatorial climate and annual rainfall up to 600 mm. Somalia has two rainy seasons and pronounced fluctuations in monthly and annual rainfall are experienced. Crop failures due to drought occur periodically.

Thirteen dominant soil types are reported in Somalia. Typical desert soil (Yermosols/Xerosols) carries a sparse vegetation cover over large tracts in northern and central parts of the country. However, in the north-west mountains area where the climate is more favourable, good soils with high mineral reserves are found. The southern part of the country, where rainfall is relatively more (up to 600 mm), contains well developed fertile soils with good agricultural potential. They range from heavy clayey soils to medium textured soils along the rivers and in the inter-riverine area. Some of these have low permeability and require special care with regard to irrigation methods.

* Vice Mininister of Agriculture, Ministry of Agriculture; General Manager, National Tsetse and Trypanosomiasis Control, Ministry of Livestock; and Director, Agricultural Research Institute, Ministry of Agriculture, Mogadishu, Somalia, respectively.

Agricultural Resource Base

It is estimated that Somalia has 8.5 million ha that are potentially suitable for crop production; however, presently only about 1.0 million ha are cropped. Eighty four percent of the cultivated area (0.84 million ha) is under rainfed farming, and 0.16 million ha are irrigated.

The surface water for irrigation is obtained from two rivers, the Shabelle and the Jubba. The Shabelle has an annual flow of over 2 billion m^3 and runs for 7-8 months per year. It is estimated that nearly 120 000 ha could be potentially irrigated. Water quality seriously suffers during low flow periods due to high salinity. The Jubba river in southern Somalia has an average annual flow of 6 billion m^3. The total net area in Jubba valley is estimated at 230 000 ha.

The farming community is largely comprised of individual small-farmers who cultivate 94% of the cropped area and provide more than 90% of the country's total food crop production. The number of families is estimated at 150 000-180 000. A few large scale farms have been set up in the State sector for specialized crop production.

Organization of Research on Crops

The Ministry of Agriculture is primarily responsible for research and development activities in crop production and irrigation. Under the Ministry, the Agricultural Research Institute (ARI) is the major single unit responsible for organizing and executing research, although some other projects also have small research components. The research emphasis at present is on development of improved production technology in sorghum, maize, oilseeds, grain legumes, and vegetables and on better farming systems for small farmers under rainfed and irrigated conditions. Limited attention is paid to fruit trees and forage.

The ARI conducts research programs at the following stations:

Central Agricultural Research Station (CARS), Afgoi

It is the national research station and has eight research disciplines. On-farm research is an important component of the program. This centre is responsible for research in irrigated and dryland regions. The organizational chart for the centre is listed below:

Regional Research Stations—Sakow and Jillib

They are still in the initial stages of development and will be responsible for research on irrigated crops with special emphasis for the Jubba Region.

Regional Research Stations—Bonka and Aburein

These stations are responsible for research on dryland crops for the Bay and North-west Regions respectively, with major emphasis on sorghum. The research organization is yet to be developed.

The Faculty of Agriculture, National University of Somalia, with a fairly large staff is also actively engaged in crops research. The ARI and the Faculty collaborate closely in formulating and executing research programs utilizing the resources of both institutions.

Research-Extension coordination at the national level is directed by the National Extension and Research Committee headed by the Vice-Minister of Agriculture. The areas of coordination include: evaluation of research developments and identification of research priorities; planning and execution of research-extension trials in farmers' fields with new research findings; and preparation of production recommendations for farmers.

The development of crops research in Somalia has encountered a number of constraints. The first and foremost difficulty has been the lack of appropriate facilities at the research stations and a shortage of qualified manpower. Institution buldings have lagged behind, limited resources were diverted to solve immediate problems and as a result, research programs have lacked continuity as well as long-term planning. Also, research emphasis to date has largely been on individual problems or crops, rather than on cropping or farming systems.

The links of research with planners and policy makers on the top, and extension and seed

Table 1.

Research at the station	Research in farmers' fields	Support services
Crop Manager	Farming Systems and Economics	Administration
Entomology	Research Extension Coordination Unit	Irrigation & Meteorology
Horticulture	Farm Machinery	Library
Irrigation		Workshop
Nucleus Seed Production		
Pathology		
Plant Breeding		
Soils		

multiplication on the down stream, are not fully established yet, although some concrete steps have been taken in this direction.

Another major difficulty has been the lack of procedures for selection, evaluation, and promotion of research staff. Further, the existing salary structure is not sufficiently attractive and consequently there is increasing tendency for the experienced staff to move to other projects where prospects for advancement are better.

Research Developments—Crops and Soils

Rainfed

The Bay Region situated between the rivers Shabelle and Jubba constitutes the main rainfed area where rainfall ranges from 400-600 mm per year. A limited rainfed hectarage is cultivated in the Northern Region. There are two cropping seasons — Gu (March-July) and Der (September-December), which coincide with the main rainfall periods.

Sorghum is the main rainfed crop grown in both regions. It is cultivated as a sole crop and sometimes intercropped with pulses. The average sorghum yields vary from 300-500 kg/ha, although in experimental plots yields up to 1 000 kg/ha have been reported with new varieties under improved practices. Stalk borer and smuts are the main pests, which may cause crop losses up to 50%; pesticides have been identified to control them. Damage from *Quelea* continues to be high and several techniques are being evaluated in large scale tests.

Recently, a breeding program has been initiated with sorghum which aims to introduce drought tolerance, stalk borer resistance, and better yield stability in local and adapted exotic types. Also, improved crop management and fertilization practices are being developed.

Tests with different crops show that groundnut has good potential under rainfed conditions in the Bay Region. Sunflower and safflower are being investigated as potential crops. Research to evolve a long fallow system in good rainfall areas is in progress. In the North-west Region; some studies have been conducted to improve soils and water conservation through bunding in highland areas.

Irrigated

Two types of irrigation systems are used, viz. controlled irrigation and simple flood irrigation. The main crops grown are maize, rice, cowpea, mung bean, sesame, and vegetables. The fruit crops are banana, citrus, and papaya and the plantation crop sugarcane also occupies a substantial area.

Maize is the largest area crop (170 000 ha). The major research developments with this crop have been the release of Afgoi composite in the mid 70s and Somtux in 1979. A further breeding program to develop composites and synthetics with wider adaptability has been undertaken. Applied fertilizer was found to be highly remunerative with the Afgoi composite with 1 kg N/ha giving an extra 30 kg grain/ha. Similar gains were reported in Somtux with fertilization. *Chile partellus* is the major pest of maize. Furadin® and Basudin® were found to be effective against it and they nearly doubled the yield. Recently downy mildew was noticed in Somtux, to which it appears to be susceptible.

In rice, two upland varieties, viz. Dawn and Saturn have been introduced. Recently among paddy varieties from ARI, IR 24 was selected, which is now the major commercial variety. Similarly, erect cowpea variety TVU-15 introduced from IITA, was released for planting as a sole crop.

Sesame, which is the main oilseed crop of the country, is grown under single flood irrigation. The yield is low and ranges from 300-400 kg/ha. Unfortunately its improvement has received rather scant attention. Major production problems are low productivity of local cultivars, seed shattering and heavy losses caused by *Antigastra*.

In fruits, considerable success has been achieved in establishing grapefruit production through the release of appropriate root stocks and varieties. However, practically no research has been done in recent times in banana, which is the major export crop. This matter needs urgent attention.

In vegetables, three varieties of onion, viz. Bombay Red, Red Creole, and Texas Grana, and one of the tomato, viz. Roma V.F., have been released. Recently a program was undertaken to introduce suitable varieties of potato in North-East Region.

Farming Systems Research

Farming Systems Research, which was initiated in 1982, has two components:

1. The selection of two benchmark villages, one each in rainfed and irrigated regions, and the conducting of socio-economic and farm management studies to analyse the present farming systems of small farmers. Also to study the impact of new innovations on farm productivity and income, and the attitude of farmers towards adoption of these.
2. The organization of on-farm trials under farmer management at different sites in collaboration with extension staff in order to evaluate and refine research recommendations. There will be trials on varieties, pesticides, weed control and use of improved hand tools.

Surveys conducted in the rainfed village (Shawka) in Bay Region indicate that an average farm size is about 5.5 ha of which nearly 60-80% is cultivated annually. A large majority of farmers have livestock, which constitutes their major capital for emergencies and cash expenditure. Livestock graze in the rangeland or on crop residues left in the field. Stall feeding is not practised.

It was found that mainly subsistence farming is practised with sorghum as the main crop, which sometimes may be intercropped with cowpea. All operations are performed manually and inputs are used rarely. The timely availability of labour for weeding is the key factor in determining success or failure of the crop.

Under irrigated farming (village Bulo Marerto) the actual cropped area per family is considerably less due to the shortage and high wages of labour.

The small-farmer cropping pattern largely consists of maize and sesame. Cowpea is grown on a limited hectarage as an intercrop. These crops receive one or two irrigations with a limited use of fertilizers and pesticides. The farmers with assured irrigation grow vegetables and fruits together with the field crop. The production system though largely subsistence oriented, is gradually moving towards a market economy due to some of the liberal policies adopted by the government regarding the sale of agricultural commodities.

The water distribution system and on-farm water management practices need considerable improvement in order to ensure timely availability of water to small farmers and to achieve improved irrigation efficiency.

Future Plans for Crops Research

Research Organization

It is now fully recognized that research at the appropriate level is indispensable for steady increases in agricultural production and consequently, for economic growth in Somalia. Therefore, the development of a suitable research system in agriculture in line with the country's needs deserves high priority. Efforts are underway to formulate an appropriate strategy that will be largely based on the following main elements:

1. Developing a plan for the structural organization of research system in Somalia.
2. Strengthening existing research institutions.
3. Manpower training in the country and abroad, and appropriate development of a staff in the research institutions with assurance for career improvement.
4. Ensuring inter-ministerial and inter-institutional coordination in research planning and execution.
5. Setting well defined linkages of research with extension and development projects on the one hand and policy makers on the other.

Research Programs in Crops and Soils

Rainfed farming is practised on a large hectarage and improvement of production under these conditions is important. The major issues that deserve attention are improved tillage and water conservation practices, and diversification of the existing cropping system, which is now largely based on the monoculture of sorghum.

Irrigated agriculture although practised on relatively smaller areas than rainfed farming is of critical importance in stabilizing crop production. The prospects for expanding areas under irrigation through water conservation works and increasing productivity are substantial. Presently, water-use efficiency is estimated at 20%. Therefore, effective water management both at the farm level and at the distribution level are to be given urgent attention.

Also, research will be continued to develop technology for improving production of maize, sesame, and other crops. Particular attention will be paid to developing optimum cropping systems for various types of irrigated farming (flood irrigation and controlled irrigation), and input and water requirements. Research on horticultural crops, particularly bananas, will be given high priority.

Labour shortages, especially at critical periods, and rising wages have strong adverse effects on the area cultivated and yields obtained by small farmers. Therefore, research on the introduction of new efficient manually operated tools and equipment will be initiated. Also, due attention will be given to develop village practices and mechanization of some of the labour intensive operations. Possibilities will be evaluated for herbicides to control weeds, which are the single most expensive element of the crop production system.

Farming Systems Research

The data base in Somalia is still weak, particularly as far as small farmers are concerned. Therefore, priority will be given to expand the present program to study farming systems in-depth at more sites. Greater emphasis will be laid on investigations concerning labour management, crop-livestock interaction, marketing, and income and consumption patterns.

Programs and facilities for on-farm testing will be strengthened with priority to find solutions to constraints that have already been identified, e.g. weeds, pests, such as borer in maize and sorghum, and poor water management. The introduction of each crop in the cropping system will be studied in order to diversify the cropping pattern and enhance farmers' income.

Scientific Staff

Graduates employed full time on crops and soils research in the Agricultural Research Institute are: Ph.D. 1, M.Sc.2, and B.Sc. 30. In the Faculty of Agriculture, scientists working part time on crops and soils are: Ph.D. 1, M.Sc. 9, and B.Sc. 11.

Livestock Resource Base

Livestock form the main economic commodity of the country. Eighty percent of the population depends directly or indirectly on livestock and livestock by-products. Livestock further accounts for 90% of the foreign currency earnings. The national livestock population has been estimated as being cattle 4 million (Zebu), 24.6 million sheep and goats, and 5.2 million camels.

Most of the country's land is suitable for an extensive type of livestock production. The off-take numbers from these animals have been estimated as:

Livestock	National (%)	International (%)
Camels	1	10
Sheep and goats	12	40
Cattle	4	20

Apart from a few State farms, the majority of the livestock is located in the nomadic community and is thus managed entirely on a traditional pastoral system.

The riverine and inter-riverine area (about 70 000 km^2) is currently unavailable for grazing because of tsetse infestation. In view of the importance of this sector, an intensive research program is being implemented.

Organization of Livestock Research

The Ministry of Livestock is entirely responsible for research in animal health, animal production, range development and other associated activities. The serum and vaccination institute, although originally concerned with vaccine production has now been expanded to form the basic research unit for animal health production.

An animal production research centre consisting of a dairy farm, an artificial insemination centre and a fattening unit is also being integrated to form an animal production research institution.

The major vector control work is currently limited to a tsetse fly control program that is being carried out as applied research into tsetse distribution, control techniques, and environmental and land-use studies.

Livestock research has been limited by a lack of trained personnel, the absence of a research infrastructure, and the nomadic habit of the pastoral community, which does not lend itself to systemic research. Furthermore, the limited resource was mostly directed towards the treatment of diseases rather than research *per se*.

Livestock-related research is being carried out in the following institutions:

Serum and Vaccine Institute

The Institute consists of the Departments of Parasitology, Bacteriology, Virology, and Pathology. The Departments are mainly engaged in vaccine production and are producing vaccines for use against anthrax, haemorrhagic septicaemia, black quarter (black leg), contagious bovine pleuro-pneumonia, contagious caprine (goat) pleuro-pneumonia, rinderpest, and sheep pox.

Attention is also being given to ticks and tick-borne diseases. To date some 26 000 ticks have been collected and classified. A tick rearing facility for 60 000 specimens is also available to be used for acaricide resistance. The Institute is linked closely to regional laboratories, which supply it with materials for examination and experimentation.

Regional Diagnostic Stations—— Hargeisa and Kismayo

These stations are responsible for carrying out preliminary investigation and diagnosis into local animal health problems. However, they are not equipped to conduct organized research work, which is passed on to the Serum and Vaccine Institute.

The Hargeisa Laboratory deals mainly with ticks and internal parasites while the Kismayo Laboratory concentrates on trypanosomiasis and tick-borne diseases.

Animal Production Research Centre

This centre consists of a dairy farm and a feedlot unit.

The Afgoi Dairy Farm

Here a crossbreeding program involving the local Zebu, Sahiwal, and Friesian cattle has been in progress for 15 years. The objective is to upgrade the Dawara breed, which normally produces 3-4 litres of milk/day. The average yield to date of the crossbred Friesian-Dawara is 10 litres of milk/day. The crossbreds are not given special diets but graze the open range with little or no supplementary feeding.

The Artificial Insemination Centre, which is closely linked to this breeding program, maintains Sahiwal and Friesian bulls for semen production and distribution to settled farmers. The staff of the Centre carries out the artificial insemination and maintains a record of all cattle inseminated and a history record for follow-up evaluation. The Centre is soon to establish subcentres to facilitate distribution of semen to settled farmers.

Feedlot Unit

It conducts fattening studies of local cattle. The young bulls, of average age 2.2 years are kept for 90-120 days and are fed on various formulations of locally available feeds. Feeding trials of various breeds carried out at this Centre have shown that the Baran and Dawara breeds can gain 1.04 kg and 0.82 kg/day respectively, when fed the best concentrates.

Research Aspects of the NTTCP

The NTTCP (the National Tsetse and Trypsanomiasis Control Program) is concerned with developing the methodology and assessing the benefits and economics of the tsetse eradication campaign in southern Somalia. The investigations include tsetse distribution and survey methodology; tsetse control methods; environmental impact of tsetse control operations; diseases of livestock; the effect of tsetse control on land-use and livestock management; paternal assessment of the different development options opened up following tsetse control measures; and the economic evaluation of these options.

Much of this work involved the implementation of broadly established methods, but it also requires an investigatory or applied research element in adapting and developing general methods for local requirements and circumstances. Applied research aspects in the NTTCP program include:

1. Development and evaluation of tsetse survey methods both for different tsetse spp and abundance, and for assessing population stability, particularly in low density habitats. Different models and combinations of traps, targets, bait attractants and electric nets are being tested or proposed for testing.
2. Development and evaluation of control methods, including aerial incremental drift spraying, ground aerosol or fog drift spraying, selective ground residual spraying, aerial residual barrier spraying, and insecticide impregnated traps, targets and screens.
3. Identification of local tsetse habitat components and their mapping with the aid of 1:30 000 aerial photography.
4. Identification of vulnerable species and assessment of the direct impact of tsetse control measures and long-term effects following change in occupation and land-use.
5. Identification and use of key indicator species for biological impact assessments.
6. Mapping of land potential and land-use categories with the aid of 1:30 000 scale aerial photography.
7. Development of methods for recording and measuring changes in land use.

Rangeland Research

Somalia's rangeland constitutes one of the major resources of the country because it supports the country's major economic unit, i.e. livestock. To develop and initiate studies in this field, the National Range Agency has been formed. Its responsibilities involve range, forestry, and wild life. Some of the applied research that is being carried out is conducted by the following institutions:

National Herbarium

The main function is to collect and identify all the flora of the country. It is to produce a check list of the plant species and to date about 15 000 species have been collected and identified. The Herbarium has published the following works——Flowering Plants of Somalia, and Key to the Identification of Somali Grasses.

It is currently engaged in producing a check list of the flowering plants of Somalia, a bibliography of the flora of Somalia, and keys to the identification of Somali *Acacia, Commiphora*, and other important groups. The National Herbarium has developed species-exchange programs and research coordination with 15 international herbaria.

Central Rangeland Development Project (CRDP)

In recognizing the importance of Somalia's rangelands resource, it is imperative that emphasis be given to a better understanding of the range and livestock production system so that Somali people may manage the resources as effectively as possible.

To help alleviate the current lack of base line data on these systems, the Central Rangeland Development Project has provided a research program through the Department of Botany and Range Management, Faculty of Agriculture, University of Somalia, Afgoi. Objectives of the program include:

1. Setting up student thesis projects to give students 'in the field' application of work, introduce them to research techniques and their application, and prepare them for continuing work on Somalia's rangelands. These students will provide an educated group of people, who, throughout the years, will strengthen the nation's capability to manage the rangelands.
2. Establishing a forage analysis laboratory to conduct nutritive tests on important livestock forage species.
3. Establish ecological monitoring sites to determine the vegetative, edaphic, and climatic attributes of various plant communities. These sites will provide information on community responses and potential.
4. Conducting field investigation on the diets of sheep, goats, cattle and camels in relation to plant availability.

5. Assessing the effectiveness of grazing reserves in CRDP management plans.
6. Developing a feasible range research plan for the country that considers priorities, organization, staff, etc.

This research program is still in its early stage of development; all the above items have been implemented and are in varying degrees of progress. The information generated by these studies will throw light on the rangeland and livestock production constraints, and hopefully will lead to their solution.

Future of Livestock and Rangeland Research

The plan for future livestock research calls for the integration of the Serum and Vaccine Institute, the Afgoi Dairy Farm, the AI centre and the Warmahan State Farm to form a Livestock Research Institute. Forestry and Range Research, which form components of on-going projects, will be continued by the National Range Agency in cooperation with the Faculty of Agriculture.

Applied research in tsetse and trypanosomiasis will continue to be carried out by the NTTCP in cooperation with the proposed Livestock Research Institute upon the termination of the eradication program.

Scientific Staff

Graduates employed in the Ministry of Livestock are: Ph.D. 1, M.Sc. 4, and B.Sc. 27. In the Faculty of Veterinary and Animal Science there are: M.Sc. 8 and B.Sc. 7, working on a part time basis.

Frankincense and Myrrh Research

Since ancient times, Somalia has been known for the production of frankincense (*Boswellia* spp) and myrrh (*Commiphora* spp). At present, *Boswellia* spp are not cultivated although they are privately owned. They propagate spontaneously from seed in the hills and limestone area of the Northern Coastal highlands.

A cooperative research effort between Somalia and Sweden on the domestication and chemistry of frankincense and myrrh spp has been in progress since 1981. The ultimate goal of the project is to demonstrate some of the economically most important frankincense producing species.

In order to achieve this, the following subgoals have been set, viz. study the natural habitat of the species, investigate seed and vegetative propagation, and find safer and more economical tapping methods. There is some evidence that most of the species can be propagated vegetatively with good results.

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Agricultural Research Priorities in the Sudan

H.A. Musnad, H.H.M. Faki, and A.H. El Jack*

The Sudan, with an area of 2.5 million km², lies between latitudes 3° N and 23° N. It is mainly arid and semi-arid with as much as one third of its area as a desert. The remainder receives rainfall that increases from north to south up to 1 400 mm. In most areas it is summer rainfall in a short rainy season extending from June to September. Its distribution within the seasons as well as among years is erratic in both time and space. However, in southern Sudan it is continuous while in part of eastern Sudan there are some winter rains.

Temperatures are normally high, and range from 18°C to around 40°C. Winds are active and mainly from south and north directions creating dust storms under dry conditions.

The country is generally flat with a low series of hills, viz. the Red Sea Hills in the east, Nubu Mountains in the centre, Gebel Murra in the west and the Immatung in the south east. The river system comprises mainly the Nile and its tributaries running through the country for 4 000 km and providing the country with 18.5 milliard cubic meters of water representing its share of the Nile water measured at Aswan. (A milliard equals one thousand millions). Other water sources represent small seasonal streams of which Gash and Baraka in eastern Sudan are the most important.

Soils fall into three main types, i.e. (a) clays extending through the central and eastern plains, (b) sands occupying the north and west, and (c), the lateritic soils in the south.

Of the Sudan's total area of about 243 million ha, 80 million ha are estimated to be potentially suitable for agricultural production of which 80 million feddans (33.6 million ha) represent rangeland.

The population is about 22 million which implies a sparsely populated country in average terms. In 1973 the census estimates showed a density of 5.9 persons/km², which is low compared with the African average of 9. However, if the desert is ignored, the figure becomes 6.9 persons/km². Population pressure leads in some cases to over-use of natural resources in heavily-populated areas. The same situation pertains for animals where pastures and water resources are depleted.

The country is mainly agricultural with about 80% of its population engaged in this sector. Moreover, 71% of the population are settled in rural areas where agriculture predominates, and 11% are nomads. Agriculture contributes 95% of exports and some 50% of government revenue. In the period 1961-1974 its share in the GDP averaged 44%.

Agricultural Systems

Generally, climate, soils and demographic factors play a major role in defining the type of agriculture. In dry areas, the growing of early-maturing crops, e.g. sorghum, is common. Marginal areas are well utilized by nomadic tribes. In areas of higher rainfall different crops and varieties are grown.

To define the prevailing agriculture systems in the Sudan it is plausible to follow the conventional classification of agricultural activities into two main categories, i.e. a traditional sector and a modern one.

Traditional Sector

The traditional sector is characterized by a high dependence on subsistence crops, more dependence on family labour, use of traditional tools, meagre input use and less innovations. Crop yields are generally low and variable. The crop-livestock interaction is substantial. Traditional agriculture exists under both irrigated and rainfed conditions where the bulk is rainfed (82% of cultivated area). Traditionally irrigated areas are found along the river banks and where underground water is accessible. Rainfed agriculture is

* Forestry Scientist, Soba Research Station, Khartoum; Agricultural Economist, Agricultural Research Corporation, Medani; and Animal Scientist, Gezira University, Medani, Sudan, respectively.

practised traditionally all over the country where rainfall is enough to raise a crop.

Modern Sector

The modern sector is characterized by more commercialization, more intensive use of machinery and other inputs, and generally better yields are obtained. Distributed among both rainfed and irrigated activities, modern agriculture is mostly practised on a large scale compared with traditional agriculture. It enjoys better infrastructure and provides employment opportunities for wider sectors of the population.

Irrigated agriculture constitutes about 17% of the area under cultivation but produces more than 50% of the production of the main crops. Modern rainfed agriculture originates mainly within the vast central clay plains and constitutes about 30% of the total area under rainfed cultivation. It predominates where rainfall ranges between 500-700 mm and in the form of large mechanized crop production schemes that average about 400 ha and are privately owned and operated.

The crops grown are sorghum, millets, and sesame. The expansion in these schemes is at the expense of natural forests and pastures. Under modern irrigated agriculture the range of crops grown is wider and substantial intensification is practised. The main crops are cotton, wheat, groundnuts, sorghum, sugar cane, fodder crops, and a variety of vegetables and fruits.

Agricultural Systems and Resource Use

Within the traditional sector there is overuse of natural resources, which is apparent in soil deterioration, low yields and eventually symptoms of desertification, which sometimes lead to migration. This is more evident in areas of permanent cropping than where shifting cultivation or nomadism is practised. However, even in those areas increasing pressure is detrimental to natural resources.

In this sector labour is mainly devoted to crop growing and animal rearing. There is a high degree of division of labour in addition to its seasonality. This seasonality is sometimes broken in cases when gum tapping and its collection is practised in the dead season in areas where gum trees grow or where people migrate to irrigated areas to supply hired labour. There is little manuring although, as mentioned, there is substantial crop-livestock interaction.

In the modern sector, resource use depends on whether it is rainfed or irrigated.

Rainfed

In rainfed areas mechanization of agricultural operations is practised. Due to the vast clearance of natural forests and the negligence of the recommended rotation, soils are affected by monocropping and erosion is the result. In spite of the considerable degree of mechanization there is high dependence on family labour,mainly for harvest operations. Nevertheless, these schemes have the potential to accept innovations especially in the field of land preparation and new varieties that are combinable and early-maturing.

Irrigated

In the irrigated sector, although more efficient resource use is practised than in the traditional one, its use is still below optimum. Water-use efficiency is low and there are problems with water management practices. Related to irrigation are the hazards of water-borne diseases like malaria and bilharzia. Plant nutrition and protection are other areas where resource use suffers from low efficiency. Labour seasonality is less manifested than in the other sectors. Labour-peaks exist and movements from labour-surplus areas to irrigated schemes, especially at the time of cotton picking, are common.

Agricultural Problems

The clays are generally heavy cracking soils, which are difficult to prepare, are subject to soil compaction and water erosion, and create problems in harvesting some crops, e.g. groundnuts. They are generally deficient in organic matter and nitrogen. In some areas of the irrigated clays, there are salinity problems.

Sandy soils are light, vulnerable to wind erosion, with low fertility and low water retention capacity. The last feature, when coupled with low and erratic rainfall, necessitates crop management practices to reduce the risk of crop failure.

Although active research has been conducted in all aspects of crop husbandry practices and soils, still more is needed to answer many questions on productivity, quality, and postharvest problems in the irrigated areas. In the rainfed areas of the sandy soils there is hardly any research conducted, especially on important crops like gum arabic, oil seeds, and millets where breeding for early-maturing, drought-resistant and high-yielding varieties is needed in addition to better cultural practices. Due to the complexity of problems, a team approach is more appropriate to consider important aspects such as the ecosystem and socio-economic considerations.

Livestock Problems

The livestock population (millions) in the 1977 census consisted of cattle (Zebu) 15.4, sheep (desert 80%, Nilotic 20%) 16.22, goats 11.3, camels, 2.34, donkeys 0.75, and horses 0.93.

Livestock production is far below its true potential. The reasons for this situation are that many problems exist and many constraints are present. The most important of these are summarized as follows:

1. High temperatures and seasonal rainfall variation have adverse effects on productivity. However, through time, the local breeds have adapted themselves to such conditions. For this very reason it is not advisable to introduce exotic breeds from the temperate zone.
2. Health problems: In this respect and in spite of the huge efforts to combat animal diseases, many still occur that cause great losses in livestock and poultry such as rinderpest, CBPP, trypanosomiasis, anthrax, foot-and-mouth disease, black quarter, rabies, tuberculosis, brucellosis, fowl cholera etc. The Sudan has recently joined JP 15 (international campaign) against rinderpest in the Eastern Africa zone and hopes to completely eradicate this disease in the near future.

   Trypanosomiasis is still playing havoc in the Sudan and many grazing areas are still out of bounds for livestock production because of the tsetse fly infestation. However, the Sudan has managed to reclaim some of these areas. But, and to the total disappointment of the livestock owners, soon after the reclamation team left the area, sedentary farmers moved to cultivate the land leaving the pastoralists once again deprived of good grazing land.
3. Feeding and watering problems: As a result of relatively better animal healthcare and more efficient disease-control, livestock mortality has declined, especially in calves thereby leading to a considerable increase in production. More feed and water are required to support the additional numbers. This can best be achieved through raising the carrying capacity of the available natural pastures by proper range management practices and the provision of water in grazing areas that have remained non-utilized due to lack of water.

Natural pastures need special consideration since they have been neglected so long. Many of their problems are that they are free range, poor in species composition, non-protected against hazards (bushfires are known to destroy annually more than 50% of the total grazing land) and because there is no control on natural pasture management, over grazing is a common feature.

Subsidized supplementary feeding using some local feed material such as cottonseed cake, wheat bran, groundnut cake, molasses etc. are being used at a limited level and only during the dry season. It is becoming more popular. With proper irrigation facilities, it would be highly advisable to introduce fodder crops into the rotations of present and future irrigation schemes.

Sudan cattle are basically beef types though there are two varieties with propensity for milk production. Therefore it is advisable to develop these animals for beef production by selection breeding only. As far as milk production is concerned, it should be confined to areas where green fodder is available throughout the year and where a high level of feeding and management can be maintained, i.e. irrigated schemes and rice farms. In this case it is permissible to use suitable exotic breeds of cattle for out-crossing with local cows provided the crossing is not allowed to exceed 50% in general, and 75% in only special circumstances.

Retarded livestock development in the Sudan is undoubtedly due to the serious lack of research inputs required to remove constraints on feeding and productivity.

Research priorities should be oriented to answer many crucial questions such as:

(1) The most appropriate animal species that does not impose any nutritional competition with human needs. Improve livestock by breeding, e.g. in dairy cattle by crossbreeding with exotic breeds, in beef cattle by selection and breeding, and in sheep by selection only among the local breeds.

(2) Attempt to establish suitable feeding standards that provide livestock with exact nutritional requirements. Feed resources such as crop residues should be better utilized.

(3) Appropriate feeding systems for beef and milk production. Increase the productivity of available forages through selection and agronomic practices. Forages are badly needed during the critical dry period (April-July) when livestock mortality is very high.

(4) Modern approaches for beef utilization of available feed resources.

(5) Intensification of disease control. Potent vaccines should be produced in quantity and quality especially for use against rinderpest, anthrax, CBPP, and rabies. The trypanosomiasis problem in the south and the liver fluke problem in the central area should be tackled.

(6) Improvement of range pasture by raising the carrying capacity of natural pasture and by providing water in grazing areas. Fire hazard control by wide fire lines.

(7) Proper marketing organization.

(8) The production of sufficient fodder in all irrigated schemes.

Forestry

The forestry resource decreases with the decrease in rainfall. Therefore arid and semi-arid areas, which are heavily populated, have scarce forestry resources. This implies the excessive demand for forestry products especially fuel, wood, and building poles. The savannah region where there is a reasonable forest cover suffers from severe felling for agricultural expansion in arable crops, especially mechanized crop production.

Agroforestry has a long tradition in the Sudan where crops are grown under *Acacia albida* or in rotation wth *Acacia senegal*. Where irrigation is feasible, trees are used as shelter belts against dust and wind, and for shade. Social forestry has started to become important with the increasing trend in urbanization.

The indigenous tree species are mostly slow growing and scattered. This has reduced the level of investment in the forestry sector. Moreover, the quality of timber is not suitable for the many types of use and the timber industry has developed only to a minor extent in local areas, e.g. railway sleeper production in the south. The major shortage in Sudan is for fuelwood.

Farming Systems Constraints

Traditional sector

The land tenure in the riverain areas is one of the main constraints where land fragmentation and scarcity have resulted in maintaining very small holdings implying a lot of scale diseconomies. Accessibility to capital, credit, marketing and storage facilities constitute other problems.

Modern sector

In government schemes where close supervision of production prevails, conflict of objectives exists between tenants and the scheme's management where crop preferences and accordingly resource use are different. This applies to livestock keeping where their integration, although preferred by tenants, is not officially recognized. There is an excessive use of chemicals in these schemes, which creates both ecological and economic burdens.

In mechanized rainfed areas, more profit-maximization objectives have resulted in negligence regarding recommended rotations leading to poor soils, low yields, and eventually soil mining.

In both sectors energy and transport are major constraints.

Socio-Economic Aspects

Studies dealing with socio-economic aspects are often neglected in planning and implementation of projects. They are only recognized in later stages. Even within applied research, the economic viability of recommended practices is not verified. This leads often to lack of acceptability of these recommendations. There is hardly any research done on the optimization of inputs, e.g. fertilizers, seeds, chemical pest control, and mechanization. This implies that chances for inefficient resource use exist. Moreover, research on marketing is rudimentary and needs to be supported and coupled with biological research. Sound planning taking biological, economic, and social aspects into consideration should constitute important research targets.

Extension services are very limited. The available extension staff works with meagre facilities that render their effectiveness questionable.

Current Research Priorities

All of the on-going agricultural research in the Sudan is applied research which, subject to the available human and material facilities, have been directed to solving most of the problems mentioned earlier.

Agricultural research is conducted mainly by four bodies, viz. the Ministry of Agriculture (Agricultural Research Corporation), the universities, the National Council for Research, and the Central Laboratory for Veterinary Vaccines and Toxicology. The Agricultural Research Corporation (ARC), being the oldest and with full-time attention for research, shoulders most of the agricultural research responsibilities.

The organizational set up of the ARC consists of a council (Management Board), which operates through two committees—one for administration and finance and a technical committee, which is responsible for the following:

1. Execute the policy of the council regarding the direction of research to serve agricultural development.
2. Coordinate and approve the research programs submitted by scientists.
3. Initiate and direct research necessary for agricultural and scientific development.
4. Determine cooperative programs and exchange information with local and international organizations.
5. Establish the policy for study courses, training, conferences, seminars etc.
6. Submit recommendations to the council for the establishment and designation of new stations, centres, or institutes.

The ARC has 17 research stations and centres scattered throughout the country, serving both irrigated and rainfed sectors. These stations are currently manned by 130 scientists with postgraduate qualifications, 139 assistant research scientists, 625 technicians, 4 000 skilled and unskilled labour, and a supporting staff of clerks and accountants of up to 400. The National Council of Research employs 7 Ph.D. graduates; there are also 7 Ph.D. graduates in the Central Vaccine and Veterinary Research Laboratory.

The ARC with its available staff and facilities has accomplished many achievements in a number of research fields in the various regions. These are briefly described through the scientific disciplines below:

Soil Science

Activities cover mainly soil chemistry, physics, formation, and microbiology. Research has concentrated on properties of Sudan soils, methods of analysis, fertility assessment, soluble salts, fertilization, water movement in soils, water requirements of the various crops, and biological nitrogen fixation.

Agronomy and Crop Physiology

Both irrigated and rain-grown crops are investigated with emphasis on husbandry practices, mainly time of planting, plant population, fertilization, water relations, harvest, mechanization and the inferaction and the interaction of the various physiological factors. It also emphasizes investigations on crop rotations, and factors governing fluctuation of yields of cotton. Cereals, oil crops, fibres, grain legumes, and forages are given priority.

Botany and Plant Pathology

Diseases caused by bacteria, fungi, viruses, and nematodes in both field and horticultural crops, and methods of control are studied. In addition, research in the various methods of weed control in important crops is actively pursued. Bacterial blight in cotton, cotton wilt, groundnut diseases, and diseases of horticultural crops are given high priority.

Entomology

The main interest is in the ecology and biology of important crop pests and their control in the various production schemes through agronomic, chemical, and sanitary measures. Chemicals for insect pest control in cotton are screened for effectiveness and recommendations are given on the method of application, rate, and number of sprays. Currently the use of integrated pest management is emphasized. Besides cotton, interest is directed towards wheat, sugar cane, grain legumes, and horticultural crops.

Breeding

This research is concerned generally with the selection, adaptation, and breeding of improved crop cultivars of the main crops such as cotton, sorghum, wheat, sesame, groundnut, grain legumes, sugar cane, and horticultural crops. The main emphasis is given to cotton breeding, leading to commercial varieties of long, medium, and short staple cottons, which are high yielding, good quality, and generally resistant to diseases and pests. In cotton breeding, studies related to fibre quality and lint stickiness are given due weight.

Horticulture

Horticulture is considered a relatively new research activity. Emphasis is given to trials on various vegetable and fruit crops for local consumption, export, and processing. Studies have included varietal introductions, agronomic practices, viz. time of planting, methods of planting, irrigation, fertilization, and harvest. Due consideration is given to quality of production and postharvest losses. Work is also initiated on medicinal and aromatic plants.

Statistics and Agricultural Economics

These activities are concerned primarily with advising and helping research scientists in adopting proper experimentation methods, designs, and statistical analysis. It also helps in the analysis of seasonal and long-term experiments. Currently, the discipline is being strengthened to cater for aspects related to production relations, cost of production, fluctuation trends of crop yields, and crop yield assessments, input-output analysis, and farm management.

Food Technology

The main research activities cover postharvest physiology, dehydration, cereal technology, canning, microbiology, chemistry, engineering, fats and oils, meat technology, marketing, and training and extension.

The technology of processing onions, tomatoes, potatoes, leafy vegetables and fruits such as bananas, mangoes, citrus, and dates is currently emphasized. Grain technology research with respect to quality and application of decorticated sorghums is actively pursued. Disciplines of chemistry, microbiology, engineering, economics and marketing support the whole spectrum of technologies adopted in canning, oils, milling, dehydration etc.

Forestry Research

Currently activities concentrate on silvicultural research in the various regions, forestry in the arid zone, wood technology, forest botany, gum arabic and shelter belts, land reclamation, and forest hydrology.

Fish Research

Emphasis is given to fish breeding and production in fresh water culture in rivers and ponds with respect to suitable types of fishes, feeding habits, method of catch, stock assessment etc. In addition work is in progress in oyster culture in the Red Sea with respect to their breeding, feeding, and protection.

Wildlife Research

It is concerned with collecting base-line data on wildlife populations, their habitats and the degree of use in wildlife-rich areas. Specific studies cover areas such as range evaluation, forage quality, intensity of use, trend of animal numbers distribution, migration patterns, feeding habits, breeding, and diseases.

Range and Pasture

Activities cover the ecology of natural pastures, pasture composition, conservation, and reseeding. Currently studies concentrate on varieties, agronomic practices and harvest of important irrigated forage crops.

Agricultural Research in Kenya

F.J. Wang'ati*

Agriculture dominates the national economy of Kenya. It accounts for about 35% of the GDP, supports over 80% of the country's population, and provides over 65% of Kenya's export income. Large and small-scale farming are practised with the latter being the more prevalent and engaged in growing food crops for subsistence with little surplus for the market.

Two-thirds of Kenya's land surface is arid or semi-arid. The rapid rate of population growth, the small proportion of high-potential land, uncertain weather conditions, and the absence of alternative sources of income outside agriculture are factors that continue to pose challenging problems to agricultural development. In order to have a substantial impact within the agricultural production sector, agricultural research has been accorded high priority. Research policies, programs, and projects have, therefore, been designed and effected to develop new technologies and improved farming systems relevant to both large scale and small-holder agriculture.

Organization of Research

Agricultural research in Kenya commenced in 1903 to serve the large-scale farming agriculture, then dominated by the foreign settler community. Wheat, tea, coffee, and pyrethrum were the dominant cash crops. By the mid-fifties, however, a plan to incorporate small-holder cash crop production was formulated following the recommendations of the Swynnerton Plan to intensify the development of African agriculture. Regional research stations were set up in addition to the existing commodity-oriented research stations already in existence. Basic and long term research were made the responsibility of the former East African Agriculture and Forestry Research Organization (EAAFRO) to serve the three East African Community States.

With the break-up of the East African Community, the EAAFRO facilities in Kenya reverted to the Kenya Government and are now the nucleus of the Kenya Agricultural Research Institute operating under the Ministry of Regional Development, Science, and Technology. However, scientific research under the Ministries of Agriculture and Livestock Development continues and efforts are in hand to delineate specific responsibilities between institutions in order to avoid overlap.

The National Council for Science and Technology, which was established in 1977, provides machinery for advising and coordinating all activities of scientific research, including technological development in the country.

Facilities for Agricultural Research in Kenya

Kenya has diverse ecological systems, which have necessitated the establishment of a large network of research stations and experimental sites throughout the country. There are 14 national research stations and 11 regional stations distributed to cover the foci of major crops, land use, or ecological conditions. While most of the national stations are well developed in terms of equipment and personnel, the regional stations have inadequate facilities to fulfil their responsibilities. In particular, the National Dryland Research Station in Katumani, which is charged with the responsibility of coordinating research for dryland agriculture covering two thirds of the land resource, requires substantial support in terms of facilities and qualified scientific staff.

Research Programs and Priorities

Land and Water Resources Research

The main objectives are to:

1. Develop and standardize procedures for

* Acting Deputy Secretary, National Council for Science and Technology, Nairobi, Kenya. (Compiled from inputs provided by Scientific Research Divisions of the Ministries of Agriculture and Livestock Development and the Kenya Agricultural Research Institute).

collecting data on climate, rainfall, soil types, vegetation, land relief, soil infiltration rates, and other soil and land characteristics.

2. Prepare maps and reports for land use planning.
3. Define problems of reclaiming potentially productive land through irrigation and drainage, and to advise on how best such land can be utilized for crop and animal production.
4. Conduct research into soil/plant/water relations and on the basis of the results to rationalize plant improvement and production programs under different moisture conditions.
5. Develop and advise on agricultural machinery, equipment, and tools with special emphasis on land tillage equipment for small scale farmers, both in the high and medium potential areas.
6. Conduct research into the chemistry of agriculturally important Kenyan soils to determine the soil carrying capacity for water and important elements, e.g. N, P, K, S, and some micronutrients, and the discrete chemical forms in which the important elements occur so that chemical changes that take place when fertilizers are applied can be understood.
7. Carry out research into methods of conserving and upgrading soil fertility.

Considerable activities have been carried out or are in progress to fulfill these objectives. The Kenya Soil Survey has conducted extensive surveys and land-use characterisation programs. A country-wide exploratory soil map is available and a number of semi-detailed and detailed surveys have been carried out, especially for areas earmarked for development projects. The agro-ecological classification maps already published are invaluable in designing research projects.

In the field of agricultural chemistry, the greatest challenge is that of maintenance of soil fertility, particularly in the medium and low potential areas where rainfall uncertainties make economic returns on fertilizer use risky for farmers. Inoculation of legume seed with rhizobia is being investigated as a means of enhancing nitrogen fixation.

Research in agricultural engineering emphasizes the development of appropriate tools and implements for minimizing energy requirements in tillage and other farming operations. A special need is the development of minimum tillage techniques for dryland farming and improvements in the management of irrigated soils where salinity and other forms of soil degradation are limiting productivity of irrigation schemes.

Crops Research

Although Kenya has made substantial achievements in breeding, agronomy, and protection of agricultural crops, the maintenance and increase of yields, remains one of the most important objectives of agricultural research, particularly in food crops. Major research needs for various important crops are as follows:-

Maize

It is the major staple food crop in terms of total area under cultivation and value. Maize research is aimed at providing high yielding varieties with resistance to major pests and diseases, as well as being adapted to the ecological zones of the country. Good results have been obtained for the high and medium potential areas; however, suitable varieties for the arid, semi-arid, and the coastal areas require further improvement.

Small Grains

There is a steady decrease in farm sizes in areas where small grains were once grown under an advanced large-scale farm technology. Inevitably, agricultural research will have to develop an appropriate technology for small-scale farmers intending to grow wheat, barley, oats, and triticale in the high-potential areas. Agronomic practices and appropriate technology is required for large-scale production of these crops under marginal conditions.

Sorghums and Millets

Adaptive agronomic research will be expanded to enable sorghums and millets to be grown under varying ecological conditions and farming systems. Special emphasis will be given to the development through breeding of early maturing sorghum and millet types with drought tolerance and high grain quality characteristics for both human and livestock consumption. Bird damage is a major problem in the production of these cereals.

Beans

Development and production of superior high-yielding food-bean types and other legumes is emphasized in order to alleviate the crucial protein gap created by the soaring prices of animal protein foods.

Upland Rice

The development of high-yielding rainfed rice cultivars is a relatively new activity. The objective is to supplement irrigated rice and thus reduce rice imports. Results from experimental plots in various ecological regions show that rainfed rice cultivars and their eventual cultivation is possible but much adaptive research is needed.

Cassava

Improvement of high-yielding disease-resistant cultivars of cassava suitable for varying ecological zones, especially in marginal areas will continue. Further work with cassava will include the establishment of seed multiplication centres for bulking disease-free material to ensure a permanent source of planting cuttings for farmers.

Vegetable Seed Production

Current experimental results show that a large variety of vegetable seeds can be produced locally. Development of local vegetable seeds will enable the country to save on foreign exchange and at the same time enable farmers to acquire seeds at fairly low cost.

The major focus for food crop research in future will therefore be on the development of varieties that produce reasonably well under low rainfall conditions, and increasing their tolerance to insect pests and diseases.

Livestock Production Research

1. Policy Objectives

The Ministry of Livestock Development policy paper of 1980 clearly states the broad outlines that will guide the various livestock sectors for improved output of livestock and livestock products. This policy paper is further reinforced by the Sessional Paper No. 4 of 1981 on National Food Policy, which together are considered to be part of the overall National Food Policy strategy in an integrated livestock and crop production system for the efficient utilization of land and human resources.

The main objective is to avoid shortfalls in livestock production that would be either expensive to satisfy from imports or else the welfare of the people would be seriously compromised. Due consideration was given to both producers and consumers, and to the national economy in the establishment of these objectives. Objectives specific to the primary livestock production sector are:

(1) Production of sufficient animal proteins to ensure adequate nutrition for the people of Kenya.

(2) Production of the necessary raw materials for agro-industries in Kenya.

(3) Intensification in use of high-potential land to ensure greater land and other resource productivity, and full development of the extensive rangelands, which account for 80% of Kenya's land area of 569 260 km^2m.

Although the Food Policy document largely dealt with the 'Food Crop Policy', it also called on the Ministry of Livestock Development to coordinate the implementation of a comprehensive and integrated national production research program. Priorities are required to be given to the identification of production constraints on both small and large farms and of strategies for their solution; an improvement in the genetic potential of beef and dairy animals; the increase in forage productivity in high and medium potential areas through breeding and agronomy; the development of forage crops produced on farms to replace purchased feeds; the integration of small stock (small ruminants) into farming systems in dryland areas to increase output and stabilize on-farm incomes; and the improvement of animal productivity per unit of land. In both these documents intensification of animal production is seen as the only basis for the expected increased output of milk, meat, and eggs from the livestock industry to satisfy the expanding Kenyan population.

2. Animal Resources

Kenya's human population of 15.3 million approximates about one animal unit and one bird per person per year in 1978 and a slightly lower ratio for the 1981 figures. However, figures on livestock population have been based on estimates, except in 1965 when a countrywide survey was done. The Kenya Rangeland Ecological Monitoring Unit (KREMU) has recently provided estimates in the range areas based on airphoto interpretation.

Lack of proper statistics has hampered meaningful planning of livestock projects in the country and the need for a national livestock census is already recognized. Table I indicates livestock and poultry populations as estimated by various means for 1978 and 1981. The table shows a decrease in cattle, sheep, goat and poultry, and an increase in pig, rabbit, camel and donkey numbers. However, wool sheep, dairy goats, and improved dairy cattle have increased between 1978 and 1981.

3. Land Resources

The current livestock production systems are largely dependent on natural grasslands (beef) and/or planted fodders in the intensive systems geared towards milk production on small-scale farms. The major part of these grasslands are found in the rangeland and cover about 80% of

Table 1. Livestock population in 1978 and 1981 (thousands).

Type	1978	1981
Cattle:		
Improved dairy cattle	1 127	1 466
Improved beef cattle	660	486
Indigenous Zebu	8 460	7 844
Total	10 247	9 796
Sheep:		
Wool sheep	500	629
Hair sheep	6 000	4 980
Total	6 500	5 609
Goats:		
Dairy goats	2	7
Meat goats	8 500	6,996
Total	8 502	7 003
Poultry:		
Indigenous	c 15 020	13 890
Imported hybrids	1 760	2 480
Total	16 780	16 370
Others:		
Pigs	70	74.0
Rabbits	34	69.5
Camels	607	638.0
Donkeys	137	264.0

the Kenyan land area. The distribution of the available grazing land and future projection is indicated in Table 2. Earlier studies have estimated that in 1975 there were about 50.4 million ha of land available for grazing. As a result of increasing demand for arable land and the extension of small irrigation schemes into the rangelands, it is estimated that about 1.6 million ha will be converted to crop farming thereby reducing the available grazing land to about 48.8 million ha. The land encroached by crops will be in areas that can hold a higher stocking rate and will result in a reduction of the grazing land as follows: ecological zone II (20%), III (33%), IV (4%). Though this reduced carrying capacity resulting from crop encroachment can be partially compensated for by zero grazing in zones II and III, the actual reduction in livestock production is likely to be very high (20%) instead of the 15% implied by the percent decrease in both land available and livestock units.

4. Human Resources

There are abundant human resources (15.3 million) that are increasing at about 3.4% per annum, with the nomadic pastoral communities comprising of 1.4 million, and increasing at 4.9% per annum. The greatest challenge to livestock producers is to increase production to meet the basic demand for proteins, meat, milk, eggs, and other livestock products for the increasing population.

5. Livestock and Poultry Production Systems for Milk, Meat, and Eggs

The major livestock production systems and practices found in small and large-scale farms is very much a function of the ecological and other socio-economic constraints. It is therefore convenient and perhaps realistic to relate the various livestock production systems to the ecological zones and the availability of feed resources at the farm level.

In ecological zones II and III, pasture and fodder production compete with food and cash crops for the available arable lands. In the large-scale farms in the high rainfall areas, pasture leys can be established and hay and silage produced because the scale of operation justifies the investment. The majority of small farms will largely depend on the use of productive fodder crops such as Napier grass as a source of feed under intensive and semi-intensive regimes.

Table 2. Available grazing land and its carrying capacity.

Zones		1975 Land (million ha)	1975 Livestock Units/ha	1990 Land (million ha)	1990 Livestock Units/ha
II	High Potential	2.0	3.8	1.6	3.0
III	Moderate Potential	4.0	4.0	3.0	3.0
IV	Low Potential	5.4	1.4	5.2	1.4
V	Fair Rangeland	26.0	2.2	26.0	2.2
VI	Poor Rangeland	13.0	0.4	13.0	0.4
Total		50.4	11.8	48.8	10.0

The success of any research programs and priority will depend on the extent the technological innovations developed are geared towards the amelioration of these constraints at the farm level.

6. Priorities in Dairy Research

The research strategy for increased milk and dairy products will focus on the following factors that affect the herds production:

(1) NUTRITION AND FEEDING

The nutrition of lactating animals must ensure that the metabolizable nutrients intake meets their requirements. Under-nutrition and malnutrition of dairy animals at the farm level result in reduced lactation yields, premature drying of cows, difficulty in getting the animal in calf, lowered dairy yields, and in extreme cases, loss of condition or death in the dry spells.

Recent studies by the Small Ruminant Collaborative Research Support Program (SR-CRSP) and the Dairy Beef Project suggest a 'net' energy deficiency in small-holder farming systems as a consequence of the inadequate quantity of dry matter intake and its quality. Research efforts will aim at increasing productivity of the available forages through selection and agronomic techniques, their strategic use, as well as conservation and processing to improve the efficiency of utilization. In cases where the costs allow supplementation, this should be encouraged.

(2) CALF REARING AND MANAGEMENT

High mortality rates of dairy calves within the first year of life results in a loss of about 30% of the annual crop. This loss must be curbed to ensure sufficient numbers for herd replacements, greater selection for future milkers, and potential contribution to the beef herds as steers etc.

Factors responsible for the heavy loss should be curbed, researched, and limited to acceptable levels of about 5%. Other diseases should be curbed to enhance faster growth rates and hence a longer productive life.

(3) BREEDING GENOTYPES

Research efforts in identifying suitable breeds or genotypes for increased milk output per animal through artificial insemination and/or crossbreeding programs should result in on-farm benefits and incomes. The increased milk production is to be realized through higher output per animal as land ratios decrease. Possibilities for selecting animals with low nutrient intake and higher conversion efficiency and use of superior foster mother dams in the process of embryo transfer techniques should be explored.

(4) FEED RESOURCES CONSERVATION

There is need to develop appropriate technology for conservation of forages for feeding during the dry season on the small-scale farm and the efficient use of on-farm by-products and the processing needed for increased digestibility and intake.

(5) ANIMAL HEALTH

Animal health research will continue to ensure that both the major epidemic diseases as well as production diseases are kept under control. Currently, the importance of 'production' diseases and conditions in milk production notably, helminthiasis, sub-fertility and infertility, mastitis, feet-rot problems, scouring etc. should receive greater emphasis than hitherto if the major killer diseases are brought under control.

(6) DAIRY RANCHING

The inevitable shift of the milk zone to the semi-arid zones necessitates the use of adapted breeds and technology in these areas where the research need will have to be redefined to satisfy the seasonality of production.

7. Priorities in Beef Research

Meat, milk, eggs, and other animal products constitute an important source of protein in people's diet. The greater percentage of red meat in Kenya is derived from cattle, sheep, and goats, which together account for over 90%. Other sources include poultry, pigs, camels, rabbits and to a minor extent wild game. Cattle alone contributes to over 70% of the red meat produced and hence the emphasis on cattle improvement programs in the past. The small stock, despite the potential and often critical role they play in the economy of the semi-arid and arid environments where their efficiency of utilization of the feed resources is higher than cattle, have not received adequate research.

(1) There is great need to develop the appropriate research technology for the different producer groups based on the importance of the various livestock production systems. Whereas 50% of the cattle, 70% of sheep and goats and about 100% of camel are found in the rangelands under traditional livestock management systems,

the research needs of goats and camels in terms of improved genotypes, nutritional requirements, and management have received little attention in the past. Furthermore, serious gaps in information exist regarding the meat production potential of the various indigenous and improved breeds of cattle, sheep, goats, poultry, and camels in the semi-arid and arid environments under improved management systems.

The different levels of management and feeding requirements for livestock classes will need to be more clearly defined. Research priority and emphasis will be given to the selection of better breeds of sheep and goats for meat and milk, and to a lesser extent, to the development of our local birds for meat and egg production. The research effort should take due consideration of the pastoralist's main dietary need i.e. milk, where applicable.

(2) The provision of research technologies for suitable fodder crops and pasture species for the high rainfall zones should result in increased beef from the dairy herd in the small-scale and large mixed-farming zones. The role and place of unconventional crops such as cassava and sorghum as constituent livestock feeds for fattening enterprises such as feedlots, will receive greater emphasis. Other agro-based industry feeds will also be incorporated, e.g. molasses and bagasse in western Kenya and cashew nut waste at the Coast.

(3) In the high rainfall small-scale zones, research needs will intensify animal production through the identification of zero-grazing and semi-zero grazing systems and the use of crop by-products.

(4) Improved grazing management systems incorporating traditional pastoral livestock components will be generated to increase the current productivity of the herds and carrying capacities of the rangeland areas. Collaborative efforts through the range research utilization programs at Kiboko and the Integrated Program for Arid Lands (IPAL) should be intensified to cover wider pastoral target groups within the rangelands.

(5) The improvement of natural grasslands through inclusion of appropriate legumes, fodder trees, and shrubs and sound management in the wet season to afford feed on a year-long calendar basis should result in benefits to the pastoralists. The improved quantity and quality, besides meeting the protein and vitamin requirements of the breeding animals, will also contribute towards increased meat and milk production.

8. Research Approach

Past research technologies have received much criticism as they have not only taken a long time to yield results, but more often they have been inappropriate to the requirement of the target farmer/pastoral group.

The research approach to be adopted will therefore use the farming systems approach in which the researchable problems will be identified through pre-extension trials in collaboration with the target groups. The farming systems approach pre-supposes a multidisciplinary team that diagnoses the disciplinary production constraints at the farm land and attempts to integrate them on a whole-farm basis within the socio-economic environment of the farmer/pastoralist.

This approach not only enhances a faster adoption rate of new research technology but also leads to the realization of relevant on-farm research. The farming systems approach will be increasingly encouraged in future as a basis for problem identification and solution. A special area of interest in farming systems research is nutrition, especially the improvement of pastures and the utilization of farm by-products.

Forestry Research

1. Overview

It is recognized in the current Fourth Five Year Development Plan for Kenya that trees and forests contribute to the provision of the basic needs of the people in a variety of ways. Forests and trees provide all the national wood demand as poles for construction and for fuel; in the form of lumber for construction, joinery, carpentry and carving etc.; plywood; fibreboard; and pulp and paper for a population that is growing both in size, affluence, and sophistication.

The rural population (about 13.4 m Kenyans) rely totally on forests for their needs in the form of fuelwood, buildings, fencing, agricultural tools, and to a large extent for medicine. There is considerable potential for developing forest products, such as tannin; edible fruits and seeds; forage, browse and fodder for animals; gums, resins, and oils for industrial development. Flowers of several species of forest trees such as acacias and eucalypts provide browse for the honey bee, and therefore constitute a source of honey and beeswax.

Forests and trees also play an important environmental role in conserving soil and protecting water catchments. A major objective of forest development is to promote the establishment and maintenance of vegetative cover on both public and private land.

The long cycle that characterizes tree crops necessitates the need for silvicultural techniques that are compatible with natural environmental requirements. A national forestry policy encompassing an integrated approach to forestry development has still to be evolved, but such a policy should be underpinned by a comprehensive forestry research program for developing new and appropriate skills, practices, concepts and products required for the management of forests in both designated and private forest holdings. Unlike agriculture, forestry research has not received much attention in the past and relatively modest resources have been expended in this area of need.

There is therefore an urgent need to strengthen and expand forestry research in order to meet important development and environmental objectives. The most desirable approach for strengthening forestry research in Kenya is the establishment of a strong Forestry Research Department within the Kenya Agricultural Research Institute (KARI). The nucleus for such a Department exists at Muguga but this needs considerable improvement in terms of research personnel and facilities.

2. Forestry Research Objectives

The long term objectives of Forestry Research are broadly defined as follows:

(1) To provide technical advice for intensification of afforestation programs in the highlands so as to satisfy the demand for Kenya's forest products on local and foreign markets.

(2) To initiate research programs for the development and improvement of indigenous commercial hardwoods.

(3) To develop new and to improve existing afforestation techniques using local and exotic tree species in the arid and semi-arid regions of Kenya.

(4) To intensify research in support of afforestation programs in the coastal region.

(5) To breed improved forest trees for the improvement of wood quality and site adaptation.

(6) To collect and conserve forest tree germplasm.

(7) To protect forest plantations against diseases, pests, fire, and other hazards, e.g. atmospheric pollution.

(8) To examine prospects for integrating forestry and agricultural systems (agroforestry) in suitable areas, with a view to maximizing total land use.

(9) To study the nutrient cycling of forest soils under different and continuous cropping systems.

(10) To improve timber technology through research and to ensure the best use of the country's timber resources and other forest products and to promote efficient development in the Kenyan timber industry.

(11) To initiate and develop studies on the economics of forest establishment techniques, harvesting, and production and marketing strategies for all forest products, particularly in areas still dominated by foreign (imported) products and goods.

(12) To encourage an orderly development of community forestry (private and co-operative) and to assist in creating conditions in which produce from private forests could be marketed for best return.

3. Research Programs

In order to fulfil the stated objectives, the research programs have been arranged in the following six major disciplines:-

(1) Forest Environment and Silviculture

Species Trials: Recent experience with pests and diseases have shown that the period of trouble-free production of the exotic species is drawing to an end. The industrial plantation program must therefore be based on a wide range of tree species to forestall a possible catastrophe. Quite recently leading plantation species such as *Cupressus macrocarpa*, and *Pinus radiata* had to be dropped on account of diseases. Threats of pests or diseases can originate locally or from a foreign source.

Establishment Methods: Although the Taungya (shamba) system has been used in establishing forest plantations for many years, the practice depended intimately upon the ready availability of cheap labour. With the phasing out of resident labour, and the generation of keen cultivators, the demand for plots for cultivation has fallen below the planting program. An alternative to the shamba system must be developed to save the situation.

WATERSHED MANAGEMENT: Environment and amenity forestry-concern has been registered from all corners of the republic regarding the rapid state of siltation of our dams and the loss of valuable top soil. This program will investigate ways and means of minimizing losses from soils compacted by grazing, soil under different vegetation cover, management of catchment forests, and development of tree species for planting along river banks to effect better stabilization of soils in order to reduce siltation and improvement of river bank protection.

EFFECTS OF POLLUTION BY EFFLUENCE FROM FOREST INDUSTRIES:

FOREST GENETICS AND TREE IMPROVEMENT: This program includes selection and breeding for tree improvement in form, volume yield, and fibre quality for saw log, peeler log and for pulp and paper; and resistance to pests and diseases.

SOIL SCIENCE: This program will investigate chemical factors affecting tree seedlings development in the nursery; soil nutrient budget in different site classes; fertilization and soil moisture regimes in different soils and their influence on tree growth; nutrient cycling with rotations; and site classifications.

FOREST ECOLOGY: Forest managers have realized the important role of indigenous forests and have consequently placed these forests on a sustained yield management program. Studies are therefore needed on forest regeneration, including the ecology of the commercial species. It is also important to understand the role of the noncommercial species in the forest succession in the entire ecosystem. The existing experiments aim at developing suitable methods of managing our natural forests without changing the character and diversity of the forest. The current research program needs strengthening in studies on mycorrhizal effects.

REFORESTATION RESEARCH ON ARID AND SEMI-ARID AREAS (ASAL): A species trial program and studies on establishment techniques have been initiated in the semi-arid areas at Hola and Ramogi. A few species have shown promising results. With the shift of emphasis into the ASAL, a comprehensive program on various methods of establishment and nursery techniques is planned for seven stations including the proposed stations at Hola, Isiolo, Kibwezi, Marigat, Marsabit, Ramogi, and Turkana.

It is estimated that 80% of forest management involves protection from damage by insect pests, man, animals, fire, and fungal and virus diseases. In the absence of effective control, only 20% or less of our plantations would grow to maturity.

Indirect losses include the volume foregone by not planting large volume yielders, such as *Cupressus macrocarpa, Pinus radiata, Eucalyptus globulus* and *E. maidenii* etc. because of threats from pests and diseases.

(2) FOREST ENTOMOLOGY AND ZOOLOGY

Kenya forests have been threatened by a wide range of pests including *Oemida gahani*, lepidoptera defoliators of pines, and pine woolly aphid (*Pineus pini*). A systematic program will therefore be maintained in forest entomology to ensure effective protection of our forests. The program will include (a) studies on the population dynamics and occurrence of epidemiology of sap sucking and defoliating insects affecting industrial plantation species, (b) studies on timber entomology including treatment of timber for resistance, (c) investigations on nursery pests, (d) studies on biological and chemical control of pernicious pests, and (e) investigations on damage by rodents and game to plantation species, and their control.

(3) FOREST FIRE RESEARCH

Kenya has a history of forest fires, which occur in cycles according to irregular drought years. During drought years forest areas otherwise considered to be safe from fire because of high rainfall and moist conditions, become dry and inflammable. Research is necessary to enable forest management to maintain effective preventive measures and to be better prepared to handle forest fires that have been regularly destroying vast forest areas estimated at millions of shillings. The urgency for initiating this program is even more pressing with the shift to the marginal areas. Studies in this program include compilation of fire weather data in representative forests, interpretation of meteorological data and forecasting the fire hazard by forest types and divisions, fire damage studies, and fire prevention practices for different industrial plantation species and indigenous forests.

(4) FOREST PATHOLOGY

Experience with forest diseases in Kenyan forestry has greatly influenced our management practices. Among these, the decision to drop *Cupressus macrocarpa* because of a canker, and *Pinus radiata* because of *Dothistroma* blight greatly shocked foresters at the time. Pathological problems affect many tree species throughout their development. The current research program therefore needs strengthening in the areas of fungal, bacterial and virus diseases, affecting tree foliage and stem; wood decay; and nursery diseases.

(5) FOREST MENSURATION AND ECONOMICS

Today the silviculture section manages a large number of experiments touching on forest mensuration. Some of their experiments have been turned to the forestry inventory section, which has made rather restricted use of the experimental data. These experiments and new ones that must be initiated should be handled by officers with competent training in forest mensuration.

The work should be supported by forest economists. The research program would include:

a. Studies of forest biomass and dendrology of plantations and natural forest stands——their structures, regeneration, and growth increments to enable guidance to management on harvesting practices that would ensure a sustained yield of desirable tree species.
b. Growth and volume yield tables for all plantation species.
c. Growth models for trees and stand simulation for a better understanding of the growing conditions and management alternatives.
d. Economics of silvicultural operations including thinning schedules, pruning intensities, spacings, rotation and value increments *vis-a-vis* royalties.
e. Economics of other forestry operations including establishment, tending and protection.
f. Feasibility of marketing minor products and identification of market outlets.
g. Economics of sawmill operations throughout the country, to identify ways of improving the industry.

4. Forest Products Research

Forest products research serves wood-based industries and consumers, especially by providing marketing information on timber properties and qualities against an array of end uses, e.g. plywood, pulp and paper, particle and fibreboard, saw log, joinery, construction and energy etc. For many years, Kenya has relied heavily on outside help in this field, but there is no substitute for self reliance in a fast-developing field where each country has its own priorities and needs. There is therefore a need to gradually develop wood products research to cover the following areas:

(1) Wood Engineering Research: It will include studies on mechanical properties of Kenyan grown wood, structural utilization, time and moisture effects.

(2) Wood Chemistry and Processing: Wood extractives will be researched with emphasis on recovery of raw materials for industrial manufacture including drugs, developments in pulp and paper manufacture, the use of adhesives, and protection of wood in storage, performance of wood in fire and the use of fire retardants, the use of products in painting and other coatings.

(3) Wood Anatomy: Anatomical studies will be conducted to provide information on wood formation and wood changes in the life of the tree and characteristics of different kinds of wood *vis-a-vis* desirable wood qualities for different end uses. Bark properties and utilization will also be studied.

(4) Wood Technology: Properties and utilization of Kenyan wood; characteristics and properties of Kenya timber for the entire spectrum of commercial and industrial use will be evaluated.

5. Special Program for Arid and Semi-Arid Lands (ASAL)

The current development plan has given emphasis to the development of the arid and semi-arid areas. ASAL areas occur in Kenya's 27 districts, and support 20% of the human population, 50% of the entire livestock population, and virtually all parks and game population. Forestry developments were first introduced to ASALs of Machakos, Nyanza, and Kitui districts in the early 50s during the African Land Development (ALDEV) program in county council land parcels. Many districts including Tana River, Turkana received attention for the first time during the 70s with the establishment of the Rural Afforestation program.

Although forestry constitutes the core for ASALs development strategy, forestry has not been established as a development activity in these areas. The relatively poor performance of forestry in these difficult areas lies primarily in the previous development plans. It is now clear that tree planting in these areas will only be possible if solutions to a number of basic limiting factors can be obtained.

Undoubtedly the over-riding constraints are limited and erratic rainfall, pedologic conditions including soil compaction, salinity and soil infertility. Strong dry winds and drifting sand are also important bottlenecks to reforestation. Other constraints are scarce and inappropriate technology, inadequate forestry infrastructure, and unsettled conditions of land ownership, with attendant competing alternative land-use systems that are heavily slanted to the traditional pastoral economy.

A clear understanding of how these constraints can be manipulated to develop appropriate technological packages for tree cultivation in these areas would be realized only through a program of systematic research. It is therefore proposed that a central section be established at the National Forestry Research Station at Muguga to plan, coordinate and implement dry land afforestation research in the whole country. Regional stations should be established to tackle local and regional problems, as follows:

(1) Isiolo Forest Research Station

This station will look after the Isiolo District, the lower parts of Meru boardering Kitui, and the arid areas of Embu districts, around Kianiro Hill. The soils in most of these areas are sandy, compacted, low in organic matter, and saline in certain areas. The research program will investigate nursery techniques, establishment methods, preparation of planting sites, and tending practices.

Special elimination trials will be carried out at each specific site condition. The study is designed to produce easy and cheap techniques that can be applied to plantations and community woodlots by the people themselves.

(2) Marigat Forest Research Station

This station is strategically placed to serve Kabarnet, Maralal, and Rumuruti areas, which are unique areas in many ways; methodologies developed elsewhere would not be replicated widely.

(3) Marsabit Forest Research Station

There is no material forest development in the North Eastern Province today. Marsabit forest forms an enclave but one facing considerable pressure from the local people for various forest products including wood. Forest research is geared to conduct dry land afforestation research in Mt. Kulal, Huri Hills, Marsabit, and Garissa. Most of these areas are ecologically fragile and today remain extremely threatened by total destruction as a result of man and animals.

(4) Lodwar Forest Research Station

The Government has just signed an agreement with NORAD, that will realize funding of an integrated development program for the Turkana district. Forestry research development forms a major component of this project. This station will support this development project in addition to covering the areas east of Lake Turkana. Most of the district is arid to semi-arid. The meagre vegetation in the riverine forests, dry river beds and in the upland forests in Loima and Karasuk Hills are greatly endangered as a result of uncontrolled harvesting without any replanting.

(5) Kibwezi Forest Research Station

Though originally established to support the Machakos Integrated Development Project, this station should be strengthened with desirable competence to conduct reforestation research within and outside Machakos district in Kitui, Kajiado, and the surrounding Taita Hills and Voi area.

(6) Ramogi Forest Research Station

Situated on the northern shores of Lake Victoria, in Siaya district, Ramogi represents a difficult marginal site, lying on a hill with massive rock outcrops, scanty soils overlying a murram pan and marginal (bimodal) rainfall. Similar sites occur in Funyala of Busia district, and the Homa Mountains of South Nyanza.

(7) TANA RIVER RESEARCH STATION

Situated at Hola, the Tana River station covers reforestation research in the dry sandy plains, dry seasonal river beds and irrigated plantations for the Bura irrigation schemes at Hola and Bura. Most of the district receives low rainfall, i.e. 500 mm which is erratic; there is high evapotranspiration. The vegetation is extremely sparse, and many sites are devegetated, eroded and endangered. The program for Hola extends to the black cotton soil areas in Witu forests to the east.

Agricultural Research Scientists in Kenya

Information on the total number of graduates and the number of degree levels is given in Table 3.

Conclusions

An attempt has been made in this paper to describe constraints in various aspects of agriculture in Kenya that are amenable to research, the strategy adopted to deal with these constraints and the existing research institutions. Experience has shown, however, that in agricultural research sudden breakthroughs are rare and an increase in agricultural production usually consists of small gains made from time to time as a result of sustained research efforts over a long period. This is certainly the situation in Kenya.

The development of agricultural research since independence has been rapid but not rapid enough to cope with the problems of food production in the next decade. The principal limiting factor is the number of qualified and experienced research staff in both scientific and technical cadres. The Kenyan agricultural research system has, however, attracted a large number of university graduates who need training and on-the-job guidance in order for them to make a contribution. It is therefore expected that research projects supported by donor agencies should have a strong manpower development component and should be designed to last for periods longer than the usual 3-5 years, if they are to make a lasting impact.

The highest priority is now placed on the overall development of arid and semi-arid areas, the most vital aspect of this development being in agriculture. Crop research is reasonably well developed and the shift in emphasis to dryland agriculture will involve mainly institutional building and direction of research effort.

The situation is, however, different in the vital fields of animal production and agroforestry where the shortage of scientfic manpower is acute. The problem of the development of dry areas is a common one throughout the Eastern Africa Region and it is hoped tha ACIAR will make available to the Region on a sustained basis, Australian expertise in this research activity.

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Table 3. Formal qualification levels of agricultural research scientists in Kenya compared with other LDCs, 1978-1982.

	Year	Nationality	Total	B.Sc.	M.Sc.	Ph.D.	(M.Sc. + Ph.D)%	Number of LDC Countries where (M.Sc. + Ph.D)% Greater
Kenya (inc. IARCs[a] + univ)	1978	Kenyans & Foreigners	529	173 (32.7)	193 (36.5)	163 (30.8)	67.3	1/30
Kenya (exc. IARCs + univ)	1978	Kenyans & Foreigners	334	144 (43.1)	144 (43.1)	46 (13.8)	56.9	4/30
Kenya (exc. IARCs + univ)	1978	Kenyans	244	127 (52.0)	102 (41.8)	15 (6.1)	47.9	7/30
Kenya (Wang'ati estimate)	1979-1980	Kenyans & Foreigners	304	165[b](54.2)	88 (28.9)	51 (16.7)	45.6	7/30
Kenya (ISNAR/NCST estimate)	1982	Kenyans	566[c]	284 (50.1)	242[d](42.7)	15[d](2.6)	45.3	7/30

Notes:

a. IARCs = international agricultural research centers. The International Laboratory for Research in Animal Diseases (ILRAD) and the International Center of Insect Physiology and Ecology (ICIPE) have their headquarters in Nairobi. Figures in parentheses are percentages.

b. Reads '107' in the text but summary B.Sc. totals by research sector yields 165.

c. These figures include the 100+ graduates recruited in 1981 and also agricultural research scientists in training at local and overseas institutions. Qualifications obtained by 42 scientists could not be ascertained so qualifications are expressed as percentages of 525 − 42 = 486.

d. Scientists currently undertaking M.Sc. and Ph.D. courses are also included in these totals.

Source:

1978 Data: B.M. Jamieson, Resource Allocation to Agricultural Research in Kenya from 1963 to 1978, (Ph.D. thesis, Toronto University, 1981).

1979 to 1980: F.J. Wang'ati, 'Allocation of Resources to Agricultural Research: An Inventory of the Current Situation in Kenya,' (mimeo, NCST, 1981).

Agricultural Research in Tanzania

J.R.N. Kasembe, A.M. Macha, and A.N. Mphuru*

Agriculture is central to the economy of Tanzania and will continue to be so for the foreseeable future. More than 85% of the population is directly or indirectly engaged in agricultural activities, while about 50% of the GDP and more than 75% of the foreign exchange earnings accrue from the agricultural sector.

In broad terms, the agricultural policy in Tanzania directs the development of an integrated agricultural sector, using methods of scientific husbandry and technology appropriate to the respective crops, natural resources, livestock and size of operation. The location of agricultural, forestry and livestock research stations is shown in Fig. 1.

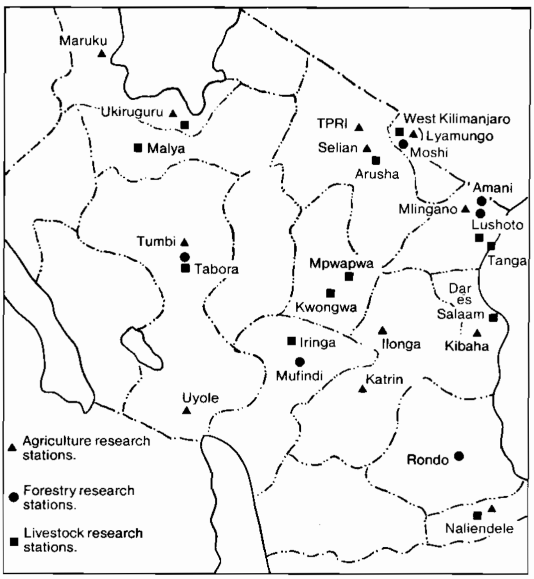

Figure 1. Location of agricultural, forestry, and livestock research stations in Tanzania.

* Director General, Tanzania Agricultural Research Organisation; Director General, Tanzania Livestock Research Organisation; and Head, Division of Agriculture, Faculty of Agriculture, Forestry and Veterinary Science, University of Dar es Salaam, Tanzania, respectively.

Tanzania is a large country with an estimated area of 884 000 km^2. The altitude varies from sea level to the summit of Mt. Kilimanjaro at over 5 700 m. The country can be broadly divided into the coastal plains, the semi-tropical belt, and the temperate belt. Water is the most vital factor in Tanzanian farming. The greater part of the country has an average rainfall of 750-850 mm. Rainfall patterns show great variation from year to year and this creates uncertainty, particularly in the semi-arid areas.

Soils, Crop Management and Farming Systems

Organization of Crops Research

To obtain sustained agricultural production a well-structured and functional agricultural research system is necessary. Overall research in crops is the responsibility of the Tanzania Agricultural Research Organisation (TARO) that was established in 1980 to provide for a systematic approach to the planning, co-ordination, direction and conduct of the national research program.

The main functions of TARO are to:

1. Control and manage affairs of the institutes and research centres as shown in the organizational chart (Fig. 2).
2. Initiate, organize, conduct and establish priorities to promote the carrying out of basic and applied interdisciplinary research into all aspects of crops, soils and farming systems.
3. Monitor and co-ordinate basic and applied agricultural research.
4. Establish a system of documentation and dissemination of research findings.
5. Provide advisory, consultancy, and other services on matters affecting crop research.
6. Promote and provide facilities for training personnel involved in agricultural research.

The role of food crops, e.g. maize, sorghum, rice, millets, cassava, sweet potatoes, and leg-

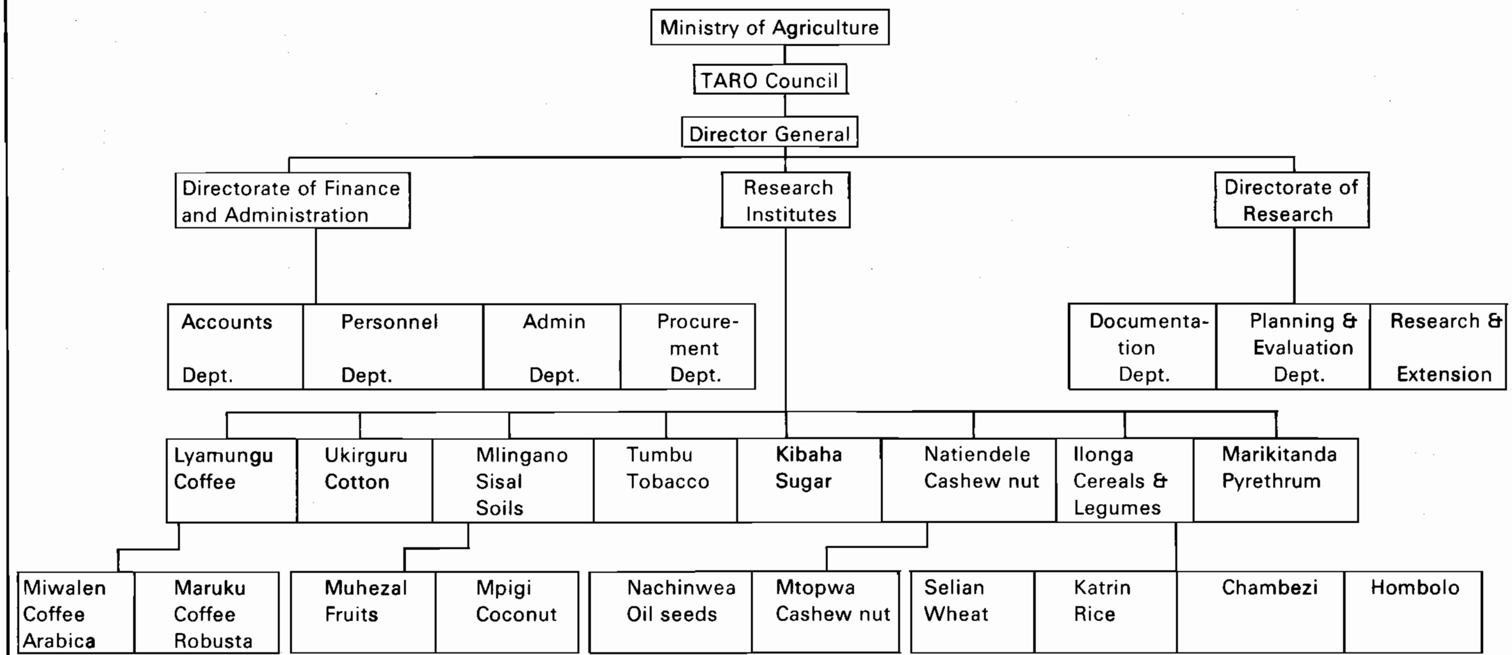

Figure 2. Organizational chart of TARO.

umes; and coffee, cotton, sisal, tobacco, tea, and cloves in the cash economy of this country cannot be over-emphasized. In order to increase the productivity of these crops per unit area and per unit time, it is imperative that continued efforts in research be made and the results of research be conveyed to farmers for implementation.

Agriculture in Tanzania consists of two production sub-sections, i.e. subsistence peasant farming, and the commercial export-oriented plantation sector. The majority of the population depends to a large extent on the subsistence sector, the principal feature of which is its great diversity between ecological zones, farming systems and management practices.

Tanzanian soils show a wide range in fertility from the rich volcanic ashes around Mt. Kilimanjaro to the relatively poor granite sands of the west associated with miombo woodlands. Only 6 million ha are under cultivation out of 39 million ha. Much of the country is marginal and consists of tsetse fly infested woodlands. Despite the existence of a large area of suitable land for agriculture, the goal of self-sufficiency in food has not yet been achieved.

Basic to the attainment of agricultural development is increased productivity in terms of both farm yield and the optimum utilization of available resources.

A primary consideration is the promotion and support of research, which is relevant to the needs of the country. In order to appreciate the priority needs in agriculture, a clear understanding of agricultural practices and farming methods is essential.

Existing Farming Systems in Tanzania

Due to environmental conditions, agricultural production varies widely from place to place and over periods of time. Variation is a result of the process of adapting cropping patterns and farm practices to the conditions of each location and the aim of the farmers, resulting in more or less distinct types of farm organizations and systems.

Attempts have already been made to classify generally the farming systems in Tanzania (Conyers 1971, Moris 1980). According to Moris (1980), eight broad agricultural zones can be identified, each of which contains several constituent farming systems. These broad zones are shown in Table 1.

Conyers (1970) on the basis of homogenous agricultural practices, divided the districts into areas known as agricultural zones. Those zones, which are similar to each other in different districts, have been combined into zonal subgroups. All zonal subgroups with similar agricultural patterns have been grouped into zonal groups.

According to this system, Tanzania can be divided into 16 zonal groups, which can further be subdivided into 46 zonal subgroups. These zonal subgroups consist of about 230 agricultural zones. Each agricultural zone may contain several constituent farming systems.

A farming system may be defined as a specific agricultural enterprise satisfying well defined objectives and involving various kinds of plants and operations, with which they are managed in a given environmental setting. The traditional Tanzanian farming systems can be divided into three groups:

1. Shifting Cultivation System

Shifting cultivation is confined almost to annual crops such as maize, sorghum, millets, and sweet potatoes. Rotations vary from a cycle of 40 years to 3 years. This system, which is confined to very few areas in Dodoma, Singida, and the Arusha region, is dying out.

2. Semi-permanent Cultivation System

This farming system is more common in the semi-arid areas of Tanzania, and about 6 million people are known to practise it. The system is common in Kilombero Valley where cotton, rice, and millets predominate. Here, most farmers are forced to move into other areas because of flooding.

The system is also common in Sukumaland where cotton, maize, sorghum, and sweet potatoes are grown in the fertile soils while the hardpan soils serve principally for grazing.

3. Permanent Cultivation System

It is common in all areas where annual crops are grown, especially on the high altitude areas such as parts of Mt. Kilimanjaro, Southern Highlands and West Lake, where coffee and bananas are the principal crops.

Within these cultural systems, there are farm-

Table 1. The major agricultural zones and the farming systems of Tanzania.

Zone		Constituent systems	Type areas
Coastal	1.	Fishing	Pangani, Pemba
	2.	Perennial crops	Zanzibar, Kibaha
	3.	Estate agriculture	Korogwe
Piedmont	4.	Coastal hills	Mandera, Kichi Hills
	5.	Southern plateau	Rondo, Newala
	6.	East-central	Turiani, Kisaki
	7.	Northern	Kisangiro, Gonja
Miombo	8.	Wet miombo	East Handeni
	9.	Dry miombo	Tumbi, Nachingwea
Steppe	10.	Pastoral areas	Kiteto
	11.	Ranching areas	Kongwa
	12.	Bush collecting	Yaida
	13.	Arable dry farming	Bariadi, Lolkisale
Plateau	14.	Dry plateau	Singida, Kondoa
	15.	Intermediate plateau	Ismani, Karatu
Montane	16.	Annual crop montane	Nguru, Luguru
	17.	Perennial crop montane	Marangu, Rungwe
	18.	Estate agriculture	Usambara
	19.	High altitude	Kitulo, Kainam
Lake	20.	Fishing	Kigoma, Itungi
	21.	Plateau	Bukoba
	22.	Highland	Gombe
	23.	Piedmont	Rukwa
Riverine	24.	Floodplain	Rufiji, Kilombero
	25.	Irrigated	Mbarali, Ifakara

Source: Moris (1980)

ing methods that are adapted to the system of culture and local conditions. The most common methods include sole cropping, mixed cropping; minimum tillage, full tillage; relay cropping and intercropping.

Major Constraints of Research

Manpower Resources

During the period 1930-60 research efforts were centred mainly on export commodity crops such as coffee, cotton, and sisal. In the late sixties, the Government decided to pay more attention to food crops in order to achieve self-sufficiency in food production. To achieve this, two additional research stations were established, i.e. Uyole and Kilombero Agricultural and Research Training Institute (KATRIN). However, there was not enough corresponding increase in manpower resources required to handle the additional workload.

The existing manpower is still far short of the national demand and this situation is likely to persist for several years. In order to improve the situation there is need to boost the training program, especially at the postgraduate level.

Lack of Physical Facilities

This constraint includes facilities such as vehicles for conducting operations outside the institutions, staff housing, laboratory equipment, libraries and farm machinery.

Lack of Co-ordinated Research Effort

From past experience it is becoming increasingly apparent that a team approach to problem identification and solving in agricultural research pays higher dividends than when such problems are tackled by individual scientists in isolation. The recent achievements of CIMMYT and IRRI in the production of high-yielding varieties of wheat and rice respectively, provide ample evidence to the notion of team approach.

In developing countries such as Tanzania where a strategy for agricultural research planning is seriously lacking and manpower is a scarce resource, there is a greater need for a co-ordinated effort. A research project drawn up by a team of scientists from various disciplines is likely to have the goals more clearly specified, the resource base better analyzed, the problems identified with greater accuracy and the order of priority more meaningful. A team approach will also help to eliminate duplication of projects.

Lack of Clearly Defined Goals

Success in research depends to a large extent on having sound and well prepared projects. The component of projects must be precisely defined as to character, location and time. Both the resources required in the form of finance, materials and manpower, and the generated benefits such as increased production must be estimated in advance. There must be a rational balance between our ambitious intention and what is practical.

Finally, an expanded research program on food should be viewed in a 20-year time-frame because problems such as low soil fertility or breeding in annual crops cannot be resolved through a series of short term, and ad hoc research projects.

Lack of Properly Trained Extension Staff

Research will not bear fruit until it reaches the farmer. This cannot be accomplished without proper and adequate extension services. Apart from the Ministry of Agriculture, the various research institutes throughout the country have a vital role to play in this respect.

Research Priorities for Agriculture

Introduction

Methodologies for determining research priorities that will cater for large- and small-scale farmer requirements and short- and long-term requirements are difficult. Because of this, most research has been haphazard.

Idachaba (1981) has reviewed in detail the criteria to follow in determining research priorities. These include the foreign exchange contribution of the agricultural commodity, fiscal role of the crop, value of production, value of urban consumption, regional development, employment-generation potential, politically visible crops, nutritional significance of crops, foods that the poor people eat, resource allocations in input research, import-substitution industrialization, and narrowing of wealth and income inequality.

Although these criteria are both relevant and important in determining priorities in research, the lack of production statistics, particularly for those crops consumed on farms, makes this methodology difficult.

Research Needs

1. Screening and breeding for crop varieties suitable for semi-arid areas: Sorghum and millets should receive the first priority. The program should consider, among other aspects, palatability, bird resistance, easiness to mill and increased yield.
2. Because the semi-arid areas are characterized by variable and erratic rainfall, the development of cropping pattern strategies to optimize the use of scarce and unreliable rainfall needs to be investigated.
3. Crops should be investigated that can withstand adverse conditions such as delayed onset of rainfall, long gaps in rainfall, or early cessation of rainfall. Ideal crops include sweet potatoes and cassava.
4. Exploration of field innovations that might retain water more effectively, e.g. mulching and minimum tillage.
5. Search for cash crops more suited to semi-arid conditions, e.g. jojoba.
6. Research on minimum fertilizer use and simple methods for application.

7. Soil mapping studies to establish more precisely the most suitable areas for different crops.
8. Studies on pest and disease control techniques. The use of ultra low volume spraying should be stressed because of the shortage of water in semi-arid areas.

Highlights of Current Crop Research Programs

1. Maize

Maize is the most important food crop in Tanzania and provides an estimated 27.5% of the average calorific intake in an average diet. Major research is aimed at producing improved composite varieties for the semi-arid areas, and developing an appropriate technology packet suitable for the small-scale farmer.

2. Sorghum and Millets

Sorghum and millet production combined, rank next to maize in total cereal grain production. Their production is concentrated in the semi-arid areas where maize production is constrained by moisture stress and drought situations.

Major technical constraints on sorghum production are bird damage and fungal infection before harvest. Another area requiring immediate attention is the quality of grain that can be processed and which is acceptable to the farmer.

Local varieties of sorghum are very tall, late maturing, and low yielding, but their grain is hard-flinty, stores well, and is palatable. The improved variaties, Lulu and Serena, yield well but are poor in grain quality, unpalatable, and highly susceptible to bird damage.

3. Grain Legumes

They include cowpeas, french beans, haricot beans, and pigeon peas and constitute a major source of protein, particularly in the rural areas. The total production is just under 200 000 tonnes.

The current grain legume research program focuses primarily on developing improved varieties with high yield and nitrogen fixing properties. Resistance to diseases, insect pests and good adaptability to various intercropping schemes are also receiving top priority.

4. Rice

Rice research for mainland Tanzania is co-ordinated at KATRIN, at Ifakara. The major thrust has been selection in the local and introduced material, as well as hybridization between the two to evolve high-yielding, dwarf, and early maturing varieties.

5. Wheat

A wheat improvement/production program has been conducted with Canadian assistance (CIDA) since 1970. The agronomic research program (especially soil management and moisture conservation) at Selian is geared almost exclusively to highly mechanized production.

6. Bananas/Plantains

The pest complex of weevils and nematodes has been the major constraint in banana production. Some agronomic and weevil/nematode control work is currently underway at the Maruku research station.

7. Cotton

The cotton research headquarters are located at Ukiruguru. Research over the years has led to the development of adapted varieties and packages of improved cultural practices. However, insect pests are still the major limiting factor. Increasing costs of insecticides are threatening production at present and other control aspects are therefore being investigated.

8. Coffee

From its inception in 1933, the coffee research station at Lyamungu made selections within the existing coffee populations and imported hybrids. During the 1950s, some improved selections were released and now cover most of the planted area. Selection for rust resistance was successful but work on incorporating coffee berry diseases (CBD), which began in 1962, has yielded only limited results. This disease is the most limiting factor in coffee production and at present is receiving top priority research.

9. Tea

Tea research was carried out by the Tea Research Institute of East Africa (TRIEA) until the collapse of the East African Community in 1978. At present, research is conducted at Marikitanda which was formerly a substation of TRIEA. Little research has been carried out since 1970.

10. Sugar

Sugar research is conducted at Kibaha, which was formerly under the auspices of the East African Agriculture and Forestry Research Organization (EAAFRO). Research priority involves breeding new varieties that are high-yielding and smut resistant.

Livestock Production

Historically, livestock research in Tanzania (formerly Tanganyika) was started by the British after World War I. Unfortunately continuity of the research effort was not maintained due to the frequent changes of staff and policy. Since independence in 1961, livestock research has severely suffered from lack of adequate research personnel and financial support.

A considerable amount of sound research work was carried out between the 1920s and 1950s, much of which has been reported in the literature (Brzostowski 1960, 1961, 1962, 1964, 1966; Epstein 1955; French 1939, 1940; Mahadavan 1965, 1964; Marples 1964; McDowell 1971, 1972; Stobbs 1966, 1967; Tidbury 1954; Trail et al. 1971; Wagner et al. 1969; Wigg 1973; Williams and Bunge 1952; Wilson 1957).

Any new research program should take into account the fact that:

1. Some of the conclusions arrived at in earlier years are no longer necessarily valid due to changed circumstances. For instance, early workers ruled out the raising of *Bos taurus* cattle in the tropics because of a very hostile environment. Since 1975 Tanzania has imported several thousand head of pure-bred exotic dairy cattle from New Zealand and the United States.

   Our limited experience has shown that, under good management, such animals do perform well in high altitude areas. It is now generally accepted that in most cases management is a more important factor than genetics *per se.*
2. Because some of the experiments carried out in earlier years were limited in scope and were inconclusive, there is a need to repeat them under present conditions and knowledge.

Re-organization of Research

Following the break-up of the East African Community (EAU), the Tanzanian Government took steps to ensure that the former EAU research institutes situated in Tanzania continued their research programs. At the same time it was decided that the opportunity should be taken to review and reorganize the existing Tanzanian research institutes of the Ministries into autonomous organizations (parastatals) to which qualified scientists and administrators were posted.

Accordingly, the Tanzania Livestock Research Organisation (TALIRO) was established by an Act of Parliament in 1980. TALIROs organizational chart is shown in Figure 3.

Functions of TALIRO

TALIRO has been given the mandate to:

1. Initiate, organize, conduct and establish priorities to promote the carrying out of basic and applied research designed to facilitate livestock research and other fields related to livestock development.
2. Promote and/or provide facilities for the training of local personnel for conducting livestock research.
3. Monitor and co-ordinate basic and applied livestock research carried out within Tanzania and/or in collaboration with other institutions elsewhere on behalf of or to the benefit of the Government of Tanzania, and to evaluate the findings of that research.
4. Establish a system of documentation, registration, and dissemination of research findings through technical and advisory services and to promote the practical application of these findings in livestock development.
5. Conduct research on livestock products and by-products.
6. Advise the Government on all matters affecting the livestock industry as an outcome of livestock research.
7. Research on, produce, and register vaccines for control of livestock diseases.
8. Carry out any other functions within its jurisdiction and as may be conferred upon TALIRO by or under the relevant Act or any other written Law or by the Minister of Livestock Development.
9. Prepare and execute agreements with other Tanzanian and external organizations.

The other research organizations have similar functions within their respective fields.

Need for External Support

During the last 20 years many sound proposals

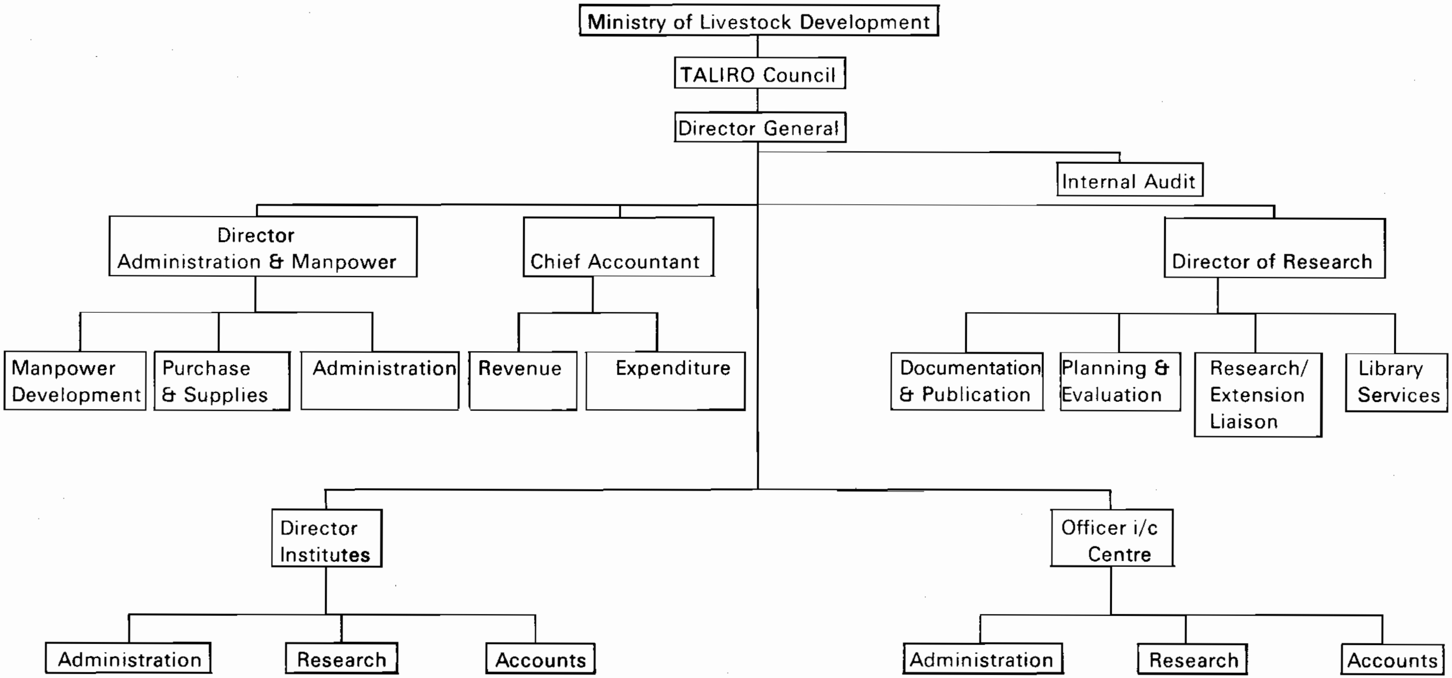

Figure 3. Organizational chart of TALIRO.

were formulated but never started due to the lack of financial and/or personnel support. Over the years, massive raw data have been collected and await analysis, pending publication. Before embarking on a new long-term research program, a comprehensive review of past research work should be undertaken to avoid unnecessary duplication of effort and resources. TALIRO is seeking external support (a) to analyze, evaluate, and publish past results (this will call for technical assistance), (b) draw up an integrated long-term research program that will take into account 'old' and 'new' research proposals from conception to completion, (c) plan and realistically cost associated field stations development, (d) advise on research manpower planning and training, (e) advise on extension-linkage development and publish results needing translation into field language for extension use, and (f) establish library, documentation, publication, and general information services.

Research Priorities

Much of this section of this paper will dwell on an area that has been neglected for years, but has been accorded high priority, recently.

Pasture Research

The major problem is that over 90% of livestock production takes place in an uncontrolled grazing situation which makes the application of improved pasture technology difficult, if not impossible. Since Australia has considerable experience and expertise in tropical and subtropical pastures, it is hoped that ACIAR will be in a position to co-operate with Tanzanian scientists in the following areas:

1. Evaluation of natural and sown pastures: Such a program would aim at assessing the productivity and quality of natural and sown pastures under different grazing management systems. Least-cost methods of establishment would also be investigated.
2. Evaluation of grass-legume mixed pastures: Past work in Tanzania has established suitable grass and legume species for various ecological zones. There is little information, however, on the compatability of grass and legume species under various ecological and management conditions, particularly at low altitudes.
   An assessment of various grass-legume mixtures under both cutting and grazing management conditions with regard to yield, quality, animal production, species persistence and soil fertility improvement needs to be made.
3. Pasture breeding and seed production: The local demand for pasture seeds is so high that in recent years overseas importation has had to be made (including from Australia) at an enormous cost. Research will limit itself to production of mother seed only, to be multiplied by commercial producers for general use. Promising local and exotic grass and legume species/varieties will form material for selection, breeding work, and seed multiplication.
4. Studies on soil fertility status: Such studies will lead to useful information that will be the basis of fertilizer recommendations for pasture in various ecological zones. Emphasis would be placed on the higher potential areas in view of the high price of fertilizer application and the problem of inadequate moisture in the low potential areas.
   The studies would establish areas of critical mineral deficiencies in the country and make recommendations for the alleviation of such deficiencies. This problem is particularly serious in higher rainfall areas, e.g. West Lake.
5. Range management studies: Little has been done in this area. There is a need to initiate various studies, including grazing management, stocking rate, reseeding denuded areas, introduction of browse plant species, and the evaluation of the nutritive value of various range species.

Animal Nutrition

Most livestock subsist on rangeland grasses and browse, sometimes supplemented by seasonal crop residues and by-products. Very little formal supplementary feeding is practised.

Both the quality and quantity of intake vary markedly from region to region and from season to season, but inadequate nutrition is probably the most widespread and important 'disease' of livestock in the country. This is especially so in the drier areas, where an inadequate feed supply during the dry season often causes animals to lose most of the weight gained during the rain season. Milk production also falls drastically.

The most important area of animal nutrition research would therefore seem to be the feeding of preserved forages to cattle, especially dairy cows during the dry season. This work has to be closely linked with what has been discussed under pasture research. New methods of preserving forages have to be devised as the conventional systems of hay and silage-making are not applicable to peasant farmers.

Animal Health

Disease problems are a serious constraint on livestock production. Adequate, economic methods of control have not yet been developed for a number of important diseases, including trypanosomiasis, East Coast fever, and streptothricosis. Methods of controlling other diseases, such as rinderpest, and foot-and-mouth disease, have been developed, though they are not always readily available to livestock producers.

Since the use of chemicals to control ticks has its limitations, the time has come to pay serious attention to Australia's experience in selection of cattle for tick resistance.

Animal Breeding

Since the 1920s exotic breeds of cattle have been introduced into Tanzania and crossed in many combinations with local and other exotic breeds. Several improved Zebu breeds are available for crossbreeding purposes, e.g. the Boran, Brahman, Mpwapwa, and Sahiwal. In terms of size and milk production these breeds are superior to other local zebu breeds, e.g. the Ankole and Tanganyika Shorthorn Zebu (TSZ).

Over many years of natural selection the breeds native to the tropics and subtropics have become adapted to a harsh environment characterized by high temperatures and humidity, diseases, and generally poor nutritional conditions. A certain amount of improvement has been brought about in some of the zebu breeds by artificial selection. The inherent adaptation found in the improved zebu breeds should go well with known production traits in the taurine breeds.

A major constraint to production plans at present is the lack of specified knowledge on the kind of beast best suited for commercial dairy and beef production, in different ecological zones.

Due to the shortage of improved breeds, the tendency has been for small-scale holders to accept anything available on the market. It is not unusual to find beef crosses in 'dairy' herds.

Areas in which ACIAR cooperation might be envisaged are:

1. Introduction of new germplasm. Breeds developed under Australian tropical and subtropical areas can be expected to do well under similar climatic condition in Africa.
2. Further crossbreeding of local and exotic breeds to find the ideal combination of *Bos indicus* x *Bos taurus* under different environments.
3. Pure breed comparison of exotic animals to find out the 'best' breed for a given area.

Whereas a generation of some plant material can be evaluated in a single season and improved varieties multiplied a thousand fold in a year, it takes several years to obtain the results from one livestock cross and several decades to extend new types to local producers. It is also much more difficult to control or predict the nutritional levels and disease hazards that improved animals are likely to experience over their lifespan. Thus, although genetic improvement remains a tool in livestock research and development, the greater emphasis needs to be placed on the improved management of existing animal resources.

Forestry

Forestry activities are administered by the Forest Department in the Ministry of Natural Resources and Tourism. Currently, the main contributions of the forestry sector to Tanzanian socio-economic development are:

1. Provision of fuel wood, which is the main source of domestic energy to over 90% of the population.
2. Protection of water catchment forests for ensuring a sustainable water flow in rivers and streams.
3. Maintenance of a sound vegetation cover for environmental protection.

This paper describes the situation of fuelwood supply in Tanzania, problems being created by the prevailing fuelwood crisis and how research can assist in minimizing the problem. The problems associated with water catchment forests and environmental degradation are discussed within the fuelwood frame.

Fuelwood Consumption

Quantitatively, fuelwood constitutes about 91% of the total energy consumed in Tanzania. Oil and hydro-electricity accounts for 7% and 2%, respectively. Fuelwood accounts for 97% of the total wood products consumed in the country. Nearly 99% of fuelwood used is harvested from the natural forests, which are not protected nor managed for sustained production.

The average fuelwood consumption in Tanzania per capita per annum is about 2.0 m^3 of solid wood. However, consumption varies significantly from one region to another depending on fuelwood availability, cooking habits and climatic conditions. (It varies from 0.7 m in Dodoma to 2.7 m^3 in the Tanga region, Lushoto district).

Fuelwood is mainly used for domestic purposes, cooking, and heating. In rural areas firewood is used directly, while in urban areas charcoal is used. Fuelwood is also used for agricultural and industrial purposes mainly in tobacco curing, fish smoking, tea drying, pottery, ceramics and brick burning.

In 1981, it was estimated that the total fuelwood consumption was 36 million m^3 of solid round wood, of which 30.6 million m^3 were used as firewood in the rural areas, 3.4 million m^3 were converted to charcoal, which produced 290 000 tonnes, and 2.0 million m^3 were used for agricultural and industrial purposes.

Fuelwood Supply

The main source of supply is the natural forests, which are mainly classified by the Forest Ordinance as public lands. Legal protection is not enforced and the forests are not managed for sustained production of fuelwood. They are the same forests that are being cleared daily for agricultural and livestock expansion and by fuelwood gathering.

At the end of 1981, natural forests covered about 30 million ha. The allowable fuelwood annual cut from these forests was estimated in 1981 to be 19 million m^3. This amount could be harvested without causing deforestation. This created an over-exploitation of about 17 million m^3, which caused the deforestation of about 340 000 ha in semi-arid areas in which there is no regeneration (one ha of woodland produces about 50 m^3 of solid round wood when clear felled).

This high rate of deforestation, which has been going on for decades, has created a fuelwood scarcity throughout nearly all the country, with significant environmental degradation. Soil erosion, floods and signs of desertification are becoming common in most regions (15 regions out of the 20 regions).

Cow dung and farm residues as sources of domestic energy are increasing in the semi-arid regions with the fuelwood scarcity. A survey in 1982 by the Forest Division discovered that about 67% of the villages within the semi-arid zone were using cow dung and farm residues as substitutes for fuelwood. These factors have resulted in increasing soil degradation.

The Socio-economic Aspects of Deforestation

A substantial amount of potential productive labour in agricultural production is wasted in collecting fuelwood. For example, it has been observed in the semi-arid regions of Tanzania that up to 300 man days per family per annum are used for firewood collection. Where fuelwood could be collected in the immediate vicinity of most households a few years ago, it now has to be gathered and carried from distances up to a full day's walk.

Solutions to the Fuelwood Crisis

Great efforts have been put into education on (a) the importance of conserving and managing properly the few existing natural forests, and (b) the planting of trees around houses, farm boundaries, along avenues and other areas not used directly for agriculture, and following recommended agroforestry practices. Also, planting of mountains, hill tops, valleys, and gullies is recommended.

Currently the Government is assisting in providing free seedlings and expertise, while villages, schools, and institutions plant and tend trees on a self-reliance basis as part and parcel of their socio-economic development efforts.

Between 1975 and 1982, an equivalent of 59 000 ha of woodlots were established on a self-reliance basis by villagers, with an annual average of about 10 000 ha per annum. However, great efforts are still required to solve the fuelwood shortage. In order to strike a balance between supply and demand at least 200 000 ha of woodlots need to be established annually for a period of about 10 years.

Major Problems in Forestry

1. Encroachment of catchment areas: In the highlands of Tanzania, encroachment by villages on water catchment forests is becoming a major problem. As villages have no alternative sources of fuelwood, they are inclined to collect fuelwood from the water catchment forests, consequently destroying the forests as well as their water sources.
2. Some of the problems that afforestation has experienced include poor tending of communal woodlots, lack of transport facilities, poor initial planning, lack of effective organization to co-ordinate national and international community forestry authorities, inability to assess field survival rates, inadequate manpower, inadequate funds and lack of appropriate technology.

Research Priorities

The following research aspects have been identified as essential for solving the fuelwood scarcity.

1. Identification of suitable tree species for agroforestry for the different climatic zones of Tanzania, i.e. tree species that can serve multiple purposes like providing fodder, fruits, shade, cash crop, medicines, nitrogen fixing, etc. in addition to providing fuelwood and other small wood products.
2. Development of methods and techniques of managing the natural forests more efficiently, in order to increase the production per unit area, as well as ensuring a sustained supply.
3. Proper management of water catchment forests——with water flow monitoring in respect of water quality and quantity.
4. Development of more efficient firewood and charcoal stoves.

Research Staff

In TARO and Forestry there are 6 Ph.D., 32 M.Sc., and 119 B.Sc. research personnel,all of whom are Tanzanians. In addition, expatriate staff include 7 Ph.D. and 23 M.Sc. scientists.

In TALIRO, there are 2 Ph.D., 15 M.Sc., and 39 B.Sc. graduates.

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Agricultural Research in Uganda

H.S.K. Nsubuga, W.A. Sakira, and P. Karani*

The primary production activities of crop and animal farming, fishing, and forestry constitute the most important sector of Uganda's economy. Over 90% of the population derive their income directly from rural production. Agriculture accounts for over 50% of total domestic output and over 60% of government revenue. Agriculture also dominates the export sector accounting for 97% of the total export earnings (Anon 1982).

Traditionally, Uganda's main agricultural exports have been coffee, cotton, tea, tobacco, and sugar.

Agricultural Systems in Uganda

There are six main agricultural systems viz:

1. The Robusta coffee and banana system.
2. The Teso system.
3. The Northern system.
4. The West Nile system.
5. The Montane system.
6. The Pastoral system.

The Robusta Coffee and Banana System

This system is found in the Lake Victoria crescent where rainfall is high and where soils are deep and fertile enough to support these perennial crops. The cooking type of banana locally known as matoke is the staple food for the inhabitants of this area. Robusta coffee is the main cash crop grown. Other crops include tea, cocoa, sugar cane, sweet potatoes, maize and beans.

The Teso System

The Teso system is practised by the Teso tribe in Teso, North Busoga, and North Bukedi. All these areas are in eastern Uganda. The system is characterized by the predominant use of oxen as draught animals. Consequently, farmers commonly practise mixed agriculture and strip cropping as a means of soil and water conservation. Finger millet is the main food crop while cotton and to a small extent, groundnut, are the main cash earners. Cowpeas, sweet potatoes, sorghum, and maize are also grown as food crops. Soils in the system are sandy or sandy loams in some areas and usually infertile.

The Northern System

Farmers who practise the Northern system are located in Lango and Acholi. In these areas, finger millet is the main food crop while cotton and, in some parts, tobacco are grown as cash crops. Cowpeas, groundnuts, and pigeon peas are the main sources of protein. Sesame (simsim) is widely grown and forms an important component in the diet of the people in this area.

The West Nile System

In this system, basic agriculture is similar to the Northern system except that there is a predominance of cassava as the staple food. The main cash crops are cotton in the south and flue-cured tobacco in the north.

The Montane System

This is found in eastern Uganda (Bugisu/Sebei on Mt. Elgon), in the west (Ankole), and south west (Kigezi). The system supports Arabia coffee and bananas and in the east, wheat and maize are grown in Sebei while sorghum is the major staple in Kigezi.

The Pastoral System

This type of farming is practised by the Bahima in Ankole in the west and by the Karamojong in

* Associate Professor and Head, Department of Animal Science, Makerere University, Kampala; Senior Agronomist, Kwanda Research Station, Kampala; and Principal Research Officer, Department of Forestry, Nakawa, Uganda, respectively.

Karamoja district. The Bahima live on milk, meat, and root crops such as cassava and sweet potatoes. The Karamojong too, live on milk and meat but in addition feed on blood and grain mixtures of sorghum, finger millet, and bulrush millet.

According to Ruthenberg (1980) semi-arid climates are those with at least 2-4.5 humid months. In Uganda this is applicable to Karamoja district only. The Karamojong can be divided into two main groups depending on where they live, viz. the plains dwellers and the hill tribes. The plains dwellers are composed of the true Karamojong, the Suk, the Jie, and the Dodothi. These grow grain mixtures consisting of sorghum, finger milllet, and bulrush millet. These tribes are able to grow one crop a year when the weather permits.

A study carried out in Karamoja revealed that out of 29 years, 7 years had experienced crop failure throughout the district, while on 9 other occasions yields had been poor (Parsons 1970).

The hill tribes consist of the Tepeth, Tobour, Nyakwai, Nangia, and Tenso. Unlike the plains dwellers, they depend more on agricultural produce than animal products. They grow grain mixtures similar to those on the plains and crop failures are usually less because more rain is received.

Generally, rains in Karamoja are unreliable and the dry season is usually long——between November and April. The Karamojong attach much importance to cattle. They regard cattle as a sign of wealth and they are used to provide food and dowry. This attitude towards cattle leads to several problems of overgrazing,, overstocking, and consequently soil erosion. In most areas the top soil has been eroded resulting in gullies and areas devoid of vegetation. Soil conservation methods are unknown, except in Dodoth and Jie where trash bunds are found.

Research Needs in Karamoja

Sorghum and bulrush millet are widely grown in the whole of Karamoja. Research should focus on the development of drought-resistant varieties of these two crops.

The main problem is lack of water. Peasants are constantly faced with crop failures due to unreliable rainfall. It is necessary therefore, to carry out irrigation studies in the area. Research into forest trees that can grow in the Karamoja environment is urgently required.

Cropping Systems in Uganda

There are four main types of cropping systems practised by farmers in Uganda. These are shifting cultivation, mixed cropping, interplanting, and mixed farming.

Shifting cultivation is mainly practised in the northern and eastern regions where soils are generally less fertile than those around Lake Victoria and in the west. Cotton is grown as the main cash crop for export while finger millet is the staple food. A typical farm consists of about one ha of cotton, one ha of finger millet, and small areas of other crops, which are often intercropped. Shifting cultivation is still possible in this area, particularly in the north because there is still plenty of land to which to move when the 'old' plot is exhausted.

Mixed cropping is practised in nearly all agricultural systems in the country. For instance in the eastern and northern areas, it is common to find groundnuts being grown in the main crop mixed with maize, cowpeas, or green grains and sesame. In this case, maize is usually planted in lines. In these areas finger millet is grown as the main crop mixed with maize planted in rows, and sesame.

Interplanting is widely practised in virtually all areas. For example, in the Teso system finger millet is often interplanted with sorghum, while in the Robusta coffee and banana system, beans are usually interplanted as cover crops. In the same region, sugar cane is sometimes interplanted with beans. The intercrop uses land and light while the main crop is still small.

Mixed farming has not yet been widely adopted despite many people keeping cattle, goats and sheep, particularly in the Teso, Northern and pastoral agricultural systems. In general, kraal manure, farmyard manure, and compost are used on a very small scale, and integration of animals and crops has not yet been appreciated.

Farming Systems Research (FSR)

Farming systems research has not been conducted in the past and this continues to be the case. Research projects are formulated by research workers without identifying farmers' problems or priorities at farm level. There is a need to integrate

FSR into the overall research strategy. Thus, it will be necessary to have FSR in each of the eleven major agro-climatic zones in Uganda. By so doing, research will provide an essential link between the researcher and the farmer and ensure that the research carried out is appropriate or suitable to the farmer. Team work, involving a sociologist, a farm management economist, an agronomist and an extension worker, will be necessary.

Currently, experiments being conducted in the area of FSR are aimed at evaluating the potential of traditional systems such as interplanting maize with beans, interplanting cotton with beans, and evaluating the potential of minimum tillage and zero tillage in modern agriculture in crops such as maize. However, these are not on-farm trials. In 1982, the IDRC mission to Uganda recognized this as an important aspect in research strategy and recommended that farming systems should be given high priority in Uganda's research endeavour.

Agricultural Research Organization

Agricultural research in Uganda is primarily administered by the Departments of Agriculture and Forestry (which are under the Ministry of Agriculture and Forestry) and the Faculty of Agriculture and Forestry at Makerere University, Kampala. The National Research Council, which was established in 1970, is supposed to coordinate all the research in Uganda. The Research Division is headed by the Chief Research Officer, who is directly responsible to the Commissioner for Agriculture; the former is expected to advise the Commissioner for Agriculture on all matters related to agricultural research and to advise researchers, in all categories.

The Chief Research Officer is in charge of three research stations in the country, viz. Namulonge, Kawanda, and Serere research stations and six substations, i.e. Buginyanya and Bugusege (for Arabica coffee); Kutuza for Robusta coffee, cocoa and sugar cane; Ngetta for livestock and cotton; and Kalengyere for highland crops, mainly Irish potatoes and wheat. In addition he is responsible for managing 46 experimental centres, formerly known as Variety Trial Centres (V.T.C's).

Each main research station has various disciplines, viz. soil science, botany, entomology, nematology and agronomy. Each of these sections is headed by a senior officer who together with individual research workers initiate research project proposals that are then discussed by all research workers at each station, at Experimental Committee meetings. District staff are also involved. Next, the proposals are screened by the Agricultural Research Advisory Committee, which is chaired by the Commissioner for Agriculture.

Agricultural Research Staff

The Research Division has 142 scientists consisting of 2 Ph.D., 21 M.Sc., and 119 B.Sc. Currently there is a crash training program to train 10 graduates to the M.Sc. level in postharvest crop production.

Since the mid seventies, organization of research has moved from the discipline-type to the commodity-type approach, but this approach has not been fully implemented. Commodity-type research includes cotton and fibre crops; coffee, cocoa and oil palm; cereal crops; grain legume crops; horticultural crops; sugar cane, banana and root crops; oil crops, tobacco and medicinal crops; pastures and animal husbandry; soil science and agricultural chemistry; plant protection and crop storage; and basic research and research services.

Research Priorities

The main emphasis of the Research Division is directed to farming systems research and to those crops that earn foreign exchange and those that are the staple foods of the people, i.e. the economically important crops. The priorities are:

1. Farming Systems Research: Many aspects of declining agricultural productivity in Uganda require urgent research attention. Information generated from the three research stations will be of little value if it is not immediately applicable and acceptable to the farmer. Integration of FSR into the overall research strategy will provide the essential communication between the various levels of research, extension and production. Thus it is imperative that FSR, which has been found to create an impact in other areas of Eastern Africa, be investigated in the various zones shown in Table 1.

Table 1. Agricultural systems in eleven zones in Uganda.

Zone	Districts	Agricultural System
1	Busoga/Bukedi	Banana, millet and cotton system with outliers of the main coffee-banana system.
2	Bugisu/Sebei	Montane System: Arabica coffe, bananas (wheat and maize in Sebei).
3	Teso	Teso system: finger millet, cotton and cattle (mixed agriculture).
4	Karamoja	Pastoral system——cattle.
5	Lango/Acholi	Northern systems: finger millet, cotton, tobacco (some mixed agriculture also).
6	West Nile/Madi	West Nile systems. Basic agriculture like Zone 5 but with predominance of cassava as staple food.
7	Bunyoro/Toro	Arabica, Robusta coffee and banana systems: Heterogenous agriculture but basically bananas, coffee and tea.
8	Ankole	Montane systems in the west. Pastoral to the east. Arabica and Robusta coffee, tea, bananas, cattle.
9	Kigezi	Montane systems but with larger annual crop coverage than other montane systems. Sorghum is major staple. Arabica coffee and tea are also grown.
10	Lake Victoria crescent	Mainly by Robusta coffee and banana system. Robusta coffee, bananas, tea, cocoa and sugar.
11	Northern Buganda	Western extension of the banana-millet-cotton system but now largely taken up by big ranching projects.

2. Cotton: Breeding for yield, disease resistance and lint quality; evaluation of fungicides and pesticides; management of cotton pests; and combined agronomic package including fertilizers, intercropping etc.
3. Bananas: Nematode control; banana weevil control; and improvement of organic practices, e.g. mulching.
4. Maize: Breeding for yield potential and streak resistance; and improvement of agronomic practices.
5. Finger Millet: Breeding for yield potential by introduction and testing successful crosses between Indian and African material developed in India; pest control; and agronomic practices.
6. Sorghum: Breeding for yield and in Karamoja developing short-term, drought resistant varieties.
7. Cocoa: Control of *Verticillium* and black pod diseases, and pest control, e.g. capsids.
8. Soya beans: Breeding for yield potential and seed viability; seed technology, improvement of agronomic practices; nitrogen fixation; and fertilizer use.
9. Arabica coffee: Evaluation of fungicides against CBD and coffee leaf rust; evaluation of insecticides against *Antestia*, coffee berry borer, and white stem borer; and breeding for yield and resistance to diseases and pests.
10. Pulses (garden peas, cowpeas, pigeon peas): Breeding for yield, bush-type, and adaptation to lower altitudes; management of pests, including nematodes and birds.
11. Rice: Screening for high yielding varieties adapted to local conditions; resistance to blast disease; management of pests, e.g. stem borers, nematodes etc.; and improvement of agronomic practices and fertilizer use.
12. *Phaseolus*: Breeding for yield and resistance to major diseases, e.g. rust, angular leaf spot, anthracnose etc.; pest management, including pests of stored products; and agronomic practices, e.g. date of planting, fertilizer use etc.

13. Root crops (mainly cassava and sweet potatoes): Control of green cassave mite, leaf spot, and bacterial blight; selection for high yielding varieties; and improvement of agronomic practices, particularly fertilizer use.
14. Weed control: Evaluation of the efficacy of candidate herbicides.
15. Soil surveys and soil testing: Surveying government farms; fertilizer trials and other development projects; soil fertility advice; evaluation of soil testing methods; and the study of physical and chemical properties of soil.
16. Crop protection: Advisory service to farmers on disease and pest control; surveys to monitor disease and pest attack; and postharvest losses in economic crops.
17. Horticulture (local and exotic), including Irish potatoes: Breeding for yield and disease resistance, e.g. bacterial blight and bacterial wilt; agronomic practices including fertilizer-use; and pest management.

Socio-Economic Constraints

Below are some of the socio-economic constraints which in one way or another hinder agricultural production in Uganda.

1. Armed robbery in rural areas and cattle raiding in Karamoja and Teso——rich people tend to spend rather than invest.
2. Funerals and in Bugisu, initiation ceremonies lead to much wastage of time, sometimes at critical periods such as planting and harvesting crops.
3. Land tenure——heavily populated areas, e.g. Kigezi, land fragmentation is the rule. Land is divided by the father for his sons. In the north, communal herding of animals hampers investment such as in fencing.
4. Unstable marriages——frequent departures of wives (divorce) result in farms not receiving proper attention.
5. Illiteracy——makes an extension worker's job very difficult to impart knowledge.
6. Bride price——especially in Pastoral communities and Teso. Parents are forced to have unproductive animals as an insurance to obtain sufficient animals to give to their sons to pay for dowry.
7. Lack of sufficient capital——there is a general lack of liquid cash to enable farmers to acquire machinery, agricultural inputs, and to pay for labour. Well-organized credit and subsidy schemes would alleviate the situation.

Socio-Economic Research

It should focus on the economics of input utilization, farm management, and on-farm or farm research studies.

1. Economics of Input Utilization

There is no available information on the economics of using fertilizers, insecticides, herbicides, fungicides etc. The cost/benefit ratios will enable researchers to provide recommendations that will make farmers realize high economic returns.

2. Farm Management Studies

This important area has not been widely investigated. Future studies could examine combinations of different enterprises on the farm, managerial problems that face farmers, and profitability studies.

3. On-farm or Farm Research Studies

This new approach to problem solving has been tried in Eastern Africa and Central Africa with some success. It could be used to determine the impact that it could create, and if found feasible, be recommended to farmers. Ideal places for its application would be areas such as Teso and Lango where the cash economy is based on annual crops.

At present an agricultural economist is not attached to each research station. Before socio-economic factors can be studied, such appointments are necessary.

Livestock Production Research

As early as 1961 the World Bank Economic Commission's report to Uganda included a major recommendation to diversify within the crop sector, and equally important into the livestock sector (IBRD 1961). To this end considerable resources of funds, staff training, and research were mobilized in the 1960s to expand and intensify livestock production with the objective of achieving self-sufficiency in all animal protein products, and exports of surplus in subsequent programs.

Livestock Production Systems

In the early 1960s the livestock sector was characterized by the following three recognizable systems. First, the pastoral system, which is confined to Karamojong in Karamoja district and the Bahima pastoralists in Ankole districts. Second, the crop and animal husbandry system that is predominant in all other districts of Uganda. Third, the specialized modern beef cattle ranchers, dairy farmers, poultry and pig farmers, who utilize up-to-date inputs of breeds and breeding, nutrition, and strict animal health regimes.

The development of the first two systems of pastoralists and mixed farmers required carefully co-ordinated developmental and research inputs introduced in an appropriate order to meet technical, economic, and social requirements of the various human communities and their respective ecological environments.

As a result of the above measures, livestock production became a major component of the total wealth of Uganda and it provides a livelihood for a large proportion of the population. In 1977, the population of livestock was estimated at 4.9 million cattle, 2.4 m goats, 1.1 m sheep, and 0.2 m pigs. Since then numbers have declined due to various technical, economic, and social constraints. Table 2 shows the livestock population in 1970-1980.

Approximately 14-20% of the cattle population is kept by pastoralists and within semi-arid regions experiencing periodic drought conditions in the north and north eastern districts of Uganda.

Livestock Research Organization

Research in animal health and production has been shared by the government ministries responsible for Agriculture and Animal Resources, and by the Faculties of Agriculture, Forestry, and Veterinary Medicine in the Makerere University. Before the break-up of the East African Community an important research input in animal trypanosomiasis was the responsibility of the East African Trypanosomiasis Research Organization based at Tororo in Eastern Uganda. Presently the Uganda Government has taken on this responsibility, which is based at the same place. Some research in animal production was done by the East African Agriculture and Forestry Research Organization (EAAFRO), Muguga, Kenya.

Priorities

In general, Uganda Government research activities have the primary objective of solving urgent field problems. Problem solving oriented research programs receive the highest priorities in allocation of resources. Makerere University research activities in animal health and production give equal weighting to basic and applied research.

Through the auspices of the National Research Council, two specialized committees, viz. the Medical and Veterinary Research Committee (Animal Health) and the Agriculture and Animal Husbandry Research Committee (Animal Production) discuss research priorities. On agreement, they are recommended to the government through the Ministry of Planning and Economic Develop-

Table 2. Livestock populations (millions) 1970-1980.

Animals	1970	1975	1977	1980
Cattle	4.3	4.8	4.9	4.5
Goats	1.8	2.0	2.4	2.0
Sheep	0.8	0.9	1.1	1.0
Pigs	0.1	0.2	0.2	0.2

Source: Anon, Recovery Program, p.35, 1982-1984.

ment. The research committees have an equitable representation from government, university, and the private sector.

Research Needs in Livestock Production and Health

Nutrition

Undernutrition is endemic in the tropics. The basic feedstuff of cattle, sheep and goats, i.e. pastures, are in permanent undeveloped grazing areas. Most of Uganda experiences a bimodal rainfall pattern. During the dry periods, drought conditions produce deficiencies in energy, nitrogen, and other essential nutrients.

Research into supplementation of the major food factors of ruminants under these conditions is usually concerned with the maintenance or even survival of animals during the critical drought period. Under less severe conditions, nutritional anoestrus would be obviated by the introduction of new pasture species (that can withstand arid conditions) in combination with supplementation techniques. Research in pasture legumes is given high priority.

Breeds and Breeding

Indigenous livestock are characterized by low levels of meat and milk production.

There are three main alternatives to livestock research and development in Uganda. First, there is the improvement of productivity through patient selection within the indigenous gene pool and subjecting the selected animals to optimum levels of management, including adequate nutrition and animal health.

Second, there is the transformation approach in which exotic high yielding stock are introduced and bred under similar, but not identical, systems of husbandry to their countries of origin, e.g. Northern Europe, Australia, USA, Canada, and New Zealand.

Third, there is the approach in which benefits accruing from the first and second options are combined in a crossbreeding program. This choice essentially recognizes the genetic limitations of indigenous stock for traits that produce high economic products. However, the stock are better adapted to less than ideal nutritional and animal health standards. On the other hand, exotic breeds have the reverse attributes, viz. are well bred for producing high levels of meat and milk, but are poorly adapted to the local environment, which includes major constraints in the fields of nutrition and animal health.

During the 1960s Uganda's major research thrust was in the field of crossbreeding beef cattle using exotic bulls on indigenous cows and exotic semen on local cows in artificial insemination programs in dairy areas. Some evaluation of the results showed that offspring from crossbreeding had a better weight gain and higher milk yield than indigenous stock. Also the crossbreds had a higher degree of tick resistance (in bovine) and exhibited hybrid vigour (Trail, Sacker and Fisher 1971).

Research priorities in the 1980s need to focus attention on comparative studies on the three options under optimum inputs of management, including animal nutrition, and animal health.

Animal Health

Research embraces a wide range of problems of infectious and non-infectious diseases.

In the infectious diseases field, the greatest problems are in the need to find cost effective methods of containing and eventually eradicating Contagious Bovine Pleuro-pneumonia (CBPP), rinderpest, and foot and mouth disease in cattle.

Among the non-infectious factors limiting production is livestock infertility, which has been associated with low energy and nitrogen intake and the stress imposed on cattle, sheep and goats by lactation.

Haemoprotozoal diseases notably trypanosomiasis continue to be widespread, despite tsetse control efforts. These yield only slowly to eradication methods.

Field control of tick-borne diseases through control of the tick vectors has been a major input and has used considerable capital and variable investments since the Uganda Parliament passed an act proclaiming the whole country a compulsory tick control area in 1968. To date research is necessary to review developments in the therapeutic industry with the objective of making new recommendations to farmers regarding frequency of acaricidal dipping/spraying of animals. Acaricides are a major cost, and can be a constraint on many cattle properties.

Environmental Physiology

There is need to study the response of exotic livestock to exposure to high temperatures that obtain in parts of Uganda and also to study the utilization of factors such as water and electrolytes by livestock in the different ecological situations of Uganda.

Forestry including Plantations, Agroforestry and Social Forestry

Uganda has 622 467 ha of natural forest, 565 367 ha of which are productive, and 57 100 ha are protective. The protective forests occur on steep terrain and water catchment areas. Apart from botanical exploration, no research has been conducted in protective forests. In the productive forests research has been on postharvest regeneration tending and trial on enrichment planting. The main purpose of regeneration tending is to monitor the progress and performance of tree species that naturally regenerate, as well as to find out suitable replacements for those species which are difficult to regenerate naturally.

With regard to plantation forestry there are 31 290 ha of fuelwood and timber plantations. Research has concentrated on species and provenance testing to determine suitable species for a variety of climatic conditions occurring in the country. A large number of indigenous and exotic species have been tested, some of which have already been used in large scale afforestation. *Eucalyptus grandis* and *E. tereticornis* have proved suitable for fuelwood plantations and others like *E. paniculata, E. robusta, and E. camaldulensis* have also shown great potential for fuel or timber plantations. For a number of years *Acacia siamea* has been used for planting in fuel plantations, but recently has been replaced by *E. tereticornis*.

Of the 31 290 ha of plantation, one half is grown for production of construction timber. Research has concentrated on testing species and provenance suitable for timber production. Recently efforts have been put into looking for species that can be grown at low altitudes where most of the land is available for afforestation. Species like *Pinus caribaea* and *Pinus oocarpa* from Central America have already shown that they can produce general construction timber in cycles of 20-25 years on sites at 600-1 200 m for *Pinus caribaea* and 1 200-1 700 m for *Pinus oocarpa*. Other species like *Pinus kesiya* have also shown promise, except that its stem form is resulting in a low yield of usable wood for production construction timber.

There has not been much time and funds spent on agroforestry research. This important aspect of the country's farming system has been limited to observation only and has yet to be quantified. The purpose of such observation has been to look for suitable tree species that can be used by farmers and which confer benefits on food or cash crops. In this respect *Sesbania sesban* Linn Marr has been found to grow with matoke (Plaintains). It is a short lived tree, used for fodder and it produces fuelwood. It belongs to Papilionaceae family and confers fertility to the soil. In Uganda it is grown with matoke and coffee. The leaves and flowers are fed to goats and cattle as fodder, especially during the dry season when grass is dry. It also yields fibre that is used by fishermen. *Albizia coriaria* is a member of Mimosaceae; it has the ability to increase soil nitrogen. In the soils of Bulemezi and Bululi counties, which are sandy loams with little or no weatherable minerals, *Albizia coriaria* plays an important role in fixing atmospheric nitrogen into the forms beneficial to coffee and matoke. Farmers in this area have been careful with their trees. They are even reluctant to log them for fuel. *Albizia cariaria* yields first class furniture timber. For many years *Meosopsis emnii* has been recognized as one of the best trees to grow with cocoa and in cocoa growing districts, and it is used for this purpose.

Owing to a lack of funds and personnel, it has not been possible to quantify the yield of food or cash crops grown under various tree species and sites. Suffice to say that farmers would not maintain such trees with food or cash crops if they (trees) where harmful to such crops.

In the field of social forestry, little research has been conducted. It is only now that the whole country is beginning to look at the problem of wholesale deforestation and recognize the value of trees as shelter belts as well as their ameliorating benefits to local microclimate. Deforestation in many areas of the country has already led to serious deterioration of the environment. Soil and wind erosion have already carried away the best top soil, especially where it has been followed by overgrazing. Under this situation, funds will almost certainly be spent on tree planting and research will be relegated to the advisory role, and finding the best method of re-establishing the trees on difficult sites that have been exposed to the sun and rain for many decades.

In one locality it has been found difficult to establish tree species belonging to the former vegetation communities. In another locality this problem was overcome by planting exotic pines; they create a forestry environment in which indigenous tree species begin to establish themselves once more. The main reason is that very many local species cannot compete as seedlings with grass and probably the majority of large tree species need some form of shading when they are seedlings.

Last, forestry research in Uganda has for many years suffered from lack of funding and many programs and projects have never been implemented. In this connection, important aspects of forestry like agro- and social forestry have yet to be investigated. One of the main areas where research has suffered has been the loss of personnel. For many years after independence, this country depended on expatriate personnel and at the time when local people were beginning to be available, political and economic conditions forced some of our best people to flee from Uganda and they have not come back yet, despite many appeals. Economic conditions are probably not yet conducive for their return. Another problem facing forestry research in general is the lack of transport facilities, plus other badly required equipment like calculating machines etc.

One of the urgently required inputs is the ability to collect seeds. Since 1978 there has been a program of seed collection and seed improvement. The Forestry Department has started a tree planting program for production of fuelwood resource and restoration of tree cover on catchment areas and overgrazed sites for soil and general environmental protection. However, all these programs need seeds as a springboard. Our ability to move and to collect the badly needed seeds is minimal unless something is done in the field of transport. Unless this is done, our policies about community, social, and protection of the environment will remain on paper.

Conclusion

Farming in Uganda is based on a subsistence economy characterized by small landholders throughout the country. Uganda is endowed with good soils, a favourable climate and has a people willing to reconstruct their economy in the near feasible future.

However, there is a relatively small area, the Karamoja district, that is semi-arid and requires urgent attention to land reclamation in order to avoid further soil erosion and denudation. In this area, research strategies should be geared to producing grain mixtures of sorghum, finger millet, and bulrush millet (and possibly cowpeas), which are all short term, drought resistant, and high yielding species.

Because rains are unreliable, attention is required to develop appropriate modern irrigation techniques suitable for the area in order to enable farmers to grow crops during most of the year.

Before any research projects are mounted, it is imperative to consider and understand the socio-economic constraints being experienced by Uganda farmers, especially those in the Karamoja district.

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Summary of Discussions——Session 1

Ethiopia

In response to a question on the use of the farming systems approach in Ethiopia to identify priority problems that require research, it was stated that the role of farming systems scientists is to bridge the gap between the farmer and the researcher. Farmers are involved in identifying problems and then research programs are developed to aid in solving the problems.

The position of forestry in the Ethiopian agricultural research system was raised. Although there are afforestation and soil conservation programs underway, they are not administered by the Institute of Agricultural Research. About 4% of the country's area is forested but forestry as such is not given high priority. Nevertheless there are institutions where forestry is taught.

A point was raised concerning the provision of scientific manpower for Ethiopian agricultural research. The university is the main source of graduate and postgraduate scientific manpower. Supporting middle cadre staff are obtained from colleges.

The productivity (offtake) of livestock in Ethiopia is apparently relatively low and despite the large number of cattle, sheep, goats, poultry, camels, and equines, the country may not have a self-sufficient supply of animal protein. Efforts are being made to improve indigenous livestock and to increase their productivity. Aspects of animal nutrition and health are being studied to promote the productivity of the national herd and flock. The meeting was informed that although diseases are a major factor affecting livestock production, research should be focused more on animal nutrition.

Somalia

There have not been any new incidences of rinderpest following past eradication campaigns, but tsetse remains a major problem.

It is widely accepted that irrigated agriculture will provide crop security. So far only about 60% of the potential irrigable area is being used. Moreover the current use is inefficient. Plans are underway to build large capacity dams and to introduce more economical methods for using water, with a view to irrigating larger areas to settle more people. Livestock would also benefit from an expansion of irrigated croplands. Problems of salinity have developed and are affecting banana and sugar cane crops.

Ninety percent of Somalia's foreign currency resource accrues from the livestock industry. This could be increased by improving the offtake and quality of the animals.

Water harvesting techniques have been introduced in the northwestern highlands that receive 500 mm rainfall over 20 000 ha of cropland and range area.

So far there is no organized forest research activity. Investigations in forestry research have been haphazard, including species trials such as with *Leucaena*.

The existing conflict between crops and livestock is not due to scarcity of land but is a consequence of inadequate planning. As a result, animals damage crops in search of watering points. It is hoped that as more land becomes reclaimed from the tsetse menace, the grazing area will be increased.

Lack of manpower has been identified as a major bottleneck in agricultural research. There is constant staff attrition to other sectors and to overseas. Agricultural engineering and general research are greatly affected.

Regarding land reclamation from tsetse flies, land capability studies have been conducted to provide information on integrated land use by the relevant subsectors etc. However, an original parcel of 1 200 ha reclaimed on a pilot-scale was occupied by nomads and provides an invaluable opportunity for studies that will greatly benefit the use of larger areas to be reclaimed. There is a rapid change occurring from nomadism to settled agriculture. There has been a shift from 80-60% nomadism and a 10-20% increase in settled farmers.

Sudan

In response to a question as to why crossbreeding of livestock should not exceed the 50% level, it was explained that under Sudan conditions, animals with more than a 50% crossing with exotic animals are more prone to die from health problems and climatic factors than the local animals. The problem is more serious among farmers than with research stations where the standard of maintenance is high.

Clarification was sought on the mechanization system and the integration of livestock in dryland farming. It was explained that mechanization in crop production in the dryland is on large-scale farms and is of an uncontrolled nature. Farmers use large machinery and clear all trees in favour of only the monoculture crop (mainly sorghum). These farmers do not own the land permanently and are therefore not interested in sustaining its potential. Generally livestock are not accepted in this system of farming.

Sesame, a major crop in the Sudan, still has a problem of shattering at harvest. It can be minimized by harvesting when the pods are not too dry.

In Sudan there has been a progressive decline of crop yields over the years that have been caused mainly by the monocropping system and the lack of crop rotation, particularly using legumes. Due to a lack of markets, legumes are not popular. Also because fertilizers are not used in sorghum production yields are low. In the case of dryland farming, variations in varietal potential and rainfall also affect yields.

Suggested research priorities include agroforestry and studies of the water requirements of sorghum under irrigated conditions.

Kenya

It was noted that land available for livestock production in the wetter areas of Kenya is expected to decrease as more and more land is put under food and/or cash crops in response to the increase in human population.

Dairying is likely to shift from the high rainfall to the semi-arid areas. In the latter, production of milk may have to be on an extensive rather than an intensive basis and be seasonal rather than on a year basis in adjustment to the eco-climatic conditions in these areas and their effect on pasture productivity.

The number of indigenous cattle in the natural herd has decreased between 1978 and 1981. One of the reasons is that there is a major national effort to upgrade indigenous cattle to exotic dairy cattle using artificial breeding.

Currently in Kenya there is tree planting, good management, and maintenance of exotic and indigenous forests. The industry is receiving support at the highest level of national leadership. There is a widespread awareness of the importance of trees for the protection of the environment and the provision of wood products, including fuel. Both rural and social forestry are receiving attention.

The question of the role of minimum tillage in crop production was raised. There is a need to identify economically efficient methods that reduce the cost of seedbed preparation and weeding while at the same time ensuring that these operations are carried out at the optimum time to conserve soil, and soil moisture.

The role of arable and industrial crop by-products were discussed. It seems that these agro-industrial by-products have a role as feedstuffs mainly near to where they are produced. The cost of transporting these generally dilute sources of metabolizable nutrients may sometimes reduce their wider usage.

An inadequate number of trained and experienced scientific manpower in various disciplines of agricultural research has been identified as a constraint in the generation of technology for development of specific areas. The delegates questioned whether ACIAR could play a role in manpower development particularly in further in-service training of young research scientists.

A manpower survey document is available for certain Eastern Africa countries. The material needs to be updated regularly if it is to remain valid.

Tanzania

The meeting was interested to know why only 6 million ha of Tanzania's 39 million ha are cultivated. In reply it was stressed that only 6 million ha are arable while the bulk of the country (about two thirds) is marginal and consists of millions of ha of woodlands infested with tsetse flies.

Fuelwood consumption statistics for 1981 show that 36 million m^3 of fuelwood were used in Tanzania. By contrast, in the same year in Australia, with a population of 16 million, total consumption of wood as timber and bulk, and paper peeler logs etc. amounted to 16 million m^3.

This difference is due to the fact that the bulk of Tanzania's 17 million people use fuelwood exclusively for cooking, compared with the urbanized population in Australia.

Difficulties in determining priorities for small-scale farmers arise from the lack of quantifiable statistics from these farmers, who produce and consume grains and other crops locally.

The meeting sought clarification on differences between range lands and cropping areas in shifting cultivation systems. It was noted that research on rangelands would be applicable to state ranches but would be irrelevant in the open free-for-all grazing areas.

On the question of focusing policy on a farming systems approach, it was noted that this fits into the small-scale farm level. In practice, a survey is conducted first in the area to document the traditional practice and then the specialists on crops, livestock, and forestry etc. team up to undertake appropriate research. Co-ordination is effected by the national co-ordinating committee.

Regarding an apparent contradiction of Tanzania's policy of self reliance and the excessive importation of food during the last four years, it was clarified that production of traditional foodstuffs is recommended for the rural populace. Wheat cultivation is restricted to suitable sites on the plateaux for the urban population. Tanzania is expected to be self sufficient in wheat production over the next five years.

Uganda

The following clarifications were made during subsequent discussions:

It was noted that Uganda previously published its forestry research findings in the East African Agriculture and Forestry Journal. There now appears to be little coming from Uganda. The meeting observed that despite the collapse of the East African Community, the journal is still operational and continues to receive contributions from Tanzania, Uganda, and elsewhere. Currently the journal is experiencing difficulties with editorial matters etc. and is in need of support.

In the crossbreeding of beef cattle using exotic bulls on indigenous cows, and exotic semen on local cows, there is a shift after F_1 to indigenous males. This is because farmers desire to continue with the Baran and other local varieties.

The meeting observed that Uganda's list of research priorities would require a large research organization. It was stressed that the priority of items be arranged on a farming systems research approach. Further discussion established that the priorities had been determined by an IDRC mission and later considered by ministry officials. The government is still examining a strategy for implementation. There are good prospects for initiating farming systems research in a district such as the Teso district.

From 1950-70 Uganda was self sufficient in food production. With the current growing population, traditional crops such as bananas have been pushed to marginal areas. New situations have also arisen from the introduction of new crops, e.g. cassava, with concomitant introduced pests and diseases. The meeting noted that cocoa is produced largely for export to Kenya and the U.K., and brings in valuable foreign exchange. Uganda is conducting some work on tomatoes and cabbages for local consumption and incidental export. Research focuses on exotic crops such as cabbages and citrus.

Session 2

Eastern Africa: International Perspective

Participants at work during one of the Consultation sessions held at ILRAD, Nairobi.

Research Priorities in Semi-Arid Eastern Africa from the Development Point of View

J.K. Coulter*

The World Bank can be viewed as both a generator of new technology through its support of agricultural research in a variety of forms, and as a consumer of such technology in its development projects. It has been involved in the latter for more than two decades but major involvement in research spans little more than one decade. There is therefore considerably more knowledge of the impact of development projects than of research *per se*.

Table 1 summarizes the total investment of the Bank in agriculture in the six countries of the region.

The investments in other forms of agriculture cover a wide range of activities——rural or area development, agricultural support services such as credit, research, extension and production, and processing of tea, coffee, sugar, cotton, cashew nut, and tobacco. Commonly, Bank investment in a project represents around 35% of total project costs, the remainder coming from other co-financiers and the country itself. A project may be defined as a distinct entity that can be appraised for the purpose of an investment. Furthermore, project financing is a relatively small percentage of a government's overall investment in agriculture.

Attention to the problems of agricultural development has increased following the publication in 1981 of the report 'Accelerated Development in Sub-Saharan Africa', commonly referred to as the Berg report. This report followed a request from the African Governors of the Bank to prepare a special paper on the economic development problems of the African countries.

Tables 2 and 3 taken from the report illustrate the problems facing agricultural development in these countries.

Table 2 shows that in spite of relatively large investments, negative growth rates, sluggish agricultural development and increasing food imports (except Kenya) have been a feature of the 1970s and this has continued into the 1980s.

It is not proposed to analyse the reasons, both internal and external, for this scene; the figures are used merely to demonstrate the great need for increased agricultural production. Many factors are involved in this of which the generation and use of improved technology is only one but nevertheless an important one; this is particularly so in the more difficult areas, the drier regions with which this workshop is concerned.

* Agricultural Research Adviser, World Bank, Washington, D.C., USA. The views expressed in this paper represent those of the author and not necessarily those of the World Bank.

Table 1. Total loans and credits for agriculture (1960-82) in US$ (Millions).

	Investment in projects classified as irrigation	Investment in projects classified as livestock	Investment in other forms of agricultural projects	Total investment in agricultural projects
Ethiopia	42	36	69	147
Kenya	50	25	348	423
Somalia	—	18	30	48
Sudan	215	42	57	314
Tanzania	9	30	115	194
Uganda	—	3	7	10
Total	316	154	626	1136

Table 2. Average annual growth rate of production of food and non-food crops, 1969-71 to 1977-79.

Country	Food %	Non-Food %
Ethiopia	0.4	-0.8
Kenya	2.9	-7.5
Somalia	0.6	-0.8
Sudan	3.1	-3.9
Tanzania	1.9	-0.5
Uganda	1.7	-8.3

Table 3. Population growth——past and projected.

Country	Average annual growth of population % 1960-70	% 1970-79	Projected population (Millions) 2000
Ethiopia	2.4	2.1	53
Kenya	3.2	3.4	34
Somalia	2.4	2.3	6
Sudan	2.2	2.6	31
Tanzania	2.7	3.4	35
Uganda	3.7	3.0	24

Some General Comments on Agricultural Research

Before turning to a discussion of research in Eastern Africa and to the specific topic of research for the semi-arid areas, a few general comments about agricultural development and technology generation would be useful. The first point is the growing concern about the lack of innovative technology to support agricultural development, especially in the rainfed areas. The second is the concern that research organizations be made more effective especially in their attention to research programs for these areas.

With regard to the former it is worth noting that emphasis on greater productivity per unit area is a comparatively recent phenomenon for historically, most increases in production have come from enlargement of the areas under cultivation. In many African countries, increases in cultivated areas have gone hand in hand with growth in population but there have not been the increases in productivity of labour that have been the feature of developed countries, due to mechanization. Now the exponential growth in population (Table 3) means that increases in productivity per unit area will need to become a dominant feature of agricultural production in many countries by the end of the century and in some cases sooner.

The new technology that is needed to support this can come from four major sources: (a) from ideas developed by farmers themselves, (b) from formal research in national research programs, (c) by adaptation of technology generated in other national or international research programs, and (d) from industry financed research. Every country, developed or developing, capitalizes on these four sources but in this workshop (b) and (c) are obviously of most interest. Topic (c) will receive substantial attention in the papers that follow immediately after this, so this paper will deal with national research programs and some of the features that could make them more effective.

There are at least four important features of a successful national research organization that deserve attention. These are:

1. A research structure and organization that functions effectively within the public sector of a particular country.
2. A system for setting research priorities that takes account of the limited financial, manpower, and other national resources of the country, and that fits overall policies for agricultural development
3. A system of programming and budgeting for research that ensures stability of funding, control of the research programs, and proper monitoring of research expenditure.
4. A manpower and career development program that ensures adequate rewards for good research and suitable sanctions for poor research.

This is not the appropriate time to discuss these in detail. The purpose in mentioning them is to provide a reminder that ultimately it is the quality of national research programs that will determine the generation of useful technology and decide its use by the farmers, and to remind bilateral and multilateral agencies participating in research projects, that strong national research programs are their joint objectives.

Agricultural Research in the Eastern Africa Region

It is not easy to develop an overview of what is happening in the agricultural research subsector at a national level let alone a regional level, but a useful starting point is the total amount of money being invested in research. Obviously this says little about the quality of the research but it does give an indication of governments' commitment. The figures given in Table 4 include investment by countries themselves and the contributions from multilateral and bilateral donors. National contributions probably amount to 70-80% of the total.

While these figures probably cover a wide range of activities, loosely defined as 'research' they do suggest, first that there have been very substantial increases in investment in research in these countries and secondly, they would indicate that governments are increasingly committed to investment in agricultural research. In discussion at this meeting therefore it would seem appropriate to discuss not only additional resources for research but also how to make better use of existing resources and how outside agencies like ACIAR (and the World Bank) could help in this.

World Bank Involvement in Research in Eastern Africa

As mentioned above the World Bank is involved as both a user of research outputs and as a generator of such outputs through investment in research projects. A brief description of the latter therefore provides the opportunity to say something about activities in this area and forms a background for discussing some of the experiences. Involvement takes four forms: (1) support for the CGIAR, (2) support for national

Table 4. Agricultural Research Expenditures (in '000 1975 constant US$) and numbers of scientists (Oram and Bindlish 1981).

Country		1970	1975	1980	1980 Expenditures as % agricultural GDP
Kenya	Expenditures	1 520	7 985	14 204	1.08
	Scientists	207	321	400	
Sudan	Expenditures	4 505	6 317	9 560	0.57
	Scientists	121	178	212	
Tanzania	Expenditures	3 329	7 074	4 715	0.35
	Scientists	90	158	256	

research programs, (3) support for research components in agriculture and rural development projects, and (4) support for educational projects to strengthen universities.

1. The CGIAR

The work of the IARCs supported by the consortium of donors in the CGIAR is well known. Two of the centres, ILCA and ICRISAT, are particularly concerned with the semi-arid regions; ILRAD's program also covers this region and several of the other centres are involved to a lesser degree. Three international activities, i.e. ICIPE, IFDC, and ICRAF, supported by informal groups of donors, have substantial activities in these areas. Currently the Bank provides about $19 million which is approximately 12% of the total CGIAR budget.

2. National Research Programs

The World Bank's policy is one of very strong support for national research and extension programs and for helping bring about the kinds of institutional changes, essential for effective research organizations, that have been outlined in previous paragraphs. Of the six countries represented at this meeting the Sudan has a project, started in 1979, to develop rainfed agricultural research in the west-central region of the country. This includes two new research programs—— on livestock and crop production systems, and on water and land-use management. In Somalia the extension and research project that started in 1981, is directd mainly to extension. A national research program for Ethiopia, prepared by the FAO/World Bank Cooperative Program is presently being appraised by the Bank. A national research project for Tanzania was prepared four years ago but fundamental disagreements on organizational matters prevented the project going forward. Kenya and Somalia are expected to develop national research projects with USAID funding.

3. Support for Research Components in Agricultural and Rural Development Projects

Projects in agriculture and rural development often include 'adaptive' research components that are designed to serve the immediate needs of the projects. There are 10 such components in Ethiopian projects, 10 in Kenya, 4 in Somalia, 7 in the Sudan, 10 in Tanzania and 1 in Uganda. Such components are usually quite small, often costing less than one million dollars. Most are concerned with crop production though a few of the livestock projects have included such components. Bank experience with such research components has not been all that successful. The usual disbursement period of about 5 years is not long enough to accomplish research objectives and such projects have been criticized for drawing research staff away from national programs. Furthermore their objectives are usually limited to supporting a specific project rather than strengthening the national research institution.

4. Education Projects

Some education projects aimed at strengthening universities have an element of agricultural research, though there are no projects of this type in the countries represented here. There may be an unsatisfied need for this kind of support so that the capacity of developing country universities for training at the postgraduate level can be improved. It should be pointed out that most agricultural projects have a training component and in the national agricultural research programs provision is usually made for overseas fellowhips for M.Sc. and Ph.D. training. Short-term overseas visits are also included, as is training at national universities and the IARCs. Most countries in the Eastern Africa Region are short of trained staff, due to some extent to the difficulties of retaining well trained staff in the public sector.

Research for the Semi-Arid Areas

The FAO concept of 'growing period' (Kowal 1979) and the classification by Jahnke (1982) of less than 90 growing days as arid, and 90-180 growing days as semi-arid, is a useful way of defining these areas. Using this classification, Jahnke has calculated that 52% of Eastern Africa's 5.8 million km^2 is arid and 18% semi-arid. Large parts of the region (nearly 50% of the land area of Ethiopia, Somalia, and Tanzania and almost 100% of Uganda and Kenya) are dominated by a bimodal rainfall pattern. Other features of these areas are the unreliable rainfall pattern and the localized nature of rain-storms. In the absence of irrigation they are regarded as moderate to low potential areas that are having to carry increasingly heavy populations of man and animals. The dominant agricultural activities are rainfed crop production, including cereals, grain legumes and cash crops, and livestock production. In attempting to summarize some of the research programs and some of the research needs in these areas, the Bank's experience in agricultural development projects gives a useful perspective on the application of research results.

Livestock Production

Table 1 shows that the Bank has invested about $150 million in livestock production projects in the six countries concerned. Investment in livestock production in Africa grew at quite a fast rate until 1975; after that investment was directed more towards mixed crop/livestock projects.

In the earlier projects ranches were a major component but the involvement in this kind of project declined as other forms of investment increased. By and large World Bank experience, and that of other investment agencies, in livestock projects in the semi-arid areas of Africa, has not been encouraging. There are obviously many social and managerial reasons for this but the area of interest to the workshop, i.e. technical problems, is also worth a brief discussion here.

The early projects generally assumed that improved technology for increased production was already available and that production could be increased through improvement of management; investments were provided for this. It is worth noting too that ILCA was founded on rather similar assumptions; the mandate of the Centre, though not precluding component research, was for its research to focus on systems research so that a better understanding of livestock production systems could allow the application of known technology. However, the recent Quinquennial Review of the centre emphasized the need for more research on technical components of livestock systems. The point one should emphasize here is that the interaction between technical and socio-economic as well as political issues is particularly important in these areas.

In the lower rainfall areas (less than 600 mm) for example, control by burning, pasture rotation, legume production and adjustment of livestock stocking rates have been suggested as needing further research. Better knowledge of these as well as better information on how to apply that knowledge under practical ranching conditions and how to tailor it to specific social and political situations ('adaptive research') are needed.

There is obvious scope for more research on improving the nutrition of livestock in these areas. One interesting piece of research has been the work of ICIPE on grassland damage by termites. In dry conditions this was quite large and ICIPE's research was concerned with finding ways in which the population of termites could be reduced. Shortage of funding stopped this research but it is perhaps an area requiring re-examination.

As regards animal health there are, of course, the very intensive programs of ILRAD on theileriosis and trypanosomiasis, ICIPE's program on ticks, ICIPE and the Kenya Agricultural Research Institute (KARI) program also on theileriosis and ILCA's program on trypano-tolerance. One of the disconcerting features of livestock diseases is the recent resurgence of rinderpest (from about 1979) due to the breakdown of vaccination programs.

No attempt will be made here to discuss the priorities for research in livestock production. Obviously there are major health problems some of which are receiving a great deal of attention from national and international research. There would appear to be a need for more emphasis on epidemiology and economics of disease control. In livestock management there is a considerable amount of knowledge of the broad principles of what should be done. The gap seems to be how to get this applied in practice.

Crop Production

As population pressure increases, more and more of the semi-arid areas are subject to 'permanent' cropping. The major crops are sorghum, millet, some maize, and the legumes, pigeon pea, groundnut, and cowpea. Cassava may be grown in some areas as a 'hungry' crop, though it would be well outside its optimum zone. Breeding programs to improve the performance of these crops are a very important part of the international centres, particularly ICRISAT.

Virtually all of the national programs of this region are involved with the IARCs in cooperative programs and with programs of their own. These breeding programs are directed primarily at developing disease and pest resistance; in addition, ICIPE has a program on the 'basis of plant resistance' and on integrated pest management.

Vertebrate pests, particularly *Quelea* spp do much damage in the region and there are several projects conducting research on this problem. Lines of attack include destruction of the nesting sites, use of repellent chemicals on the grain, and breeding sorghum varieties that are less attractive. Although there are no details of economic losses due to birds it is generally believed that they are substantial and that control mechanisms would have a good pay off. This may be an area worth further examination.

Considerable progress is being made in pest and disease resistance in the cereals, in disease resistance in groundnuts, and resistance to pest attack in cowpea. Drought tolerance is also one of the research objectives for these areas. Progress is inevitably slow and there is the question of whether more strategic research on the physiology of drought tolerance would speed up the process of developing better drought tolerant varieties.

Soil and Moisture Management

Though population pressure in the semi-arid areas of this region is increasing, it is still well below that in similar ecological regions in India. Farmers in India have access to much more irrigation, including minor irrigation works, and make more use of animal drawn equipment. There is, of course, a considerable use of animal drawn equipment in parts of Eastern Africa but the presence of trypanosomiasis obviously limits it in some areas. As far as irrigation is concerned, Table 1 shows considerable investment in irrigation in this region but these are all major irrigation projects depending on either storage or major river diversions. Some attention is now being given to the use of groundwater and to minor irrigation schemes in West Africa. At Baringo in Kenya there is a pilot project on water harvesting and preliminary results show some promise. Conservation and use of surplus water is obviously a very important consideration in these areas and one that deserves further investigation.

There has been quite a lot of research on the effect of various land management systems on run-off and on methods of soil conservation. The former EAAFRO at Muguga had an intensive program in this field (Pereira et al 1962). Soil erosion is becoming increasingly destructive in several countries as both crop and livestock production intensify and large areas will probably have to go out of agricultural production if this continues. The principles of soil and moisture conservation are already well known. The question is how to implement these on a sufficiently wide scale to have a major impact. This includes the questions of motivation of farmers——how to demonstrate a benefit that is inter-farm and intergenerational, how to organize such projects, how to train adequate staff with sufficient basic knowledge to translate the principles into workable practical programs, and how to motivate governments to finance cush programs. There have been successful soil conservation programs in the countries of this region but farmers seem more and more reluctant to continue them.

There is a long history of research on management of soil fertility using fertilizers, farmyard manure and mulches. Much of the work has been in irrigated agriculture, on the major cash crops and in the better rainfall areas. Nevertheless there have been several series of trials in the drier areas, including a very long-term trial at Serere in Uganda (McWalter and Wimble 1976). If there are to be substantial increases in productivity in these drier areas then fertilizers, particularly phosphate and sulphur, and of course nitrogen in the absence of legumes, will be essential. However, the question of how best to incorporate fertilizer regimes into the farming systems and how to combine soil fertility management with livestock/cropping systems is one needing much more attention.

Agroforestry

An important feature of the drier areas is the scarcity of fuelwood for domestic fuel; families travel increasing distances to gather fuelwood and the area of deforestation around larger towns has greatly increased. The magnitude of the need is illustrated by the following calculations, made by the World Bank for hectares (millions) of fuelwood plantations required by the year 2000: Ethiopia 2, Somalia 0.2, Sudan 2.3, Kenya 1, Tanzania 1.2, Uganda 0.5. A number of social forestry projects to ameliorate this situation are being supported by the Bank. Some of these, e.g. the project in Gujarat in India, are proving very successful in that farmers are realizing the economic value of fuelwood and planting every available area. While there have been a few research components in forestry projects the Bank is now joining with UNDP to promote a collaborative project with the International Union of Forestry Research Organizations (IUFRO).

Eventually it is hoped that a series of 'twinning' arrangements will be set up whereby a forestry research institute in a developed country will join with one in a developing country to evolve longer-term research programs. This arrangement should allow the developing country organizations to capitalize on the skills and experience of the developed country research programs while at the same time giving some of the developing country institutions the opportunity to become 'centres of excellence' in the agroforestry field. Clearly there are good opportunities for research in the agroforestry field, considering how little attention it has received compared with commercial tree crops like rubber and oil palm. Improved multipurpose trees that would provide fuelwood, fodder, perhaps some edible components for human consumption, enhance soil fertility, and lead to soil conservation would be highly desirable.

Research/Extension Linkages

In irrigated or high rainfall areas simple packages like fertilizers or better seeds often make a very substantial impact. In the more arid areas the farmers will often have to apply a combination of practices, some of them quite complicated, if they are to to achieve substantial increases. Furthermore the farmer is always in a riskier situation and his exposure to risk varies greatly depending on his personal circumstances. Under these conditions the concept of a 'single' package, which all the farmers of an area would adopt, is not applicable. What is needed is a series of recommendations or options from which the farmer can select those that best suit his personal conditions.

Extension/research linkages are thus particularly important in these areas for it is a question not only of transferring the technology developed by the researcher by way of the extension agent to the farmer, but also one of keeping the researcher informed about the farmers' problems. Feedback from farmers should be used as the basis for modifying the extension messages and it should also be used to identify gaps and lead to re-orientation of the research programs. It is in this area also that farming systems research can make a vital contribution. Not only can it help to identify the farmers' priority problems but it can also help the researcher identify the kinds of technology that are most likely to be useful to the farmer.

Extension services have a lot to learn about how to advise farmers on maximizing their income from a series of very diverse enterprises, while at the same time preserving what are their most important needs, that of avoiding undue risk so that they will have enough food, for themselves and their families.

Concluding Remarks

No attempt has been made in this paper to cover the whole field of research priorities for the semi-arid areas. The few examples are based on the World Bank's experience with agricultural development projects and on experience with agricultural research in the region generally. However, it should be emphasized that the Bank's experience confirms that unless there is innovative technology there will be little hope for much progress in improving agriculture in the drier zones.

In this concluding section a few general remarks will be made about research strategies. The first point to be emphasized is the need for government to have clear ideas on their agricultural development strategies. If a government has no well-defined policy, or changes its policies frequently, obviously the research strategies and priorities cannot be kept in line and there will be little congruence in the agricultural development policies and the research strategies. Most governments have a series of agreed goals but there may be no clearly thought out strategies for the attainment of these goals, including the role of research. The question of government priority is a particularly important one for these areas of lower potential because governments quite rightly tend, from a short-term investment point of view, to emphasize research in the high potential areas. On the other hand increasing population pressure and the generally low productivity of these areas means a pressing need for improved conditions.

A second important aspect in determining research strategies and priorities is the need to recognize the limitations to research; much discussion about research fails to recognize what it can and cannot do. A good example of this are the problems encountered in rainfed farming. The importance of rainfed farming, especially in Africa, the lack of improved technology and the slow rate of improvement of productivity are recurring themes. One must agree that much needs to be done but the difficulties have to be recognized. Research in high potential areas for example, may present a series of relatively simple research problems with a high probability of successful solution and a likelihood of a large impact on production. In low potential rainfed agriculture, on the other hand, problems are generally much more difficult, the likelihood of a successful outcome more uncertain, and the impact on production is likely to be less. Furthermore such farmers are often poor and there is a demand therefore for simple, low cost solutions. However, such solutions usually demand high quality research applied to difficult problems.

The third point to be emphasized is the obvious one of analysing what has been done in the past, both in the countries concerned and elsewhere in similar ecological regions. Some of this research may have been irrelevant but this sometimes appears to be a convenient label for disregarding what has been done. In fact there is quite a solid base of good research in most countries of the region and this should be used in the design of future programs.

In conclusion it should be emphasized once more that the World Bank is a 'consumer' of research output in its investment program. It is prepared to try new technical and management ideas in pilot projects and from a poverty alleviation point of view, it gives high priority to the areas of lower potential.

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Agro-Research for Australia's Semi-Arid Tropics: Report of Darwin Symposium 1983

E.F. Henzell*

A symposium was held at Darwin, Australia on the subject of 'Agro-Research for Australia's Semi-Arid Tropics' during the week 21-25 March 1983. The symposium was sponsored by CSIRO, which is Australia's national research organization, and by the Government of the Northern Territory. There were about 185 registered participants.

This paper briefly describes the region in which the Symposium was held and the papers that were presented at it, and concludes with some comments on the Symposium's objectives.

North-West Australia

The Symposium dealt with the region lying to the north of latitude 19° S in the State of Western Australia and in the Northern Territory (Figure 1). Since 1978 the Northern Territory has exercised many of the functions of a State in the Australian federation, including those relating to agricultural research, extension, and regulation.

About 69% of Australia's land is too dry to permit cropping or pasture improvement (Nix 1979). The land that has sufficient rainfall for agricultural development is located in the coastal parts of the south-west, south-east, east and north of the continent. The least developed of it is in the north-west and in Cape York Peninsula, Queensland.

The physical environment of north-west (NW) Australia can be summarized as follows:

1. No part of the region exceeds 1 000 m above sea level, but most of it is very hilly.
2. While the north-west comprises only 8% of the continental area, it has 23% of

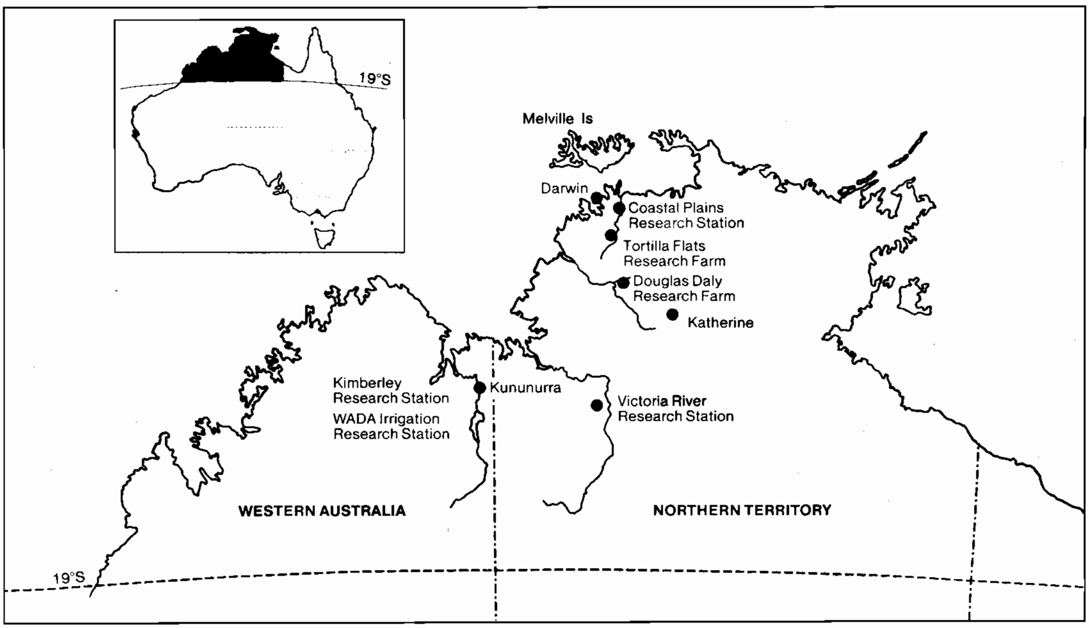

Figure 1. Map of north-west Australia.

* Chief, Division of Tropical Crops and Pastures, CSIRO, St. Lucia, Queensland, Australia.

Australia's average river runoff, allowing the possibility of developing significant areas of irrigated agriculture.

3. The dominant vegetation over most of the region is open forest or woodland, with an understorey of grasses; the size and proportion of trees and shrubs decreases with rainfall.
4. There are also important areas of native grasslands and sedgelands on the clay soils of the subcoastal plains and of native grasslands on the much-drier inland clay soil plains.
5. The rainfall is strongly seasonal (December-March), variable by world standards, and decreases from over 1 600 mm per annum at Darwin to less than 500 mm in the south.
6. Because the region has a high proportion of shallow, stony soils and of sandy soils with high contents of gravel, it has very limited areas of land with good potential for cropping.
7. Those soils with good cropping potential are almost universally deficient in nitrogen and phosphorus.

Some additional information about the climatic and soil constraints of the region is given by McCown, Jones, and Hammer (1983).

Agricultural industry to date in NW Australia has been based on extensive pastoralism. Cattle grazing on the native grasslands are gathered together, trucked to slaughterhouses (or interstate for fattening and slaughter) and the meat is exported. Some meat is obtained for export also from undomesticated Asian water buffaloes grazing on the subcoastal plains and adjoining grassy woodlands. A limited number of cattle and water buffaloes are exported alive.

Cultivated agriculture has been attempted often in NW Australia, but has not succeeded yet on any substantial scale.

The chief reason why agricultural research has been carried out in NW Australia is as an aid to rural settlement there, which has been given a high political priority by Australia since World War II.

Only about 2% of Australia's agricultural research scientists are currently working in the north-west of the country. Most of Australia's research on subtropical and tropical agriculture has been carried out in the north-eastern state of Queensland, but the main focus of the Symposium was on the research carried out in NW Australia.

The main experimental sites in NW Australia are shown in Figure 1. In Western Australia, most of the research has been done in the Ord River Irrigation Area, at the Kimberley Research Station, and at the Western Australian Department of Agriculture's Research Station, both near Kununurra. In the Northern Territory, most of CSIROs agricultural research has been carried out near Katherine (in the 1960s CSIRO worked at the Coastal Plains Research Station also), while the Northern Territory's Department of Primary Production has worked on its stations and farms at Berrimah (Darwin), Coastal Plains, Tortilla Flats, Douglas-Daly, Katherine (formerly), and Victoria River.

Symposium Papers

Table 1 lists the 27 papers that were presented at the Symposium. The institutional affiliation of the authors, counting one for each authorship or joint authorship, were: Australian universities 5, CSIRO 31, Northern Territory Department of Primary Production 18, Western Australian Department of Agriculture 10, overseas Centres 4, and other Australian institutions 4.

Briefly, the papers covered the following topics:

Section 1. Setting the Scene

The keynote address was delivered by Sir John Crawford, who is Chairman of the Board and President of the Policy Advisory Council of the Australian Centre for International Agricultural Research (ACIAR). He dealt broadly with the role of research in agricultural development and stressed the importance of infrastructural support and marketing mechanisms. The second paper was a brief history of agriculture in NW Australia that described, in an interesting and informative way, Australia's struggles to develop this very under-developed tropical region.

Section 2. Constraints to Agricultural Development

The paper on climate and soils brought out that the semi-arid tropics (SAT) of NW Australia appear to have shorter wet seasons than in the SAT of India or West Africa. The dominant soils in the Australian SAT apparently have more in common with those of north-east Brazil and perhaps Sahelian Africa than they do with those of India.

The paper on vegetation and fauna drew attention to the low nutritional quality and resilience of the savanna grasslands of NW Australia for beef production and concluded that the spectrum of biological constraints to agriculture is similar throughout the world's SAT.

Section 3. The Quest for Profitable Crops and Pasture Plants

Brief comments on each paper are:

1. Maize and sorghum——both show promise for rainfed cropping in the region and there is growing interest in their comparative climatic responses.
2. Grain legumes and oilseeds——21 kinds of crops have been researched; recently soybeans and mung beans have shown considerable promise.
3. Fibre crops——cotton was grown commercially in the Ord River Irrigation Area, which has similar soils and climate to the Gezira, from 1964-74 and abandoned then because of economic and insect control problems. Irrigated kenaf has shown promise experimentally as a source of paper pulp.

Table 1. Papers presented to the Symposium on 'Agro-Research for Australia's Semi-Arid Tropics'.

Section 1: Setting the Scene

Keynote address: The process of agricultural development and the role of agricultural research. Sir John Crawford.
A brief history of agriculture in north-west Australia. F.H. Bauer.

Section 2: Constraints to Agricultural Development

Soils and climate. J. Williams, K.J. Day, R.F. Isbell, and S.J. Reddi.
Vegetation and fauna. M.H. Andrew, P.N. Gowland, J.A. Holt, J.J. Mott, and G.R. Strickland.

Section 3: The Quest for Profitable Crops and Pasture Plants

Maize and sorghum. A.A. Done, R.C. Muchow, J.D. Warren, and I.I. Kernot.
Grain legume and oilseed crops. A.L. Garside, D.F. Breech, and P.S. Putland.
Fibre crops. I.M. Wood and A.B. Hearn.
Forest crops. D.M. Cameron.
Sugar cane. W.J. Cox and A.L. Chapman.
Horticultural crops. P.B. Scholefield and K.H. Blackburn.
Rice. A.L. Chapman, N.R. Dasari, R.J. Delane, and B.A. Mayers.
Improved pasture plants. W.H. Winter, A.G. Cameron, R. Reid, T.G. Stockwell, and M.C. Page.

Section 4. Research for Improved Crop Management

Soil surface management. R. Lal.
Weeds. D.C.I. Peake, M.C. Fulton, and P.S. Putland.
Insects. A.J. Allwood, G.R. Strickland, S.E. Learmonth, and J.P. Evenson.
Diseases. J.A.G. Irwin, G.J. Persley, B.C. Conde, and R.N. Pitkethley.
Irrigation. R.C. Muchow and D.F. Yule.
Fertilizers. R.K. Jones, R.J.K. Myers, G.C. Wright, K.J. Day, and B.A. Mayers.

Section 5. Some Agricultural Systems

Intensification of beef production. W.H. Winter, T.H. McCosker, D. Pratchett, and J.D.A. Austin.
Nature as a model. M.G. Ridpath, J.A. Taylor, and D.G. Tulloch.
The prospects for intercropping. R.W. Willey.
Evaluation of a no-till, tropical legume ley-farming strategy. R.G. McCown, R.K. Jones, and D.C.I. Peake.

Section 6. The Contribution of Research to the Design of Two Agricultural Projects and their Subsequent Development

The Ord River Irrigation Scheme. G.A. Robertson and A.L. Chapman.
The Agricultural Development Marketing Authority Scheme in the Northern Territory. B.J. Cameron and A.D.L. Hooper.

Section 7. Improving the Efficiency of Research for Agricultural Development

The farming systems approach. J.L. Dillon and S.M. Virmani.
Methods for coping with variation in climate and soils. H.A. Nix.
Organizing agricultural research in north-west Australia. E.F. Henzell.

4. Forestry——*Pinus caribaea* var. *hondurensis* has proved suitable for planting on Melville Island (Figure 1).
5. Sugar cane——an irrigated pilot farm based on Queensland technology has obtained yields in the Ord River Irrigation Area that compare favourably with those obtainable in north Queensland.
6. Horticultural crops——the fruits and vegetables most likely to be produced commercially are those that can be sold during seasonal shortages in southern Australia and south-east Asia.
7. Rice——35 years of research on irrigated rice have achieved very substantial increases in experimental and farm yields.
8. Improved pasture plants—a wide range of introduced grasses and legumes has been tested in the region and there is a useful short list of well adapted species and cultivars.

Section 4. Research for Improved Crop Management

The first paper in this section was an authoritative review of research on soil surface management in the SAT by Dr. Rattan Lal of IITA. The next four on weeds, insects, plant diseases, and irrigation brought out very clearly that good management based on sound knowledge of biology, ecology, and soil science is essential for sustainable crop production in the SAT. The paper on fertilizers gave particular emphasis to the two most important nutrients for cropping in NW Australia, namely nitrogen and phosphorus.

Section 5. Some Agricultural Systems

Beef production in NW Australia to date has been based on native grasslands that have suffered severe localized degradation because of overgrazing. The first paper in this section described the options for more effective management of the native grasslands and dealt also with the prospects for intensification through pasture improvement and feeding of minerals. The second paper, by three wildlife scientists, contained the challenging sentence: 'Expectations from agriculture in the tropics are still too often based on misleading assumptions from temperate experience'.

Then Dr. R.W. Willey of ICRISAT reviewed the possible advantages of intercropping in the SAT and suggested some research priorities for northern Australia. The final paper in this section, by Drs. Jones and McCown, dealt with research on a no-till, tropical legume ley-farming strategy for the very erodible soils of northern Australia (Jones and McCown 1983).

Section 6. The Contribution of Research to the Design of Two Agricultural Projects and their Subsequent Development

These two papers examined two governmentally-supported agricultural development schemes in NW Australia. Amongst the points that emerged were the importance of political pressures in the selection of research priorities and the difficulties of conducting relevant research in the absence of an established farm sector.

Section 7. Improving the Efficiency of Research for Agricultural Development

Professor J.L. Dillon has played a leading role in developing the multidisciplinary farming systems approach as a basis for agricultural research, extension, and development. The paper by Dillon and Virmani, of ICRISAT, was a well-structured account of the basic concepts in farming systems approach.

The next paper was presented by H.A. Nix who has been an innovator in developing strategies for agricultural research and development that can provide both general solutions to cropping problems and location-specific prescriptions for development. The paper outlined his approach, which centres on the balanced development of production systems models and resource data bases. Finally, my paper attempted to pull together the implications of the whole Symposium for the future organization of agricultural research in NW Australia.

All these papers, plus a summary of a discussion on 'The Transfer of Agricultural Technology between the Semi-arid Tropics of Australia and the Developing World', which was held during an evening session of the Symposium, have been edited by Dr. R.C. Muchow and will be published by the University of Queensland Press in 1984. The title of the book will be 'Agro-Research for the Semi-Arid Tropics: North-West Australia'.

Objectives

The organizers of the Symposium had three main objectives in mind. First, by taking stock of existing knowledge it was hoped to achieve a clearer understanding of the problems to be overcome in the quest for development of NW Australia. Second, by noting past mistakes and omissions, it was hoped to improve the future efficiency of research. Third, the Symposium was intended to encourage a small group of agricultural scientists working in this remote region to see themselves not in isolation, but as part of a worldwide community struggling to overcome the problems of agricultural development in the SAT.

Despite fundamental differences in socioeconomic conditions between NW Australia and other parts of the world's SAT, they share many common features of climate, soils, and plants that are significant in disciplinary and commodity research.

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Report on a Tour of Agricultural Research Facilities and a Symposium in Australia

J.J. Ondieki*

At the invitation of the Australian Centre for International Agricultural Research (ACIAR), I participated in a tour of Australian agricultural research facilities and also attended in Darwin, a symposium on Agro-Research for Australia's Semi-Arid Tropics. The main objective of the tour was to observe Australia's research capacity in agricultural sciences and related disciplines that may be of relevance to the agricultural research needs of developing countries in Africa. Also, informal discussions were held with research scientists on research problems of interest to these countries.

Other participants in the tour, which extended from March 7-23, 1983 were one each from Nigeria and Zimbabwe.

Tour of Queensland

The three participants arrived in Sydney on March 7, 1983 and were met by Dr. D.C. Blight of ACIAR. The following day the party flew to Brisbane in Queensland. Arrangements were made for the group to hold discussions with officials and research staff of the Queensland Department of Primary Industries, and to visit research laboratories and field stations. The research laboratories of the Division of Tropical Crops and Pastures of the Commonwealth Scientific and Industrial Research Organization (CSIRO) at Brisbane and Townsville, and the research farm of the University of Queensland at Brisbane were visited.

In Queensland, the participants were exposed to first-hand information and experience on tropical and subtropical farming in Australia. Very useful consultations were held, and the visits to the research laboratories and stations confirmed the high standards and capabilities of Australian institutions in tackling problems related to tropical and subtropical agriculture. Similarities that were observed between Kenya and Queensland agriculture are the predominance of semi-arid conditions and the range of crops and pastures. A difference in the agriculture of the two countries is that Australian agriculture is highly mechanized whereas Kenyan is not.

The Darwin Symposium—Agro-Research for Australia's Semi-Arid Tropics

From Queensland, the party flew to Darwin in the Northern Territory to join the pre-symposium tour. Two days were spent in the Katherine District observing field research activities of the CSIRO Division of Tropical Crops and Pastures at the Katherine Research Station. These covered trials on cattle grazing, pasture establishment, ley farming, zero tillage, and intercropping experiments; and visits to the Department of Primary Production crop experiments and to private large-scale farmers.

A visit was also made to the Douglas-Daly River Basin to see a settlement project in newly cleared land being undertaken by the Northern Territory Agricultural Development and Marketing Authority. New settlers are settled on land tracts of over 6 000 ha each and all facilities are provided, except farm machinery. Cropping patterns, soil conservation measures, handling, and marketing problems were discussed.

The Darwin Symposium was attended by nearly 200 participants from within and outside Australia. Its purpose was to examine the research needs of tropical northern Australia and to assess past research and development efforts. In view of the international attendance at the Symposium, a forum was created for discussion on the relevance of research in other countries to northern Australia and vice versa.

Very interesting and informative papers were presented. The keynote address dwelt on the

* Chief Research Officer, Scientific Research Division, Ministry of Agriculture, Nairobi, Kenya.

process of agricultural development and the role of agricultural research. This was followed by a brief history of agriculture in NW Australia. The technical content of papers dealt with constraints to agricultural development; the search for profitable crops and pasture plants; research for improved crop management; and some agricultural systems including intercropping, zero-tillage and tropical legume ley-farming strategies. Other topics discussed were the contribution of research to agricultural projects development in northern Australia and the role of the farming systems approach in improving research efficiency for agricultural development. During an evening session, an international forum discussion was held to explain the roles and functions of ACIAR and the international agricultural research system of the Consultative Group on International Agricultural Research (CGIAR).

The Symposium was considered to be a great success by the overseas participants as it showed the tremendous progress made by the Australian researchers in the development of tropical crops and pastures. There was willingness from the Australian scientists to share their knowledge and experience with fellow scientists from the developing nations.

Acknowledgements

The tour of Australia was made possible through the generosity of ACIAR, and I am most grateful to all the institutions visited and to the people whom we met for the many useful discussions that were held. My thanks also go to the Ministry of Agriculture, Kenya for making it possible for me to undertake the tour.

Agriculture in Australia's Seasonally-Dry Tropics and Subtropics: Climatic and Soil Constraints

R.L. McCown, R.K. Jones, and G.L. Hammer*

In this workshop we want to examine agriculture in Eastern Africa and agriculture in Australia to see what benefits there might be to a closer linkage of our agricultural research and technology development activities. The broad aim of this paper is to describe the physical environment of agriculture in Australia and to draw some comparisons with that of agriculture in Eastern Africa to 'set the stage' for subsequent papers and discussions. The scope of coverage in this paper is set by the workshop's focus on those regions of Eastern Africa where crops are grown, but where productivity is constrained by insufficient rainfall; the paper reviews those aspects of climate and soils that most strongly determine the character and productivity of Australian agriculture in the climatic zones which are most comparable to those in Eastern Africa.

Figure 1 shows the area and latitudinal distribution of land in Australia relative to Africa. Southern Australia has a Mediterranean climate. Most of Australia between latitudes 30° and 20° S is desert, not unlike the Sahara. Northern Australia has a tropical climate that is similar to Africa's Guinea and Sudanian zones but also to the coastal and subcoastal areas of Eastern Africa (Papadakas 1975) (Figs. 2, 3). Australia's subtropics are similar to areas of Mozambique and Botswana (Papadakas 1975; Russell and Moore 1976) (Figs. 2, 3). Climates in Australia that most closely resemble those of the midlands of Africa (1 000-1 500 m elev.) occur only in two very small areas, but neither exceed 1 000 m (Papadakas 1975) (Figs. 2, 3). Although they are not homologous, comparisons between the crop climates of the African tropical midlands and the Australian subtropics may be useful.

* Division of Tropical Crops and Pastures, CSIRO, Aitkenvale, (Townsville), Queensland; Division of Tropical Crops and Pastures, CSIRO, St.Lucia, Queensland; and Queensland Department of Primary Industries, Brisbane, Queensland, respectively.

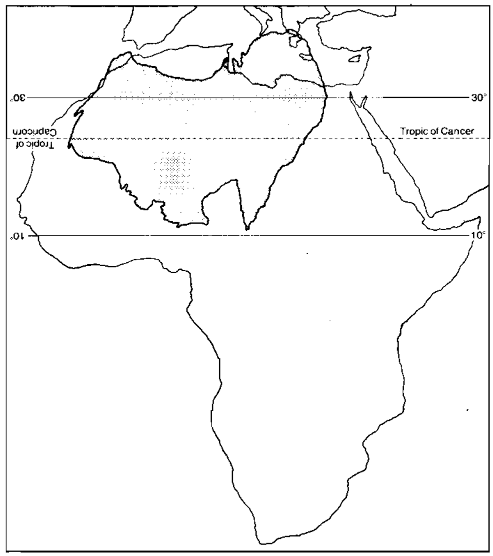

Figure 1. Australia, showing comparative area and latitudinal position with northern Africa.

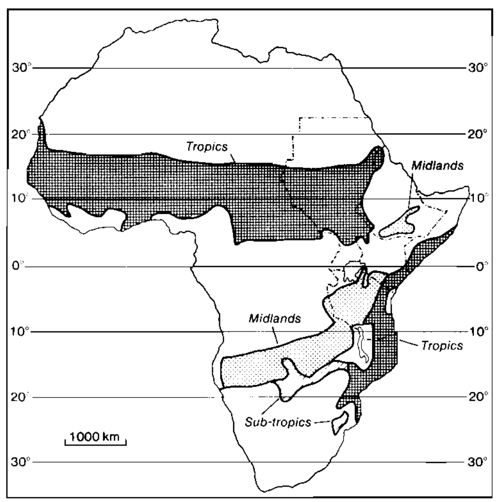

Figure 2. General distribution of seasonally dry tropical and subtropical climates in Africa suitable for agriculture.

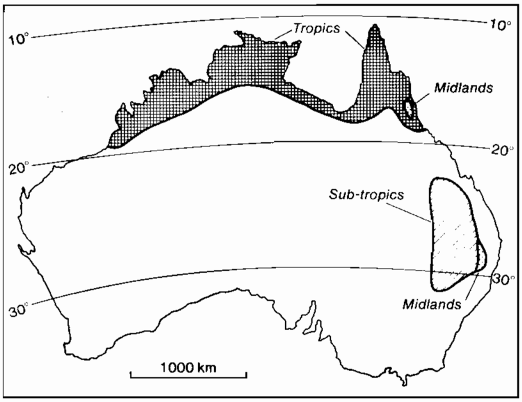

Figure 3. *General distribution of seasonally-dry tropical and subtropical climates in Australia suitable for agriculture.*

Figure 4 shows the distribution of existing and potential cropland in the semi-arid zone which rings the great Australian desert. Agricultural development began in the temperate south-east and spread north into the subtropics where it is still expanding. Sustained development has yet to begin in the far northern tropics, although agricultural resource assessment and research has been conducted here for nearly forty years.

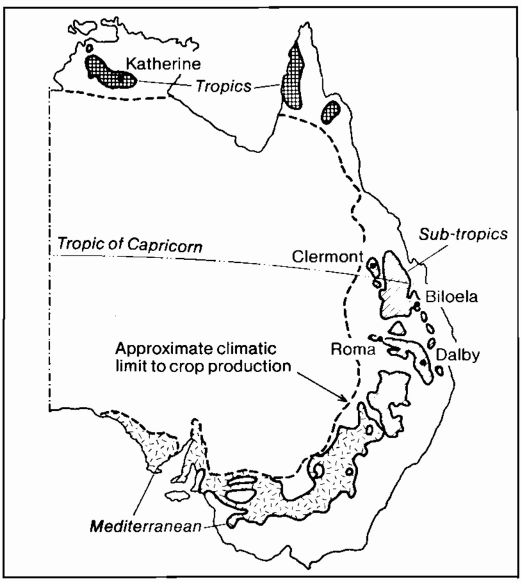

Figure 4. *Land under crops or, in the case of the tropics, with the potential for dryland cropping.*

Of the land in the far north that has a suitable climate for cropping, a large proportion has unsuitable terrain or soils (Nix 1979; Williams et al. 1983). Thus most land in this zone is destined to continue to be used for beef cattle grazing, although possibly with important linkages to new crop areas.

The Subtropical Environment in Australia

Climate

All along the east coast, the wettest zone is on the coast, with rainfall decreasing and potential evaporation increasing with distance inland. The subtropical dryland cropping belt lies between the 750 and 500 mm isohyets of effective rainfall (total rainfall minus runoff) (Fig. 5). Mean annual Class A pan evaporation varies between 1 400 mm in the east to 2 100 mm in the west. Rainfall has a summer maximum throughout the region with a slight second mode in winter in the south (Figs. 6, 7).

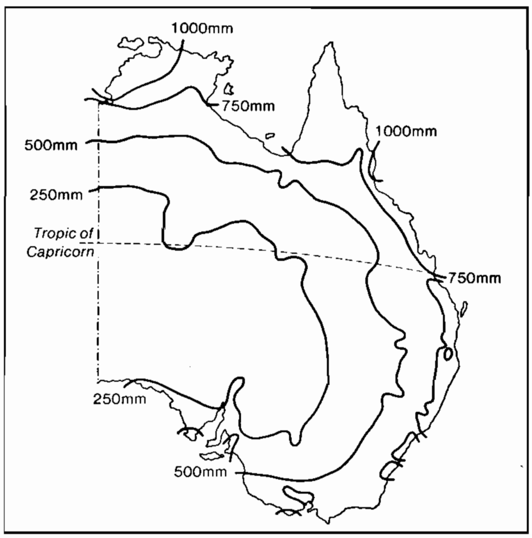

Figure 5. *Map of isohyets for 'mean effective rainfall' (rain minus runoff). (From Warner 1978).*

There is a marked seasonal variation in temperature with a difference of about 12°C between summer and winter monthly maxima and about 15°C between summer and winter minima (Figs.

6, 7). (This contrasts with the weak thermal seasonality of the highland areas of Eastern Africa, with only about 5°C fluctuations). Frosts occur throughout the region, but with risks much lower in the north (Figs. 6, 7).

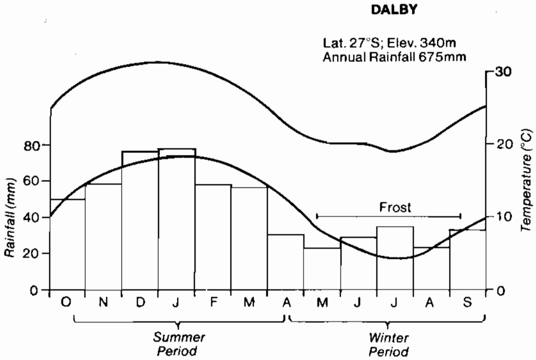

Figure 6. Median monthly rainfall, average monthly maximum and minimum temperatures, and 80% frost duration for Dalby.

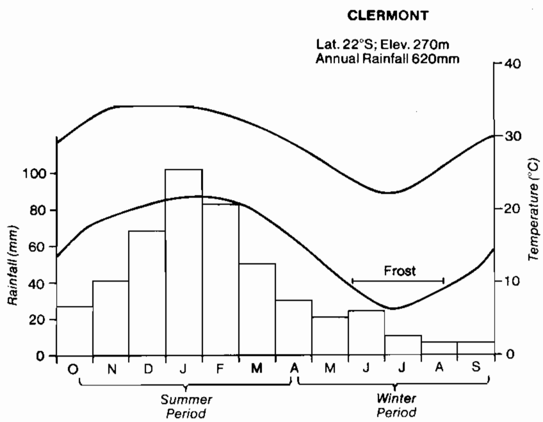

Figure 7. Median monthly rainfall, average monthly maximum and minimum temperatures, and 80% frost duration for Clermont.

Although both winter and summer crops are grown, they are rarely grown consecutively on a given field. Rather, the other season preceding cropping serves to accumulate water under a bare fallow. Wheat, grown in winter, follows summer fallow; a summer crop, e.g. sorghum, maize or sunflower follows a winter fallow.

Judging from the rainfall histogram for Dalby, it appears that the summer season has the better water supply (Fig. 6). When seasonal variation in potential evaporation is superimposed (Fig. 8), the resulting pattern of soil water availability is strikingly different from that of rainfall, and the winter season emerges as the more mesic (Fig. 8).

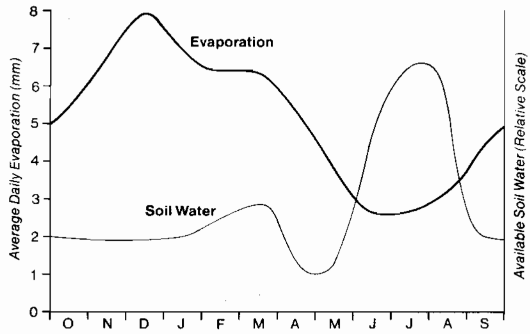

Figure 8. Seasonal trends in daily Class A pan evaporation and in available soil water at Dalby. (From Weston et al. 1975).

An appreciation of the seasonal patterns of water supply and temperature in relation to a wheat crop can be obtained from Fig. 9 (Adapted from Nix 1975). Soil water is recharged under bare fallow from January until sowing, shown in Fig. 9 as occurring on June 1st. Recharge continues up to floral initiation when both temperature and leaf area rise rapidly causing an exponential rise in potential evapotranspiration. Water supply from this time on is increasingly provided from the water store. On average, water deficiencies (Et > Ea) develop around anthesis and intensify with time thereafter.

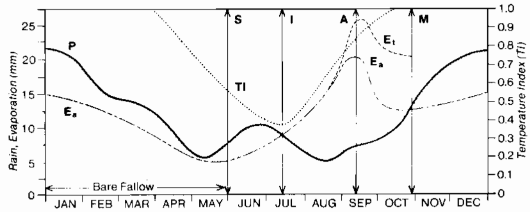

Figure 9. The seasonal pattern of environment and development of a wheat crop at Dalby. (rainfall (P), potential evaporation (E_t), actual evaporation (E_a), temperature index (TI), sowing (S), floral initiation (I), anthesis (A) and maturity (M)). From Nix 1975).

The starting point in management is the optimization of date of anthesis with respect to frost risk on the one hand and soil water depletion on the other (Nix 1975). If anthesis occurs before the last frost, yields suffer. However, even more serious losses may result if anthesis occurs too far into the terminal drying period. Woodruff and Tonks (1983) found that, in the absence of frost, highest yields resulted when anthesis occured in mid-winter, with a steep yield decline with later anthesis. They concluded that, except where frost risks are high, it may be preferable to risk the frost than the water stress.

In the case of summer crops, avoidance of frost, both in early stages of growth, and during reproduction are considerations in species and cultivar selection for a given planting opportunity, i.e. suitable moisture conditions. Frost incidence and severity varies greatly within the region, both latitudinally and locally. Indication of the duration of the frost prone periods in the south (Dalby) and in the north (Emerald) is given in Figs. 6, 7. Hammer and Rosenthal (1978) provide detailed probabilities for these plus three other representative stations in this region.

Even after selection of the most appropriate cultivar and planting date, there remains a substantial risk in any given year that the weather needs and tolerances of the crop will not be adequately met. By far the most important uncertainties are (a) the timing of planting rains and (b) adequate water supply to finish the crop. In very broad terms, about 15-25 mm of rain is needed to plant a winter crop and 50-100 mm for a summer crop (Berndt and White 1976; Hammer et al. 1983). Not only is there a risk that planting rains will be late (or will not occur), but that rain will be excessive, resulting in delayed planting due to un-trafficability of the poorly drained heavy clay soils. Late planting increases the risk of high temperatures and/or severe water deficits following anthesis (Fig. 9).

Rainfall amount varies greatly from year to year. The coefficient of variability (CV) of winter crop period rainfall varies from 40% in the south-east to 60% in the north of the region (Nix 1975). Monthly rainfall for the past three years for Dalby illustrates the degree of departure from the average pattern (Fig. 10). Addition of the soil water carried over from the bare fallow damps the variability in water supply to a CV of 30% in the south-east and 40% in the north.

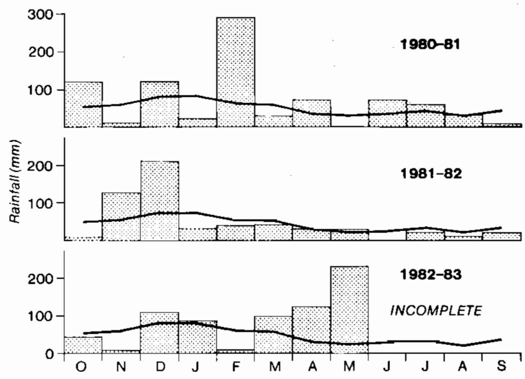

Figure 10. Monthly rainfall over three years compared with the long-term median at Dalby.

In order to quantify year-to-year variation in wheat yields, Hammer et al. (1983) simulated the yields for a number of stations using 92 years of weather records. Cumulative frequency distributions of simulated yields for Dalby and the drier, more inland, station of Roma are shown in Fig. 11. Increased marginality resulted in lesser yields and greater frequency of very low yields, but no apparent change in variablility. The curves are very flat over a wide yield range, indicating more or less equal propabilities of different yields within this large range.

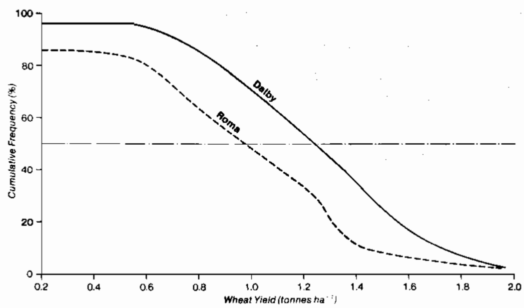

Figure 11. Cumulative frequency distribution of simulated wheat yields at Dalby and Roma for 92 years (from Hammer et al. 1983).

Berndt and White (1976) carried the simulation further to include economic returns. While the chances of losing money on a wheat crop at Dalby are 1 in 8, the chances at Roma are about 1 in 3. The summer crop is at a higher risk at both locations, such that negative income is predicted 1 in 3 years at Dalby, and 2 in 3 years at Roma.

Soils

Throughout the region, crops are grown almost exclusively on cracking clay soils. These occur typically on rolling plains, are neutral to strongly alkaline, calcareous, and moderately saline at depth. These soils appear on the World Soil Map as Vertisols, and in the Handbook of Australian Soils as black earths and grey, brown and red clays (Stace et al. 1968).

The most important feature of these soils as regards agriculture to date is their high natural fertility. It is this resource that has been, and for the most part continues to be, the back bone of agriculture in this region. In general, all of these soils are naturally high in nitrogen and some are also high in phosphorus. Rates of fertilization are gradually increasing in this region due both to expansion onto inherently less fertile soils and to the decline in fertility in the older cropping areas.

As indicated earlier, physical properties of these soils exert an important influence on farmer practices and on crop yields. Because of their high clay content and well developed structure, the plant available water range tends to be high (Williams 1983). Except where soils are shallow, this makes possible the storage of large quantities of water. During re-wetting, water enters initially via large cracks, but once these close, permeability is very low. This results in large volumes of runoff during heavy rain, slow recharge of the water store, and prolonged wet conditions following rain. The high runoff contributes to large soil erosion losses (see below); slow drainage following rain delays operations, e.g. tillage, planting etc.

By far the most important soil problem is the rate at which soil is being eroded by water under this agricultural system, which keeps soil cultivated and without cover during the main rainy period. In the southern part of the region, gullying losses of 75-200 t ha^{-1} from bare-fallow during heavy rain events have been reported (Anon. 1978). Losses on similar, but generally shallower, soils in the northern part of the region were estimated at 400 t ha^{-1} (Anon. 1978). The severity of the problem comes into sharper focus when these losses are compared with the 12.5 t ha^{-1} yr^{-1} considered to be the 'tolerable' soil loss rate in the wheat belt of south-eastern Australia (Anon. 1980).

The prospect of continued losses at these rates raises the question of how long agriculture can remain viable. Estimates made by Cummins et al. (1973), using loss rates considerably more conservative than those cited above, indicate a lifetime of only 10-50 years on shallow soils under existing land use practices (Table 1).

Table 1. Estimated erosion losses and production life expectancies for some Darling Downs soils under a range of slope conditions. (Data from Cummins et al. 1973.)

Soil	Slope %	From bare fallow t/ha/yr	From crop[a] t/ha/yr	Est. life expectancy of agriculture under existing land use (yr)
Shallow black	1-3	63	32	50
earth	3-5	98	49	30
(10-30 cm)	5-8	126	63	10
Medium black	1-3	62	30	130
earth	3-5	96	40	100
(40-90 cm)	5-8	126	52	40
Deep black	1-3	76	31	320
earth	3-5	118	48	210
(120-200 cm)	5-8	269	110	90

a. Average management, stubble incorporated.

The Tropical Environment in Australia

Climate

In the north, rainfall declines and potential evaporation increases with distance from the coast (Fig. 5). Katherine, although in the drier end of the region, serves to illustrate the main climatic features of the region (Fig. 12). Rainfall is strongly summer dominant; in many years no rainfall occurs between May and October. Because rain spoils dry legume herbage, the high probability of rainless dry seasons is important to the nutrition of cattle grazing legume pastures (McCown et al. 1981). However, crop production depends entirely on summer rainfall. Because rainfall in October and November is extremely unreliable it is prudent to delay planting until mid-December, and then to plant only with the additional safeguard of 50 mm of stored soil moisture. Crop water supply is generally reliable until late March, although there is a substantial risk of water stress sometime in this period. Crops of maize or sorghum generally mature after rain ceases, using stored soil water.

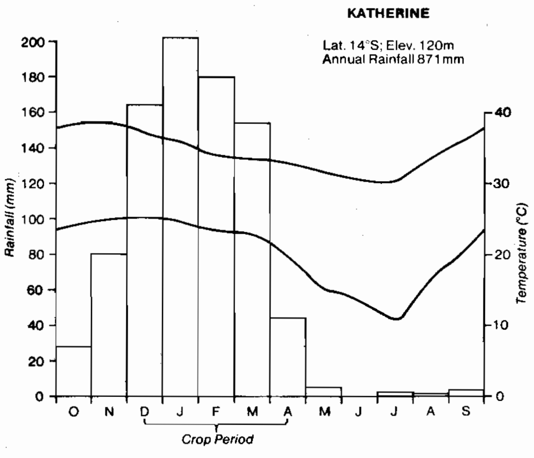

Figure 12. Mean monthly rainfalls, maximum temperatures, and minimum temperatures at Katherine, N.T.

There are two critical periods in the life of a crop in this environment. The first is between planting and seedling establishment. In this environment, final yield is more closely dependent on achieving a good stand than in a temperate environment, which allows more compensations in inflorescence densities via tillering. Good emergence is jeopardized by a dry soil surface in this period, resulting in impairment of emergence by either high soil temperatures or strong surface seals. Although soil physical properties are important variables, no problem occurs as long as the soil surface is moist during this period.

The second critical period is during anthesis and grain filling. This period, in which the crop is particularly sensitive to water stress, occurs in March and April as the reliability of rainfall is rapidly declining (Fig. 12). Premature terminal soil water depletion is a major cause of low yield in the southern part of the region.

The annual variability of rainfall for the region (Katherine = 21%) is low by Australian standards, but higher than most tropical regions receiving similar rainfall amounts (Williams et al. 1983).

Risks of drought-caused crop failure or low yields are not as yet well defined. Williams et al. (1983) estimated a low yield 1 year in 3, but the results of McCown (1982) suggest that 1 in 5 is more realistic. More work is needed to better define this risk.

Soils

Those that have been found to be most suitable for cultivation are the red earths (Stace et al. 1968) which correlate with the Ferric Luvisols and Ferric Acrisols on the FAO World Soil Map. These soils are free draining, have generally sandy or loamy surface textures, are generally deep, and often contain ironstone nodules in the lower B horizons. They generally have low contents of soluble salts, organic carbon, nitrogen, phosphorus, sulfur, and exchangeable basic cations. Following cultivation, clods are prone to slake with heavy rain and form seals or caps upon drying (Arndt 1965 a,b).

Profitable crop production on these soils requires substantial inputs of fertilizer. On the loamy soils, a maize crop needs 50-100 kg N ha^{-1} and 10-20 kg P ha^{-1}. On the sandy soils more N is required. Where a crop follows a legume pasture, much less N is required (Jones and McCown 1983). Phosphorus fixing by these soils is low (Jones et al. 1983).

Sulfur and zinc have been shown to be deficient on many of these soils. Where needed these elements are generally applied in a zinc-fortified single superphosphate.

Within this group of soils the most important differences in cropping use relate to differences in texture, which ranges from sand to clay loam. Soils at the heavier end of the range (loams) have properties that make tillage difficult. Dry soil has brick-like strength and abrasiveness that are strong deterrents to ploughing when dry. Under conditions wetter than field capacity, these soils are sticky. Soil at, or below, field capacity compacts readily under pressure with drastic loss in water permeability; this compacted soil forms strong surface seals that seriously impede seedling emergence (Arndt 1965a).

The sandy soils are much easier to cultivate. They can be worked when either very wet or dry. Strong seals are not a problem, although surfaces exposed to raindrop impact form thin seals which reduce infiltration.

A major problem on sandy soils is the extremely high temperatures that result as the soil surface dries. Under conditions of favourable soil moisture at seed depth, temperatures of over 65°C at 1 cm have been recorded on a sandy soil near Katherine. Such temperatures are lethal to seedlings and under such conditions emergence is very poor (Jones and McCown 1983).

A major difference related to texture is the more stable nitrogen balance on the loams. Wetselaar (1967) reported more rapid mineralization on the sands as well as a greater proportion of soluble N leached below the root zone (Wetselaar 1962). Jones and McCown (1983) have found the nitrogen contribution of a high yielding legume forage crop to a succeeding cereal crop, to be much less in the sand than in the clay loam.

Under a conventional cultivation system, the rates of soil erosion on the sandy soils have proved to be much higher than on the heavier soils. At present, legislation prevents the clearing and development of the sandier areas in this region of the Northern Territory. At the same time the search for a safe way to farm these soils is a high research priority because they occupy such a large fraction of the otherwise potentially arable area. Soil erosion on the heavier soils under cultivation appears less dramatic because there is less gullying, but surface soil is nevertheless being lost at an intolerable rate if agriculture is to be permanent. Cropping areas in which surface drainage is directed through sink holes to underground streams in the local limestone karst experience increasing frequency and duration of flooding back from sink holes, apparently from silting of the system.

The Northern Territory government is at present conducting a re-evaluation of dryland crop production on a carefully designed and monitored scheme of pilot farms. From the outset it was recognized that adequate soil conservation measures must be included, and farm development includes a terrace bank system designed according to widely accepted engineering codes. After several years, it is becoming clear that the costs of constructing such systems to even minimal standards are too high in relation to farm income to be economically feasible in an extended development scheme. In addition, there is an increased awareness of the physical and biological inadequacies of this approach. Attention now is turning to soil surface management strategies that may reduce the need for expensive structures and provide protective cover to soil so beneficial in this climate.

Comparisons of Northern Australia and Eastern Africa

Climate

Within the dryland agricultural areas of Eastern Africa where rainfall in an important constraint, climates vary both in relation to latitude and altitude. At the higher altitudes and close to the equator, e.g. Machakos, Kenya, rainfall is stongly bi-modal and temperatures are cool all year (Fig. 13). The most comparable climate to this in Australia is that represented by Dalby (Fig. 6). Here also there are two growing seasons, both dictated by rainfall distribution. However, summers are hotter and winters much colder than the frost-free equatorial highlands below about 1 800 m. In both places there is a high risk of water shortages for crops in both seasons. In Australia bare fallow is used to reduce this risk, but the price paid is a lowered intensity of land utilization and a high risk of soil erosion. In both places the climate is favourable for animal production on perennial pastures, since prolonged dry seasons are rare.

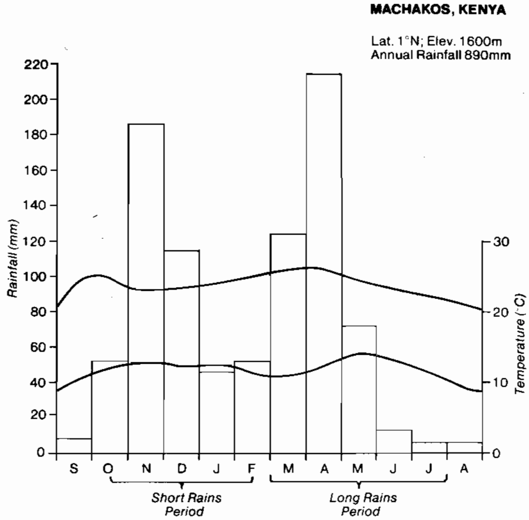

Figure 13. Mean monthly rainfalls, maximum temperatures, and minimum temperatures at Machakos, Kenya.

At lower elevations and further from the equator, Eastern Africa agricultural climates are very similar to those of the Australian tropics. The rainfall climate of the southern plateau of Tanzania, e.g. Nachingwea, Tanzania (Fig. 14), is very similar to Katherine (Fig. 12).

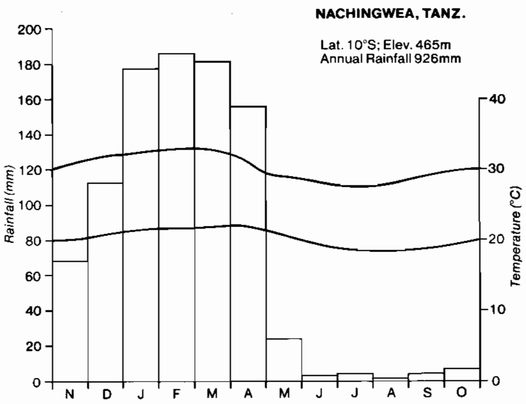

Figure 14. Mean monthly rainfall, maximum temperature and minimum temperatures at Nachingwea, Tanzania.

Soil

Study of the FAO World Soil Map and the recent soil map of Kenya (Sombrock et al. 1982) suggests that many of the red soils on Basement Complex rocks are similar in texture (light to medium) and have similar fertility constraints to the red earths in tropical Australia. The Vertisols of the two continents are also probably very similar, but these soils appear to be much less widespread than the Basement Complex soils in the African zone under consideration in this workshop. The remainder of our paper is restricted to the lighter-textured red soils.

1. Fertility

The main soil fertility constraints to development on the medium and lighter-textured soils of northern Australia relate to the supply of the nutrients N, P, S, Zn, K, Cu, and Mo——in approximately that order of priority (Jones et al. 1983). In Eastern Africa on medium to light textured soils in the semi-arid areas, the soils are often low in total N and crops growing on them are very responsive to applied fertilizer N (Anderson 1969, 1970 a,b; Evans 1963; Singh and Uriyo 1980). Some of the soils appear to mineralize N quite rapidly on wetting up at the start of the rainy season(s) but it is inadequate for the expected yields and may be leached rapidly at least below a depth of 40 cm (Bennison and Evans 1968; Semb and Robinson 1969).

Phosphorus also appears to be quite deficient on many of these soils and some extremely low total soil P values are on record (Anderson 1969, 1970a). Crop reponses to P often go hand in hand with responses to N and there is usually a strong interaction between them, such that maximum responses to P are not achieved until the N deficiency has been at least partially overcome, and vice versa. Strong responses to P have been found in many experiments (Evans 1963; Le Mare 1974; Singh and Uriyo 1980). The P sorption, or fixation, characteristics of a few of the soils have now been examined (Hinga 1973; Uriyo et al. 1977) and these were found to be relatively low on a world scale. This is supported by the fact that the amounts of fertilizer P required to give acceptable crop yields seem modest.

Information on the S and Zn status of the semi-arid soils is very sparse. Anderson (1970b) suspected that S was a problem with groundnut at Sambwa in Tanzania; Singh et al. (1979) present some analytical data for several soils from the Arusha and Mbeya areas of Tanzania.

Zinc seems to have been rarely considered as a possible deficiency and so far we have seen no reports of experiments where it has been used as a treatment. The only soil data we have seen comes from the west Lake region of Tanzania where EDTA-extractable Zn values were low on many of the soils sampled (Moberg 1972).

Soil K levels seem to be moderate to high (Anderson 1969) and instances of crop responses to additions of K relatively infrequent, except under very intensive conditions (Anderson 1970 a,b). However, Anderson (1973) does mention some reponses to K in experiments on beans at Machakos and Kitui.

Copper and Mo seem to have received very little attention (or have not shown any signs of plant responses and this has not been reported). Soil Cu values by a range of methods are presented for numerous sites in Kenya by Nyandat and Ochieng (1976) and it would appear that soils derived from metamorphic rocks such as schists are in general adequately supplied with Cu.

From the information we have had available to us in preparing this paper, it would seem that there are many parallels as regards soil fertility between areas of semi-arid northern Australia and Eastern Africa.

2. Physical Aspects

In both Africa and northern Australia, less information is available on the physical characteristics of these soils, but the literature suggests that African soils have much in common with soils in northern Australia. They appear to have the same tendency to slake when wet and form seals or caps upon drying (Christianson 1981; Njihia 1979). This results in much reduced infiltration and soil profile recharge, and greater runoff with attendant soil erosion.

Although even less information (from either continent) is available to compare soils in terms of erodibility, it is abundantly clear that the soils in both places are prone to serious erosion under cultivation or heavy grazing (Christianson 1981; Moore 1979).

We share the need to learn to produce from these soils and yet keep them for posterity.

Acknowledgements

We gratefully acknowledge the assistance of R.F. Isbell and John Williams of the CSIRO Division of Soils in preparing the sections on soils.

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Soil and Crop Husbandry: Recent Trends in Production and Research

J.K. Leslie*

The production of field crops in Australia must remain price competitive in: (a) an international trading environment, where some major competitors provide commodity price supports to their farmers, and (b) against a domestic situation where there is virtually no effective assistance in prices paid to farmers for grains and oilseeds, and where there are strong inflationary pressures on farm-input costs. Economic viability of Australian agriculture has been maintained by the substitution of capital and fuel energy for labour by highly mechanized farming with large areas farmed per man unit, and by rigorous selection of cost-effective technology. Nevertheless, in recent years there has been a slow decline in the international competitiveness of Australian field crop agriculture. This background leads to a commercial emphasis on productivity (output:input) in the short term that can conflict with the essential long-term requirement of maintaining soil fertility against exploitive nutrient run-down and soil erosion.

The objectives of research and extension efforts are to increase productivity and achieve stability or improvement of soil resources. Achievement of these dual objectives is particularly challenging in the subhumid-semi-arid tropical and subtropical regions of Australia whose location and main soil and climatic characteristics have been outlined by McCown et al. (1983). There is substantial undeveloped potential in the two regions (Table 1). In the subtropics an extensive current agriculture provides a good base for relevance in research. In the tropics, we have learnt a great deal from research over several decades and from development failures, but there are difficulties in maintaining research relevance and momentum in the absence of a significant commercial agriculture. In both regions the present commercial farming systems are continuously arable with crop sequences determined by seasonal weather variations and market prospects. Cattle fattening is undertaken on annual forage crops or grain crop stubbles on these same lands, but rotation of sown pasture with crops is insignificant and when practised, it is primarily for control of tree regrowth in pastures rather than for soil stabilizing or fertility building objectives.

There is little direct affinity, agroclimatically or socio-economically, between this agriculture and that of Eastern Africa. The climatic affinities, at least in respect of rainfall, are closer than mean monthly data indicate because the marked year-to-year variability in monthly rainfall distribution in the Australian subtropics does create individual seasonal conditions that can be very similar to the unimodal or bimodal patterns variously characteristic of Eastern Africa (McCown et al. 1983, Figure 10). Further, for each crop species we are both striving in our generally semi-arid climates to achieve subhumid to humid conditions in respect of moisture supply and evapotranspiration demand during the yield-determining phases of crop growth and development, and to minimize the effects of moisture and temperature stresses when they do, inevitably, occur. Both regions are

* Deputy Director, Division of Plant Industry, Department of Primary Industries, Brisbane, Queensland, Australia.

Table 1. Current and potential annual cultivated areas in tropical Australia (ha x 10^6). (Adapted from Leslie and Doughton 1976.)

Region	Current	Potential
Wet tropics	0.16	0.13
Subhumid-semi-arid tropics	0.03	1.95
Subhumid-semi-arid subtropics[a]	2.12	8.20
Humid-subhumid subtropics	0.51	0.65

a. North of latitude 29° S

the subject of high intensity rainfalls on soils and surface conditions of high erodibility, and hence erosion control is an important and urgent objective.

In Australian agriculture, climatic variability requires contingency plans for the unexpected. Dryland farming systems are characterized by flexibility and by an emphasis on the timing and speed of cultural operations. As examples of flexibility, it may be necessary to forego a summer crop for a succeeding winter crop, to substitute autumn sunflower for mid-season sorghum, or to utilize grain crops for forage instead of grain. Failure to complete key operations at the earliest opportunity may result in such things as coarse seed bed tilths, delayed or missed plantings, overgrown weeds with loss of antecedent water and increased weed seed populations, grain weather damage, and uncontrollable insect populations. The economic consequences may be serious and farmers have sought to minimize these with high operational speeds (ha/hour) of large machinery. This in turn places high capital and fuel costs on crop production and the prohibitive nature of these has become a major factor in pursuit of reduced tillage and herbicide substitution systems.

Soil and crop husbandry pursues the optimization of the same physical and biological responses irrespective of the methods used to manage those responses or the socio-economic criteria that are most appropriate for assessing productivity. For this reason Australian agricultural production and research is discussed in relation to five elements of management that are vital to high and sustained crop production. The elements are:

1. Crop moisture supply.
2. Genotypic adaptation to the environment.
3. Nutrition.
4. Pest and disease control.
5. Soil erosion.

Crop Moisture Supply

The seasonal dominance of summer (October-March) rainfall is a major agroclimatic feature of the Australian tropics and subtropics. The geographical distribution of summer crop (sorghum, maize, sunflower, soybean, millets) production potential is closely related to the amount, duration, and reliability of these rains. In the eastern sector there is a significant winter (April-September) rainfall component that increases in amount and reliability towards southern latitudes. This, combined with low temperatures, low potential evaporation and radiation frosts has enabled the production of winter crops (wheat, barley, forage oats, safflower, linseed) in flexible rotations with summer crops in a zone extending south from latitude 22° to approximiately 30°30" S. In the zone north of 22° S, cool season aridity restricts the options under natural rainfall conditions to summer crops. This broad delineation of tropical (northern) and subtropical (southern) agroclimatic zones within the subhumid-semi-arid region (McCown et al. 1983, Figure 4) is useful for discussion of many aspects of soil and crop husbandry.

Antecedent Moisture

Antecedent moisture is the plant available water present in the soil profile at the time a crop is sown. In the tropical zone it is essentially water derived from rainfall immediately preceding sowing. In the subtropical zone it may be accumulated during weed-free fallows maintained for as long as 20 months preceding sowing (Fawcett 1980). It represents an addition to the rainfall that occurs during crop growth and may be as much as 28 cm H_2O m^{-1} of soil on certain montmorillonitic clay soils. It provides an important buffer against crop water deficits that would otherwise occur more frequently or severely. Antecedent storage during summer fallows is a major factor in the reliability of winter crop production in the subtropical zone and is being researched to extend summer crop production to more marginal environments.

Storage efficiencies (increment in soil water:total rainfall) probably average about 20%. Earlier work obtained estimates of the value of antecedent moisture to grain production, e.g. 100 kg ha^{-1} cm^{-1} for wheat (Waring et al. 1958). It is now considered that median estimates of storage and conversion efficiencies are inadequate guides to farm strategies because of the wide year-to-year variations in efficiencies that are related to rainfall variability. Research is now directed at soil-water balance and crop production simulations from long-term weather data to examine strategies in probabilistic terms (Berndt and White 1976; Hammer and Goyne 1982).

Use of antecedent moisture as a guide to commercial planting decisions is presently limited to consideration of the depth of wet soil. In the most marginal environments, antecedent moisture is virtually ignored and planting decisions are made on whether crop establishment can be achieved under the soil moisture and temperature conditions prevailing.

Fallow Strategies

The term 'fallow' is used in the context of the period between harvest of one crop and sowing of the next.

A significant change in fallow practices was enabled by the separation of the beneficial but separate effects of fallowing on antecedent moisture, mineral nitrogen accumulation and control of weed seed populations; and the recognition that length of fallow *per se* was not commensurate with the amount of antecedent moisture. Substitution of nitrogen fertilizer for soil nitrogen mineralization and of selective in-crop herbicides for control of weed-seed populations has permitted more flexibility in length of fallows and, in general, an increase in the frequency of cropping in the subtropical zone. In the tropical zone where dry season fallowing offers little of these beneficial effects, fallow lands may be used for other purposes, e.g. grazing, and opportunities for direct drilling (or minimum tillage) crop production are crystallizing in curent research (Jones and McCown 1983).

There is a concentration of research on surface management of fallows that includes herbicide substitution for tillage and the effects of tillage practices on water entry, evaporation, and storage efficiency.

Plant Population and Geometry

Optimization of plant populations and spacing is achievable to the extent that growing season moisture conditions can be predicted. The simplest cases are where:

1. The growing season rainfall is negligible and a crop is to be grown entirely on antecedent moisture. In this case, it is desirable to delay moisture utilization as long as possible, so crops are established at populations related to antecedent moisture and at wide row spacings (high rectangularity) (Myers and Foale 1980, 1981).
2. The growing season moisture is non-limiting, e.g. irrigation. In this case crops are established at high populations (which can be defined) and equidistant spacings.

For unpredictable growing seasons, the agronomist is again dealing with probabilistic issues that have not been well analysed in Australia. For most crop species there appears to be a range of populations within which grain yield will be maximized for widely varying growing season moisture conditions. Within that range, variation in rectangularity from 1:1 to 1:4 is thought to have insignificant effects. Yield reductions due to populations at the low end of the range in high yielding seasons are probably much greater than those due to populations at the high end of the range in low yielding seasons. For these generally unsubstantiated reasons, populations are recommended at the high end of the range.

Regarding the evenness of plant stands in summer crops——a matter which appears irrelevant at the higher populations of winter crops due to compensation——there is some disagreement between farmer and agronomist. Experimental data indicate yield compensation for wide irregularities, although large variations in head size in sunflowers and unevenness of maturity in sorghum and sunflower may be associated with irregularity. Such effects cause harvesting difficulties and delays, and may be causes of inefficient weed or insect control.

This discussion of the state of the art illustrates on the one hand, how quite wrong conclusions can be drawn from limited experimentation; and on the other, how extensive experimentation may still define only very broad tolerances for commercial agriculture. Nevertheless, it appears to be the Australian conviction that these tolerances should be defined for each significant genotype grouping and for planting times.

Establishment Reliability

Australian farmers invest and innovate in machinery to improve the reliability and evenness of stand establishment, and there is a substantial applied research effort into establishment technology (Radford 1982). This is related to the practical difficulties and uncertainties of achieving plant populations within the desired range at the sowing times that are otherwise optimal for a particular species. These uncertainties are greatest for the summer crops and are a major cause of poor crop performance.

The interactions of seed and seedling properties with soil tilth, and moisture and temperature stresses are the primary causes of uncertainties but there are important instances of establishment failures caused by seed and seedling pathogens or insects (ants, cutworms, wireworms, earwigs) that have been resolved by appropriate research.

In the tropical zone, tillage for seedbed preparation is normally delayed until after the opening rains of the wet season whereas the same rains would probably be better used for obtaining crop establishment. Direct drilling techniques to permit this are still being developed. The ley-farming system research incorporates direct drilling in pursuit of this specific objective.

Seedbed preparation is an objective of traditional fallowing systems in the subtropics. One of the 'arts' of the dry- farming technique is managing the fallow to create seedbeds so that relatively small falls of rain can be effective establishment rains. This usually entails shallow, levelling cultivations late in the fallow and such seedbeds are seriously prone to erosion.

Tillage research suggests that on self-mulching and friable soils a combination of surface cover (crop residues) and nil cultivation may offer a further improvement to establishment reliability and minimize erosion. Alternative approaches are concerned with extending the period after rain within which establishment can be achieved. Approaches include the use of stubble covers, 'moisture seeking' seed drills, water injection planting, and pre-germination of seed. Recent research has concentrated in this area with particular attention to the design of seed-furrow openers, seed and fertilizer placement, and compaction of firming of seed in the bed (Radford, *loc. cit.*).

Weed Control

In semi-arid agriculture, weed control is primarily aimed at improving the crop moisture environment although severe in-crop weed infestations compete also for light and nutrients, create harvest problems, and grain contamination. Controls are directed at eliminating transpiration losses from moisture-accumulating fallows and at in-crop weed suppression. In recent years, selective herbicides have almost eliminated interrow cultivation in summer crops thereby enabling superior stand geometries,but there remain many weed/crop species combinations that attract a continuing research effort. Herbicides have permitted increased flexibility in crop sequences and fallow lengths that were previously aimed at reducing weed seed populations. At the same time, herbicides have introduced new problems of residual effects on sensitive crops; and in more marginal environments, herbicide costs are a major limitation.

Most recently there has been a substantial effort directed at herbicide substitution for tillage on fallow soils. The results are generally equal or superior to tillage in terms of erosion control, moisture conservation, and crop yields. Relative costs tend to favour tillage in the subtropical zone, although it now seems feasible to offset those costs to advantage by reducing the number of tillage implements, their draught requirements, and the horsepower of traction units. In the tropical zone, it seems likely that herbicides will replace tillage for weed control following the opening rains of the summer season. Experience is too short to know whether new suites of weeds will develop that prove difficult to control with available herbicides.

Extending the Growing Season

The marginal rainfall extremity of the tropical zone is characterized by short-growing seasons. Effective moisture supply can be extended to some degree by achieving early planting, by adopting appropriate populations and crop cultivar maturities, and by effective weed control.

Research has been undertaken into the feasibility of storing run-off from summer rain in shallow earth storages for crop irrigation immediately after the cessation of summer rains (Weston 1972; Wegener and Weston 1973). Programs have been developed for grain sorghum to optimize the size of storage relative to catchment size, crop area irrigated, and irrigation scheduling in economic terms (J.L. Clewett, unpublished data, Queensland Department of Primary Industries). The approach is quite practical and the key to its viability, is the topography and the year frequency of run-off amounts.

Genotypic Adaptation to the Environment

Genotype x Environment Analysis

Although adaptation implies a matching of multiple characteristics of a genotype to those of the environment, and although retrospective physiological analyses identify some of these characteristics, practically, environmental adaptation of grain crop genotypes is judged in terms of grain yield relative to other genotypes. Extensive use is now made of regression and pattern analysis of relative yields to determine to number and location of genotype experiments, to interpret experimental data for specific and general adaptations; and to define genotypic properties in terms of mean yield, yield stability, and deviations from regression (Brennan et al. 1981).

It has always to be remembered that the genotype experiments——whether used to identify parental lines for crossbreeding or superior progeny for release as varieties——are generally aimed at estimating the relative ranking of genotypes in a commercial population of crop performances from a very limited experimental sample that may also be biased towards better environments. Some effort has been applied to evaluating genotype experiments as estimators of commercial expectancy and it does seem that for wheat and sorghum, they are reasonably efficient.

Departments of Agriculture in Australia devote considerable resources to yield testing of crop cultivars. The rationale for this in cost:benefit terms is that superior cultivars obtain high levels of adoption by farmers, and genetic yield gains are almost entirely net profit. In biological terms, the identification of specific adaptations (to districts or even to large geographical regions) appears to require much higher numbers of experiments (sites x years) than are normally conducted within districts; and analyses of historical yield trends (Russell 1973; O'Brien 1982) tend to cast a healthy doubt on the summation of incremental gains claimed for successive varietal releases. One advantage of the G x E approach is that it encourages more extrapolative and less parochial interpretations of varietal performance.

Characteristics Associated with Adaptation

Australia has a substantial research investment in crop plant physiology both in the field and under controlled environments. This provides insight into characteristics associated with adaptation as well as suggesting characteristics for incorporation genetically, or for agronomic manipulation.

The analysis of phasic development has been valuable in adjusting the yield-determining phases of genotypes to avoid periods of moisture and heat stress and frost occurrence. In general, most crop species are managed to minimize moisture stress over the anthesis and early grain development phases, but there are many other examples where knowledge of heat sum, vernalization, and photoperiodic responses is applied to advantage. Two recent examples have been the development of autumn wheat in the northern sector of the subtropical zone, and the genetic and agronomic manipulation of sunflowers to reduce or avoid the effects of high temperatures which depress linoleic acid levels in sunflower oil (Goyne et al. 1979; Hammer and Goyne *loc. cit*; Downes and Tonnet 1982).

Existing grain sorghum cultivars appear to have lower yield potentials at lower latitudes and this is commonly interpreted as lack of tropical adaptation. Recent research by the CSIRO Division of Tropical Crops and Pastures indicates that some of this apparent lack may be offset by adjusting the agronomy of the crop. Physiological analysis is continuing as are efforts by plant breeders to produce higher yielding, i.e. better adapted, sorghums for lower latitudes.

Another application of crop physiology has been the modelling of crop growth and yield that enables simulation of yield responses to management strategies. This is developing a capacity to come to grips with the highly variable environmental conditions that tend to limit progress from single factor research. It is too early to offer any judgments on whether this new capacity will contribute to real progress, but the interdisciplinary nature of modelling has already enhanced research coordination and team effort.

The benefit of physiological research appears to be greatest when there are close linkages between physiologist and plant breeder, at least to the point of incorporating physiological diversity into breeding populations. Similarly, there has to be continuity between physiology and crop husbandry research for benefits to be realized.

Breeding Programs

Programs are conducted by public and private organizations for a number of crops, as follows: (a) public——maize, sorghum, rice, soybean, sunflower peanut, wheat, barley, navy bean, pigeon pea, mung bean, cowpea, safflower, cotton, and tobacco; and (b) private——maize, sorghum, sunflower, and millet (*Pennisetum*).

Selection programs with introduced germplasm also operate in guar, chickpea, cassava, sesame, grain amaranth, and forage oats.

For sorghum and sunflower the emphasis in public programs is on incorporating useful characteristics into breeding lines and populations for use by the private programs that emphasize release for commercial hybrids.

In general, public programs command support from other research disciplines such as plant pathology, entomology, and the product quality sciences. This support is only available to private programs at the level of routine prerelease screening for insect and disease resistance and product quality.

These programs have developed with the experience that breeding for local adaptation, specific insect and disease resistances, and quality characteristics are essential to Australian agriculture. They are relatively small programs——usually one or two breeders per crop species in each organization——relative to the major international breeding programs. There is a significant use of germplasm from international institutes and from the United States, but it is uncommon for introduced lines to meet all the requirements of commercial cultivars in the Australian environment.

Nutrition

The high total costs of crop production combined with the present ratios of grain prices to fertilizer prices defines a situation in which crops are most profitable at optimum nutrition. In terms of nutrient response curves, this point usually occurs at fertilizer rates that produce grain yields only a little below maximum yield. Thus, the general objective is to grow crops that are non-deficient in any of the essential elements.

Representative soil types are screened in glasshouse and field experiments to identify potential nutrient deficiencies——usually for a limited number of crop species. This leaves uncertainties for other crop species and for soil variants that have not been screened, so research organizations have to be alert to identify and investigate problems of poor growth for possible deficiency or toxicity causes.

This broad screening, while being a valuable background, does not address the issues of optimum fertilizer strategies for individual nutrients.

Diagnosis of Nutrient Deficiencies

The above screening approaches are normally supported by soil characterization, soil analyses for chemical properties (including 'available' macro- and micronutrients) and plant analyses. In addition, the major crop species have now been cultured in glasshouse studies to obtain nutrient concentration levels in plant tissue that relate to toxicity or deficiency conditions, and to produce reference photographs and descriptions of plant symptoms associated with these conditions.

The body of knowledge accumulated in this manner is applied to the initial diagnosis or prediction of nutrient deficiencies. It would be overstating the accuracy of these methods to imply that full reliance is placed on them. Diagnosis often requires confirmation by test strips of soil applied fertilizer or foliar sprays. These may be applied by farmers or extension officers.

Determination of Optimum Fertilizer Strategies

For annual crops, these determinations have to be made prior to planting, so the technology has to cope with (a) defining the nutrient-supply capability of a particular soil for particular elements (nitrogen, phosphorus, zinc, and copper are the most common deficiencies), and (b) the variations in fertilizer requirements that result from variable growing season effects on nutrient-supply processes and plant-nutrient demand. Research has involved a large number of field experiments to develop nitrogen and phosphorus response relationships for a range of soil type, cultural and fertilizer histories, and weather variants with supporting soil and plant analyses. The interpretation of these data is concerned with separating the ability of soil analyses to define nutrient status from the interacting effects of growing conditions on plant response.

The accuracy of prediction services derived in this way is quite high for moderate to extremely deficient, and for non-deficient soils. It lacks adequate precision in the moderate to slightly deficient range that unfortunately contains a high proportion of soils. In some cases it has been possible to assign unexplained variability to environmental factors, which indicates that definition of the nutrient status of soils is adequate.

Research is still directed at improving analytical methods for defining nutrient status, and dynamic modelling of crop growth and nutrient supply processes is being used increasingly to provide probabilistic interpretation of fertilizer-rate effects for farmer guidance. Further refinements are dependent on individual farmers developing specific interpretations for their own fields.

Vesicular-arbuscular Mycorrhizae (VAM)

Recent research has suggested (but not yet confirmed) that natural VAM populations in subtropical soils vary with crop sequence and fallow length, leading to wide variations in levels of root infection and in the efficiency of the symbiotic relationship on phosphorus and zinc nutrition of crop plants (Thompson 1982). This is thought to be a major cause of unexplained variability in the relationships between soil phosphorus analyses, plant response to phosphorus and optimum phosphorus fertilizer rates. The research is at an early stage and the current effort is directed at determining whether VAM are the only organisms associated with the observed effects and if so, how consideration of VAM populations can be used to improve crop-nutrient supply and the precision of fertilizer rate predictions.

Pest and Disease Control

Genetic Resistance in Crop Species

In all plant breeding programs, the pursuit of genetic resistance or tolerance to major soil and air-borne pathogens is a primary objective. This requires intergrated effort by pathologists and plant breeders. It may require in-depth studies on the epidemiology of a disease, techniques for assessing resistance and screening segregating populations, host-pathogen relationships and the genetic nature of host plant resistance, and the virulence of pathogens.

A number of pathogens display race differentiation for virulence. These include the rusts of wheat (*Puccinia* spp) and sunflower (*P. helianthi*), Alternaria blights of sunflower and safflower *(A. helianthi* and *A. carthami)* respectively, *Phytophthora megasperma* in soybean, *P. vigna* in cowpea, *Cercospora* spp that cause leaf spot diseases in peanut and blue mould (*Peronospora*) of tobacco. For these diseases, breeding programs are concerned with major gene resistance and with the development of more generalized resistances that are less susceptible to breakdown by race differentiation in the pathogen.

Analogous programs for insect resistance are fewer in number. The current effort is directed at sorghum midge (*Contarinia sorghicola*), *Heliothis armiger* in cotton and soybean, Rutherglen bug (*Nysius vinitor*) in sunflower, and loopers (*Chrysodeicis argentifera*), green vegetable bug (*Nezara viridula*), and lucerne crown borer (*Zygrita diva*) in soybean.

Pesticides

Pesticide research is an on-going commitment of public and private agencies. Most of the screening of chemicals is undertaken by agricultural chemical companies in conformity with registration requirements for efficacy and environmental safety. There is regular monitoring of domestic and export produce for residues, and trace-back systems operate to control improper uses.

There is increasing emphasis on integrated insect pest management in such crops as cotton and soybean, where the objectives are to reduce the costs and frequency of insecticide applications, to substitute 'soft' for 'hard' chemicals, and to maximize the role of natural predators of economic pest species. A related objective is to extend the useful life of insecticides against the development of insect resistance that has been particularly troublesome with *Heliothis armiger* and a number of stored grain insects in the tropics and subtropics. Research in these areas requires a comprehensive knowledge of pest biology and ecology.

Biological Control

Biological control by management of natural predators and pathogens of pests has been mentioned above. There has been a limited extension of bio-control of insects via the introduction of exotic biological control agents. In annual crops, parasites of the green vegetable bug (soybean and other grain legumes) and the nuclear polyhedrosis virus for *Heliothis* are the only current examples.

A number of major weed species have been introduced to Australia without the organisms that suppress their populations in their country of origin. Australia has had a few outstanding successes in controlling exotic perennial weeds (*Opuntia, Chondrilla*) by introducing insects or pathogens, and this encourages continuing effort on a significant scale for weeds of annual crops such as *Mimosa, Parthenium, Rumex*, and *Emex*.

Soil Erosion

The application of temperate region dry-farming techniques to the subtropical and tropical zones coupled with the continuous arable systems that have evolved, has caused very serious soil erosion in developed areas and constitutes an unacceptable base for further agricultural development of sloping lands——particularly in the tropical zone.

Run-off and Soil Loss Research

Research on run-off and soil loss has shown that surface covers of plant materials have to be maintained on fallows and extended well into the cropped phase. For crops like sunflowers that provide little surface protection and binding, surface covers are required throughout the crop phase. The reductions in soil erosion that can be achieved are substantial and further reductions have been obtained with zero tillage husbandries (Freebairn 1982). There is some confidence that continous arable systems can be stabilized in the subtropics by combining these methods with contour drainage systems, but there is no research experience in the tropical zone.

This confidence is tempered by the episodic occurrence of major erosion events in relation to the uncertainty of guaranteeing an adequate cover from crops and crop residues in semi-arid environments. For example, it is not uncommon for major erosive rains to occur at the end of protracted droughts when cover is absent or very light. For this reason there is a major integrated program which seeks to quantify run-off, soil loss, and crop production expectancies. The objective is to analyse cropping system stategies against long-term weather data (approximately 100 years) to enable the influence of episodic events to be correctly weighted in the evolution of new farming systems. This is another example of using modelling techniques in conjunction with definitive short-term experimentation to extrapolate realistically in time and location.

Farming Systems

Crop-Pasture Rotations

The concept of ley-farming is based on interactive benefits of reduced erodibility, soil-fertility building (soil structure and nitrogen), control of some soil-borne pathogens of crops, diversification of enterprise (which spreads economic risk across crop and livestock components), and the rejuvenation of pasture following an arable phase.

Grasses available for leys include *Panicum maximum, P. coloratum, Cenchrus ciliaris, Chloris gayana, Setaria porphyrantha, Bothriochloa insculpta, Urochloa mozambicensis.* Legumes include *Medicago sativa, Phaseolus atropurpureus, Glycine javanica, Stylosanthes hamata, Centrosema pascuorum.*

Subtropical zone

Rotation studies involving grazed pastures (lucerne or grass/lucerne mixtures) and wheat have been undertaken in the subtropical zone. They have documented (a) high animal production on pastures; (b) substantial increases in soil organic matter and nitrogen levels after 2-4 years pasture; (c) control of some weeds, e.g. *Avena fatua*, and soil-borne diseases, e.g. *Cochliobolus*, by the pasture phase; and (d) increased crop production largely attributable to soil nitrogen increase.

This research has not led to commercial adoption of ley systems. The reasons are essentially socio-economic and include the following facets: (a) net income per ha is considerably higher from grain crops than from sheep and cattle on pastures; (b) there can be long delays in the transition from crop to pasture or pasture to crop that increase still further the economic disadvantage of mixed systems, (c) mixed systems are managerially complex and create reduced economies of scale for each of the two components; and (d) livestock require special and costly management under drought conditions.

There is no information for the soils of the Australian tropics on the effects of ley pastures on the erodibility of soil during arable phases. Data from other environments indicate that beneficial effects are small and of very limited duration. For these reasons, ley pastures are not seen as a solution to the soil erosion problem of cropped lands in the subtropics. They can reduce erosive losses during the pasture phase, and thus extend the productive life of soils by an equivalent period.

Research effort in the subtropical zone is directed at identifying superior ley legumes, seeking species which can be established readily and brought under full grazing pressures within a few months, and at a concept of utilizing short-term perennial fodder crops (*Sorghum, Pennisetum, Lablab*) in lieu of longer term pasture.

Tropical zone

Pasture rotations (*P. maximum/G. javanica)* with maize and peanut were developed for kraznozem soils in the tropics and were used to rehabilitate a very degraded area in North Queensland until socio-economic forces similar to those outlined above, caused a move back to continuous arable systems.

Nevertheless, the tropical zone appears more likely to be suitable for ley systems than the subtropical zone. The reasons are discussed at length by Jones and McCown (*loc. cit.*) and include: (a) the feasibility of direct drilling of crops into pastures killed or suppressed by herbicides where there is neither the need nor opportunity for storage of antecedent moisture; (b) the ability to cycle from crop directly back to livestock production on crop residues with regenerating pastures; (c) the high cost of fertilizer-N in more remote areas and the consequent relative advantage for legume-N systems; and (d) the extreme erodibility of tropical soils.

This option will need to be researched along with the possible alternative of reduced-tillage arable systems.

Grain Legume Rotations

The total area of grain legumes presently grown in the Australian subtropics and tropics is only a small proportion (<2%) of the total cultivated area of the region. It is apparent therefore, that continuous arable systems are very dependent on inputs of fertilizer-N. It is also evident that for leguminous crops to make a significant substitution for fertilizer-N, such crops must be suitable for broad-acre dryland culture and markets must be available for legume grains produced from areas in excess of 0.5 million ha annually. Currently, the high-priced human food markets accessible to Australian grain legume production are very limited, although access may expand. It is probable therefore, that the desired scale of grain legume production may have to be achieved with a stock food or dual-purpose grain that can be produced and traded at coarse-grain price parities in large volumes.

There is a peanut-maize rotation system in more humid districts, and soybeans are grown in loose rotations with other crops in irrigation areas. New options have been developed for semi-arid/subhumid rainfed agriculture in the form of pigeon pea (*Cajanus cajan*, which is the subject of an innovative Australian program), mung (*Vigna radiata, V. Mungo*), gram (*Cicer arietenum*), guar (*Cyanopsis tetragonoloba*),and lupins (*Lupinus albus, L. angustifolius*).

The information that is available on the nitrogen contributions made by these spcies is piecemeal, but encouraging (Russell 1980). Estimates of effective N contributions, i.e. the fertilizer-N inputs required to equal the effect of a preceding legume crop lie in the 40-100 kg N ha^{-1} range. Estimates of apparent fixation based on the nitrogen yield of grain legumes compared with that of non-legumes indicate even greater levels of fixation. Symbiotic activity is reduced by mineral (NO_3)-N accumulation in fallowed soils and in this regard, grain legumes can be partly exploitive of soil-N. Research with soybeans is investigating the possibility of achieving higher symbiotic efficiency under conditions of high NO_3-N availabilty. The grain legume can effectively take some of the exploitive pressure of the non-legume crops off soil nitrogen reserves for the period in which it is grown. Thus, although the residual benefits on the following crops may be small, the grain legume can usually be grown without fertilizer-N in lieu of a non-legume crop that requires nitrogen fertilization. In this way, the fertilizer-N inputs required to sustain cropping systems may be reduced. The area of nitrogen balance in rotation systems incorporating grain legumes is attracting increased research attention.

Ancillary benefits of grain legumes on following crops are also recognized. These may be associated with reductions in the inoculum levels of soil-borne pathogens and reduced nematode populations.

Disadvantages of grain legumes in tropical systems include their generally high susceptibility to insect attack, and the high decomposition rates of legume crop residues that make them less suitable for maintaining soil cover over extended periods.

Concluding Remarks

Productive agriculture requires technological support in all elements discussed in this paper and its thorough application at farm level. Much of this technology may appear to be scientifically low key at the applied level, yet failure to manage any of the elements optimally appears to cause much greater reductions in commercial crop performance than might be predicted from experimental data on single factor effects. It seems that this may result from interactions of multiple factors in soil and crop husbandry, which are rarely, if ever, researched as complex interactions for good practical and logistic reasons.

It is doubtful whether modelling approaches can be developed and calibrated to cope with the full multiplicity of interactions but useful progress has been made already for some complex systems. It is the author's view that agricultural technology will continue to advance via progress with individual elements of agricultural systems, and that agricultural productivity will advance by thorough application of resultant principles and practices at the farm level. One of the strengths of Australian agriculture is the balance that has been achieved between basic and applied scientists, extension officers, and farmers as contributors to the total process of agricultural innovation.

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Research on a No-till, Tropical Legume-ley Farming Strategy *

R.K. Jones and R.L. McCown †

In the temperate areas of southern Australia that experience a Mediterranean climate, legume-ley farming systems have been the basis of successful wheat and sheep production for almost half a century. The pasture legumes, viz. subterranean clover and various medics (*Trifolium subterranean, Medicago littoralis, M. truncatula*, and *M. sativa*), have been the key to this success, contributing nitrogen by biological fixation for use by succeeding cereal crops as well as improving the nutritional value of the herbage for livestock (Greenland 1971; White et al. 1978). In these systems, both the cropping and the livestock enterprises benefit enormously from the introduction of an adapted pasture legume. In recent years, direct drilling (no-tillage) of crops into pastures, which have been killed with herbicides, has also increased sharply.

This very successful example of a farming system in an environment with a highly-seasonal rainfall raises the question——'Is it possible to develop a comparable no-till legume-ley farming system for the semi-arid or subhumid tropics that is both biologically and economically efficient and conservative of scarce resources, particularly soil and water?'.

In this paper we describe some recent research aimed at developing ley-farming systems for Australia's semi-arid tropics (SAT) and discuss the possibility that some of the concepts might be transferable to comparable regions of Africa.

* This paper is based on one by R.L. McCown, R.K. Jones and D.C.I. Peake, entitled 'Evaluation of a no-till, tropical legume-ley farming strategy' to be published in 'Agro-research for Australia's semi-arid tropics', ed. R.C. Muchow (University of Queensland Press: Brisbane).

† Division of Tropical Crops and Pastures, CSIRO, St. Lucia, Queensland, and Aitkenville (Townsville), Queensland, respectively.

Some Problems of Agricultural Production in Australia's SAT

Australia has a vast area of land in the tropics (i.e. north of the Tropic of Capricorn) with a mean annual rainfall of between about 500 and 1 200 mm. Table 1 gives some agricultural statistics for this land which shows that (a) the area is very sparsely settled, (b) the dominant enterprise is extensive grazing of beef cattle in large herds on large holdings and at a low stocking rates, and (c) the proportion of the land under crop or improved pastures is low, and the usage of fertilizers on pastures is extremely low.

A major constraint to cattle production in large areas of this region is the poor nutritive value of the grass pastures in the dry season. Research has given a technology for overcoming this constraint viz. oversowing the native pasture with legumes and correcting the nutrient deficiencies of the soils, but to date it has not been economic to implement this technology on a large scale. The reasons for this can be found in the high costs of the inputs and the low prices and fluctuating demand for beef on the export market.

Major constraints to crop production are the low soil fertility and the high risks of experiencing adverse climatic factors during the growth of the crop. The soils are often deficient in N and P and sometimes in other nutrients such as K, S, Cu, Zn, and Mo (Jones et al. 1983; Rayment et al. 1983); correcting these constraints can be very costly——particularly for N. The climatic risks are numerous. The period between the earliest ploughing rains and the arrival of the monsoonal rains, when soil moisture conditions are suitable for planting, can be very short; in the past this has led to overcapitalization on tractors and machinery to prepare and plant large areas of land in the short time avaiable (Fisher et al. 1978). Adverse soil temperature/soil moisture conditions often affect crop establishment; rapid drying of the bare soil surface results in excessively high soil tempera-

Table 1. Some population and land-use statistics for semi-arid tropical areas of northern Australia with average annual rainfalls between about 500 and 1 200 mm. (Data from Australian Bureau of Statistics publications for 1980-81).

State and Statistical Division	Population[a] ('000's)	Rural holdings: Number	Rural holdings: Area ('000 ha)	Rural holdings: Mean area holding ('000 ha)	Total cattle numbers ('000's)	Sown pastures: Area ('000 ha)	Sown pastures: Fertilizers used on sown + native pastures (tonnes)	Crops: Total area ('000 ha)	Crops: Area of cereals for grain ('000 ha)
Queensland[b]									
Fitzroy	68.0	3 226	10 907	3.4	1 630	1 213	1 200	397	267
Mackay	16.7	498	5 663	11.4	680	559	385	75	42
Northern	42.0	806	8 804	10.9	830	77	679	9	1
Far-North	52.8	1 942	21 498	11.1	702	157	14 572	32	8
North-West	14.8	542	30 659	56.6	1 610	37	0	0	0
Northern Territory									
Darwin & Gulf		178	17 012	95.6	309				
	8.0(est)								
Victoria River		34	14 864	437.2	511	3 (est)	1 500 (est)	2 (est)	1 (est)
Barkly Tablelands	2.4	23	13 354	580.6	401				
Western Australia									
Kimberley	17.9	149	25 466	170.9	767	13	43	4	2 (est)
Total	222.6	7 398	148 227	20.0	7 440	2 059	18 379	519	321

a. Population data exclude the major coastal cities of Gladstone, Rockhampton, Mackay, Townsville, Cairns, and Darwin.

b. Excluding data for the following Local Authority areas receiving high rainfall and producing mainly sugarcane: Sarina, Pioneer, Proserpine, Mirani, Ayr, Hinchinbrook, Douglas, Johnstone, and Mulgrave.

tures and/or strong surface seals which seriously reduce emergence of seedlings (Arndt 1965; McCown et al. 1980).

The most serious risk associated with climate however, is undoubtedly that of soil erosion; high rainfall intensities on loose, exposed soil result in high losses of both soil and nutrients (Greenland and Lal 1977).

If agricultural productivity from this vast region is to be increased and the natural resources conserved, some new approaches will be required. One approach that appeared attractive to us was to develop no-till legume-ley farming systems suited to the climate and soils of the region that would closely integrate dryland grain cropping with the existing extensive cattle industry.

Strategy for an Improved Farming System

Our research has been centred on a hypothetical farming system outlined in Table 2. The field experimentation is based at a research station at Katherine, Northern Territory (N.T.), in the wet semi-arid or monsoonal tropics (900 mm unimodal rainfall). The station was established in 1946 and researchers over the next 30 years methodically covered a wide range of crop and pasture production issues, including aspects of the integration of the two enterprises (Norman 1966; Norman and Begg 1973). Our work began in 1978 and builds on these foundations.

The hypothetical system combines the concepts of legume-ley farming and no-tillage with the existing system of grazed native pastures. The key feature (Table 2, No. 1) is the rotation of a self-regenerating legume pasture and a maize or sorghum crop, with the legume supplying all or most of the N fertilizer requirement of the crop. A number of legumes accidentally or deliberately introduced to Australia during the last 75 years have proved to be well-adapted to the pasture environments of the SAT and capable of fixing substantial amounts of N. For example, Townsville stylo (*Stylosanthes humilis*) has been found to fix between 75 and 130 kg N/ha/year in studies conducted in the northern part of the N.T. during the 1950s and '60s (Vallis and Gardener, in press, Table 1). Since then, other more-productive legumes (e.g. *S. hamata* cv Verano) have been found and hold promise of fixing more N than Townsville stylo. However, the success of a ley system depends very greatly on what proportion of the N fixed by the legume finds its way into the succeeding crop(s). Although little is known about the magnitudes of various N losses in these environments, especially under grazing, the amount of N fixed by a number of the legumes seems large enough to meet most of the crops requirement, even if losses are substantial.

The second feature (Table 2, No. 2) concerns the integration of cropping with the existing system in which cattle graze native pastures. In this region, the strategy of having cattle on native-grass pastures during the green season when they are at their best, and on sown leguminous pastures in the dry season, is that of Norman (1968). Cattle grazing dry standing hay of the annual legume Townsville stylo, normally gained weight during the dry season (Norman 1968; Woods 1970). Although even modest amounts of rain on dry legume can cause spoilage and a marked reduction in acceptance by cattle (Norman 1968; McCown et al. 1981), the low frequency of dry season rain at Katherine (R.L. McCown, unpublished data) makes the grazing of dry legume an attractive strategy for dry season nutrition of cattle. However, the test of this strategy in the late 1960s and early 1970s failed, because of the inability of Townsville stylo to compete satisfactorily with invading annual grasses and, ultimately, to its susceptibility to the fungal disease anthracnose.

Table 2. Features of the hypothetical farming system.

1.	Self-regenerating legume-ley pastures of 1-3 years duration are grown in rotation with maize or sorghum.
2.	Cattle graze native-grass pastures in the green season and leguminous pastures and crop residues in the dry season.
3.	Crops are planted directly into the pasture that is chemically killed at, or shortly before, planting.
4.	The legume sward, which volunteers from hard seed after the pasture is killed, is allowed to form an understorey ('live mulch') in the main crop.

The availability of several 'new' legumes with superior competitive ability and resistance to anthracnose makes a new attempt at implementing this strategy feasible. (The growing of a nitrophilous crop every 1-3 years should further contribute towards maintaining legume dominance by regularly depleting soil N, and by providing an opportunity for economic use of a herbicide selective for grass weeds.)

The third feature of this hypothetical farming system (Table 2, No. 3) is that of the retention of surface mulch by use of no-tillage planting technology. Although experience in the tropics is as yet limited, there are indications that the potential benefit is greater here than at higher latitudes. In temperate regions, reduced or zero-tillage is widely practised where soil and water conservation are important (e.g. in parts of North America). In other temperate areas the amounts of plant residues from previous crops or pastures may be excessive and can often exacerbate problems of low soil temperature or excessive wetness at planting (Baeumer and Bakermans 1973; Cannell 1981). In the tropics, by contrast, the need for improved soil conservation in cropping is universal and the benefits of mulch retention on this are very great (Lal 1975; Hayward et al. 1981; Obi 1982). Moreover, the effect of mulch in retarding evaporation losses and the consequent rise in soil temperature is beneficial to young crops in the tropics generally (Hayward et al. 1981; Lal 1983), because the potential evaporation is generally very high and rainfall very unreliable during this crucial establishment phase. Thus, surface mulch affects the soil moisture and temperature environment of the young crop similarly in temperate and tropical zones, but in the former the effect is often detrimental and in the latter, almost always beneficial.

The fourth and final feature of our hypothetical system concerns intercropping (Table 2, No. 4). The herbaceous pasture legumes, which are well adapted to this climate, invariably produce a proportion of seed that is still 'hard' when the re-established pasture is killed with herbicide and a crop planted early in the next rainy season. With subsequent rain, however, newly germinated seed from the 'hard-seed' pool produces a new stand of legume, which is unaffected by the herbicide. Although this can be prevented by the use of a pre-emergent herbicide, this legume intercrop (live mulch) offers several potential benefits: it does not cost anything to establish; it provides a more long-lasting protective cover for the soil than the dead mulch; it provides high-protein forage to complement the low-protein stover available for grazing in the followng dry season; and it provides an additional source for seed for pasture re-establishment in the following season. The main potential detriment is that the understorey of pasture legume may depress the yield of the grain crop. In this particular version of intercropping, this would be a very undesirable outcome because the grain crop has a much higher monetary value than the forage intercrop, and only small reductions in grain yield can be tolerated (Willey 1979). The degree to which competition for water or nutrients during the growing season jeopardizes the success of this forage intercropping strategy in the SAT is unknown. However, recent results from the humid tropics of West Africa have shown that yields of crops sown into legume swards killed only on the row zones can compare favourably with those of crops grown without this live mulch (Akobundu 1982).

An attempt is made in Figure 1 to depict the inter-relationships of the important components of this hypothetical farming system as a flow diagram. Recognition of a number of internal cycles aids our understanding of the system. On the left, cattle from native pasture enter a ley-pasture cycle during the dry season where they graze crop residues and dry legume herbage. At the end of the dry season, cattle return to native pastures. If the pasture area is cropped in the wet season, the pasture phase contributes mulch and soil nitrogen, as well as legume seed for the volunteer legume understorey. The latter is depicted (centre) as part of a life-cycle which produces seed either for re-establishment of the pasture, or for mulch and legume understorey in a successive crop. From the crop phase emerge the edible residues, and the cycle is complete.

Research Goals and Approach

How have we gone about testing this hypothetical legume-ley farming system? In the initial phase of the project (1978 to present), we have concentrated our research resources on evaluating the potential farming system at one location in northern Australia, i.e. Katherine, N.T. The Katherine region has soils and climate that are broadly

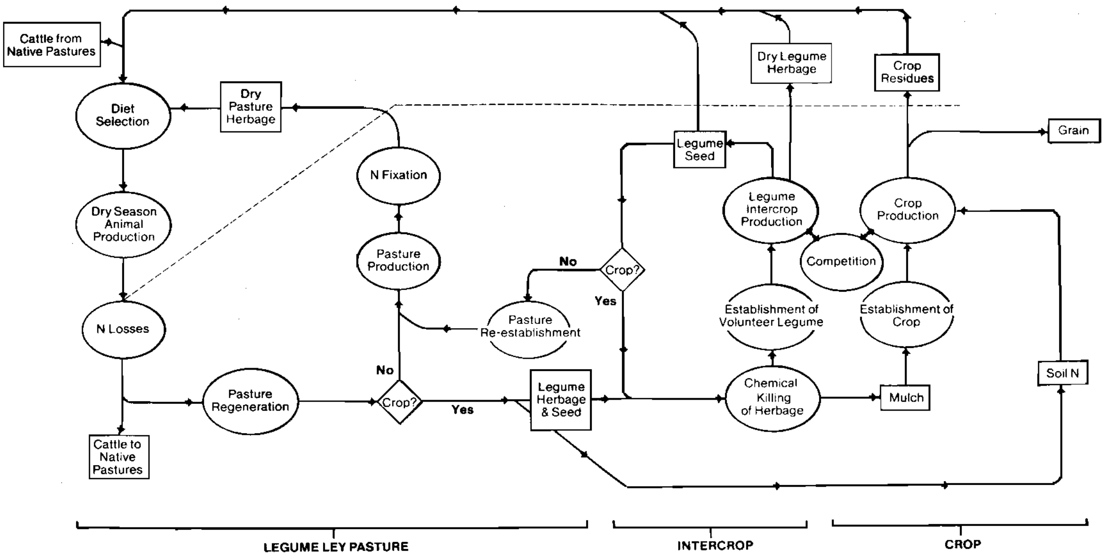

Figure 1. The hypothetical farming system being evaluated at Katherine showing flow of inputs and outputs among subsystems (boxes) and important processes being researched (ovals).

similar to the SAT of northern Australia and subSaharan Africa, and the research station there has good facilities for pasture, crop, and animal research. If we can demonstrate that the system shows promise here, we will be able to proceed with the evaluation in other environments with greater confidence. Our ultimate goal, of course, is to evaluate no-till legume-ley farming systems in the SAT in general. The extent to which we can achieve this will depend on the degree of understanding of the processes within the system that we can obtain from studies at one or a few sites, and on the extent of the interaction of these processes with climatic and soil factors.

The research resources that are required to understand all the important processes, at the level of detail that they are often studied, are enormous. Our problem was to identify a procedure for studying this complex subject in such a way that achieves our goals, but with a small team, a modest budget, and within a 10 year perod. We have found two concepts especially helpful in allocating our limited resources to this large task.

The first concerns the 'identification of subsystems', which in the words of Spedding (1975), 'possess an integrity of their own, such that when studied in relative isolation the resulting increased knowledge about them can be fitted back into the whole system from which they were derived and contribute to our knowledge of the latter'. We have identified four major subsystems: (1) the effect of legume ley/crop rotation on crop production, (2) the effect of no-tillage technology on crop production, (3) the effect of competition from the pasture-legume intercrop on crop production, and (4) the effect of cattle/ley-pasture rotations on both animal and crop production. These subsystems are manageable reseach areas and can be staged over time, are discrete areas for special funding, and can be studied at multiple sites if this is appropriate.

The second concept of 'hierarchy' enables the ordering of questions to be answered and hence of research priorities in each subsystem. Figure 2 shows the hierarchy of questions requiring answers in the legume ley/crop rotation subsystem. Initial experiments were designed to answer questions at level A, and where expedient to do so, at lower levels as well.

In our view, there is no doubt about the convenience afforded by the study of major subsystems separately. Nevertheless, there are benefits to be gained by the study of the whole system as an entity. It provides a check on the assumptions used in isolating subsystems, and also serves as a superior form of demonstration to those best situated to further evaluate this farm-

A. How much of the N requirement of a coarse grain crop can be supplied by a tropical legume ley in rotation?

B. How much do legumes differ in their ability to contribute N to succeeding crops?

C. What proportion of the N fixed by a legume is available to succeeding crops?

D. How much of the legume N is lost via volatilization of ammonia?

E. What is the rate of mineralization of N from dead leaves, stems, and roots of legumes?

Figure 2. An example of a partial hierarchy of research questions, in this case pertaining to the legume ley/crop rotation subsystem.

ing strategy at more tactical levels, e.g. workers on field sations of state agriculture departments, pilot farms, etc. We have commenced one long-term study of the system as a whole and it is already giving useful data on animal production.

One might ask whether we are doing what is normally described as 'Farming Systems Research'. It seems to us that the application of general systems theory to agricultural systems has taken two distinct paths.

The first (the 'systems approach') is characterized by the use of methods of systems analysis and simulation; reseach is generally aimed at developing mathematical models of the biological or bio-economic functioning of production systems (Spedding 1975).

The second path has developed in response to the urgent need to improve the farming systems of small holders in developing countries. In this case, the existing farming systems are analysed conceptually to identify needs for research, most of which is then conducted on farms, with farmers. This methodology has come to be referred to as FSR (Farming Systems Research) (Shaner et al. 1982; Dillon and Virmani 1983). In research-for-development, where there is a need for substantial changes in technology (e.g. the Systems Replacement case of Dillon and Virmani), the methods of these two branches of systems research can be combined. While FSR identifies the need for the research, it is best conducted initially on research stations where there are advantages in research facilities, logistics, and control. Our research approach is an attempt to adopt appropriate concepts of the 'systems approach' to enchance the efficiency of research conducted in an FSR framework.

Research Progress

Subsystem 1——The Effect of Legume-Ley/Crop Rotation on Crop Production

In studying this subsystem, the high-order objectives are to quantify the N contribution to the following grain crops by leys of various legumes grown for between 1 and 4 years (Figure 2). Substantial losses of N under grazing are expected, and elucidation of the relative importance of losses from litter, urine, and dung are objectives of a lower order and priority. It is to be expected that soil type will strongly influence N transfer processes, so studies of this subsystem are being conducted on contrasting Alfisols——a heavy-textured red earth and a sandy red earth.

A very direct experimental approach is used to estimate the N contribution by legumes, whereby a crop of maize or sorghum is used in a bio-assay. Rates of fertilizer N are superimposed on the crop so that its responses to N, additional to that supplied by the preceding legume or grass (control) swards, can be measured and compared. Supporting measurements include soil N prior to cropping, and yield and chemical composition of both the ley and the crop.

Salient results from six experiments, most of which are still in progress, include:

(1) On the loamy soil, maize grain yield with no N fertilizer, following one-year leys of various pasture legumes, was equivalent to that on plots receiving at least 50 kg N/ha following one year of grass. (Figure 3 shows data from one experiment.) Legume leys of longer duration had greater effects in the first crop and a greater residual effect on the second crop.

(2) For a given level of dry matter production by a short ley of Caribbean stylo (*S. hamata* cv Verano), the apparent N contribution to the following crop is much less on the sandy soil than on the loamy one.

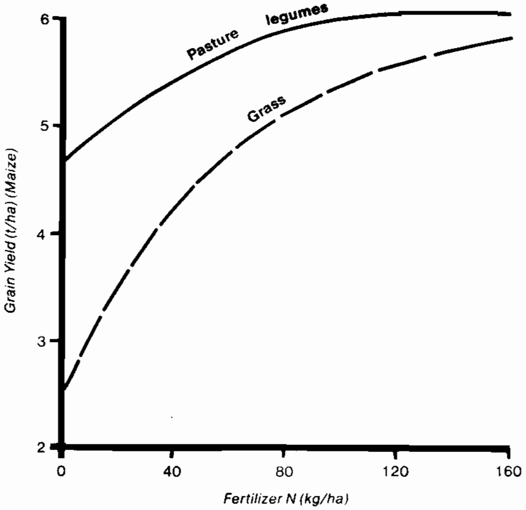

Figure 3. Maize grain yield responses to N fertilizer in the first crop following one year of legume or grass leys on a loamy red earth soil.

(3) Legume species do not differ greatly in N contribution after one-year leys, but large differences occur following four-year leys.

A study of N loss from urine has also been conducted on the loamy soil. Of the ^{15}N applied in urine in the mid-dry season, 60% was found in the soil 5 weeks later. Since no rain fell and 94% of ^{15}N in urine applied 15 cm beneath the soil surface was recovered, it seems likely that the 40% loss was as ammonia (I. Vallis and R.K. Jones, unpublished data).

Subsystem 2——The Effect of No-Tillage Technology on Crop Production

The priority objective here was to quantify the advantages/disadvantages of no-till planting of crops in relation to conventional tillage. The compelling reason for inclusion of this practice is that, wherever comparisions have been made, the inherent benefit of no-tillage in conserving soil has been demonstrated. However, the shorter-term effects of this new technology on crop yields in the SAT are not well understood.

Our first experiment was designed to test whether high soil temperatures could explain very poor maize growth on the sandy red earth. In the absence of mulch, there was high mortality of seedlings at emergence, and survivors showed thermal injury lesions and slow growth.

The results from a subsequent experiment demonstrate how important mulch is on this soil. In order to have control over water, irrigation was used and the experiment was conducted in November, just before the onset of storm rains. A single layer of hessian was used as a convenient form of experimental mulch. By the time seedlings were emerging, daily maximum soil temperatures at 1 cm were above 55°C (Figure 4a). Under this rather thin layer of mulch, temperatures were reduced by only about 4°C, but this had dramatic effects on establishment of both maize and sorghum (Figure 4b). Although conditions in this study were extreme, our overall experience is that it is not possible to establish satisfactory stands of maize on this sandy soil without a substantial mulch. In other studies on this soil, no-till and mulch retention has resulted in an average increase in maize yields of 33% (from 1.8-2.4 t/ha of grain) in two crops, but no increase in sorghum yields in four crops.

On the loamy red earth, injurious soil temperatures are less frequent than on the sandy red earth, but they are still too high, without mulch, for optimum seedling growth. However, this soil does have an additional problem, i.e. on drying, it tends to form strong surface seals which impede seedling emergence (Arndt 1965). Mulch reduces this problem by slowing the drying of the soil. In four crops, mulch retention resulted in an average yield advantage of 20% from 4.83-5.80 t/ha in maize, but had no effect on sorghum.

Having confirmed that mulch retention and no-tillage often had beneficial effects on establishment and yields, we have turned our attention to answering questions such as——what constitutes a minimum effective mulch, how do we get an effective mulch economically, and how do we plant into such a mulch efficiently? (In most years, the pasture mulch at planting time consists of a mixture of dead pasture residues, mainly stems, from the previous growing season and recently killed regrowth and seedlings resulting from rainfall received in the current wet season. The relative proportions of these components varies with the intensity of grazing during the dry season and with the amount and distribution of rainfall in the early part of the wet season).

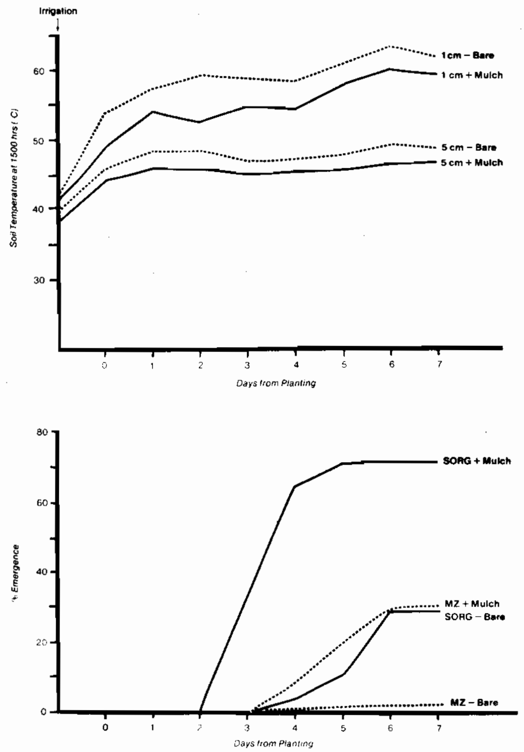

Figure 4. *The effect of mulch on (a) soil temperatures at 1 and 5 cm below the soil surface, and on (b) seedling emergence of maize (MZ) and sorghum, when planted at a depth of 5 cm on a sandy red earth soil.*

Work to date has been on the loamy soil only and we can make the following observations:

(1) As little as 700 kg/ha of mulch, in this case standing Caribbean stylo, which had been killed with herbicide, reduces soil temperatures substantially (Figure 5).

(2) Analysis of the radiation balance has shown that mulch retards the rise in soil temperature (Figure 5) and soil strength by retarding drying. This is due primarily to the interception of radiation by mulch.

(3) Pasture mulch is quite efficient in radiation interception; 1 900 kg/ha of dead standing Caribbean stylo intercepted 80%, and 700 kg/ha 55%, of direct beam radiation.

(4) Tropical grasses and weeds, in general, are killed by dosages of the herbicide Glyphosate similar to those used in temperate regions (1.5-2.0 l/ha).

(5) The most successful planter, in terms of seedling emergence over a wide range of conditions, has been a narrow tyne preceded by a rolling coulter to cut surface mulch, and followed by a narrow in-furrow press wheel.

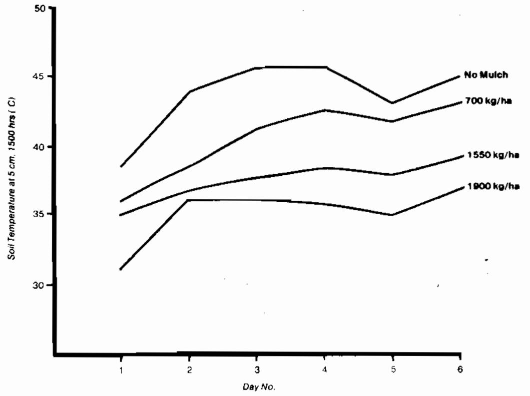

Figure 5. *The effect of various amounts of mulch (dead* Stylo*) on soil temperatures over a 6 day period.*

Research has recently commenced on planting on the sandy soil where there appear to be fewer technical problems than on the loam.

Considering the overall results of the various studies in this subsystem, our tentative conclusion is that no-tillage technology for this farming system is feasible in all major aspects, and that further progress will most likely by made in 'on-farm' research and development that is about to commence.

Subsystem 3——The Effects of Competition from the Pasture-Legume Intercrop on Crop Production

The objectives of this research are to:

(1) Assess the effect of a pasture-legume intercrop on the yield of the main crop of maize or sorghum.

(2) Elucidate the nature of the interaction between the legume intercrop and the main crop.

(3) Evaluate various legumes that are successful in pastures for their suitability as intercrops.

(4) Learn how to control grass weeds in this intercropping system.

Two studies have been conducted to assess the effect of Caribbean stylo, *Alysicarpus vaginalis*, and *Centrosema pascuorum* intercrops on maize yield. In one, intercropped maize yielded 15% more than sole maize, but in the other it yielded 30% less. To date, we have collected data only on yield, chemical composition, and weather, and it is clear that these are inadequate to explain the results. More recent work is studying the competition between the crop and the intercrop for the two resources most likely to be deficient in this system, i.e. water and N. The necessary control of water is provided by an automatic rain shelter and ^{15}N-labelled fertilizer is providing a means of distinguishing fixed N from soil and fertilizer N.

Comparison of the suitability of these three legumes indicate that:

(1) The large-seeded *C. pascuorum* establishes much less readily than the other species.
(2) All three are capable of producing about the same amount of herbage (1.5-2.5 t/ha) prior to maize maturity, but the later-flowering *C. pascuorum* can produce more than the others after this time.
(3) Caribbean stylo produces very little seed as an intercrop due to its failure to flower in the shade of a full maize canopy (50 000 plants/ha, 75 cm rows).
(4) In contrast, *A. vaginalis* produces 2 000-4 000 seeds/m², an amount sufficient to establish a dense pasture the following season.

Research on the control of grass and broadleaf weeds in the legume plus graminaceous crop mixture has yet to commence, but a number of promising herbicides have been identified.

Subsystem 4——The Effect of Cattle/Ley-Pastures Rotations on Animal and Crop Production

Study of this subsystem is conducted within our whole-system experiment. The objectives of this are to:

(1) Quantify the N contribution to a succeeding crop by various legumes under realistic dry-season grazing management.
(2) Compare live weight performance in the legume-ley system with that on continuously-grazed native pastures on improved pastures.
(3) Document the ecological stability of pastures of Caribbean stylo, *A. vaginalis*, and *C. pascuorum* particularly in relation to re-establishment and ability to resist invasion by annual grasses.
(4) Document the trends in weed abundance in both crop and pasture and to identify possible weed-management strategies.
(5) Quantify costs of production and yields of maize under more realistic operational conditions with respect to planting and harvesting than is possible in small-scale experimentation.

The cropland component of this study consists of three paddocks in which the legume-ley is Caribbean stylo, *A. vaginalis*, or *C. pascuorum*. Within each paddock, there are three areas of equal size. This allows a 1 year maize: 2 year legume-ley rotation, with a maize crop in every year. Adjacent is a large area of unimproved native pasture under eucalypt woodland, as well as an on-going experiment on improved pasture (cleared, large amounts of superphosphate over 10 years, sown legumes and sown grasses).

The native pasture area is stocked during the green season at an appropriate density (0.2 beasts/ha) with equal numbers of weaners and yearling steers. After crop harvest, three groups of four cattle (2 weaners + 2 yearlings) are moved into the cropland paddocks; an equal number remain on the native pasture. At the end of the dry season, yearlings are turned off and weaners return to native pasture; the latter return in the following year to their respective legume paddocks for finishing.

Maize is planted by no-till after spraying the regenerating pasture with Glyphosate. In half of the crop area, the legume understorey is allowed to develop; in the other half this is prevented by the application of a pre-emergent herbicide. A range of N rates is superimposed on parts of the maize crop to assess response to N above that contributed by the 2-year leys.

Botanical composition of ley pastures is measured annually near the end of the green season. Pasture on offer, and the proportion and chemical composition of leaf, stem, and seed are measured periodically through the dry season in conjunction with diet sampling with oesophageal-fistulated cattle.

This experiment was planted only in January 1982, so time trends in pasture production and ecology, as influenced by crop/pasture rotation, are not yet available. Animal production, however, is not as dependent on crop-ley sequences, and results from the first dry season should be as informative as those to come. The live weight gain on legume-ley-stover, averaged over legume species, was nearly 80 kg per head greater than on native pasture for the 4 month period mid-July to mid-November. In the cropland, during the first 7 weeks, 10-20% of time spent grazing was in the stover and, after that, virtually all grazing was on legume. There was virtually no effect of legume species on live weight performance.

Caribbean stylo and *A. vaginalis* re-established in the second year at very high densities. The density of *C. pascuorum,* however, was disappointingly low, in spite of abundant seed. This adds to other evidence that re-establishment without disturbance may be a serious deficiency of this large-seeded annual, which is so promising as a ley plant in other respects.

An Assessment of Progress to Date

The results to date are, we feel, encouraging in that the legumes, when adequately fertilized, appear to be contributing substantial amounts of N to following crops; regenerating legumes and weeds can be killed to produce a satisfactory mulch for soil and crop protection; and excellent animal production is achievable during the dry season on pasture and crop residues.

Our results, however, indicate a need for an accelerated research effort in three areas. First, a much better understanding of differences in the performance of the crop/legume rotation subsystem on the soils of contrasting texture is needed. This will require elucidation of the N and water balances to enable generalization to other conditions.

Second, elucidation of the quantitative dependence of N fixed by the various legumes on P supply is a necessary basis for optimizing P fertilizer inputs. This N-P relationship is especially important for a realistic evaluation of the potential of a legume-ley strategy for agriculture in regions where P fertilizer costs are high.

Third, quantification of the hydrological implications of this farming system is urgently needed. Local pilot farmers, presently practising conventional tillage and continuous cropping, are relying on conventional earth structures to control surface water. This approach is proving to be too costly and less than fully effective. To what extent can a no-till legume-ley system reduce the need for such structures? Can grain legume crops be substituted for pasture-legume leys without serious sacrifice in soil surface protection? To provide answers that are generally applicable, the research must relate readily-measured attributes of both soil and vegetation to hydrological processes, particularly the partitioning of rainfall into infiltration and runoff.

The Prospects for a Legume-Ley Farming System in Africa

It is interesting to speculate on the prospects for a legume-ley farming system in the SAT of sub-Saharan Africa, along the lines of that just described for northern Australia. Promising results in one environment under one set of ecological and socio-economic conditions are no guarantee of success under other conditions, but we contend that they are a reasonable base from which to conduct further evaluation.

Legumes for Pasture Leys

The concept of pasture leys is, of course, a very old one. There was considerable work on pasture leys in the 1950s and 60s (Webster 1954; Pereira et al. 1961). Much of the work, however, was on pure grass or grass-dominant pastures (e.g. Periera et al. 1961) and, while there were benefits from the ley phase in terms of soil structure and infiltration of water, there was little N input into the system. Some work was done during these years in evaluating some of the native legumes (mainly collections from *Clitoria, Desmodium, Glycine, Dolichos, Rhyncosia*, and *Stylosanthes*) and a few introduced ones (*Macroptilium atropurpureum* cv Siratro and *Stylosanthes humilis*)——van Rensburg (1969); Sands et al. (1970); Wigg (1973)——but the results were not particularly encouraging.

This general experience with ley-farming systems in Africa led Ruthenburg (1980) to conclude that the probability of successful implementation of sown-ley systems is low. 'A ley system must show itself to be better than a tumbledown grassland or other fallow system in: (1) having a better fertility-restoring capacity, (2) supporting more livestock production, and (3) allowing a more efficient use of the farm labour; and the combined effect must be higher by a substantial margin than the costs of establishing a full ley-farming system. These conditions rarely exist ....'(Ruthenberg 1980, p.123).

While we accept Ruthenberg's criteria for success of such a system, we believe that he paints too bleak a picture, and that new pasture legumes that have been domesticated only in the last decade or so, together with careful indentification and correction of soil fertility constraints, provide a much better prospect of satisfying criteria (1) and (2) than was the case previously.

In tropical Australia, pasture improvement has been based on the use of plants introduced from elsewhere in the world; as a broad generalization, the grasses have been introduced from Africa and the legumes from central and south America. This more-productive germplasm has generally been introduced without the insect and disease complex that the plants are exposed to in their native habitat, so it has been able to express its full potential. Although some of this pasture introduction and evaluation work has already been done, or is in progress, in the Eastern Africa Region, there is probably considerable scope for more work on both herbaceous legumes (e.g. *Stylosanthes, Centrosema* spp) and tree or shrub legumes (e.g. *Leucaena, Desmanthus* spp), which have shown such promise elsewhere in the world. For some of the Eastern African Region environments that are not well represented in Australia or elsewhere, e.g. the intermediate-altitude and bimodal-rainfall zones, it may be necessary to mount new collecting expeditions. There appear to be comparable environments in parts of the Andes in Columbia which warrant attention (Snow 1976).

One should not, of course, ignore the legumes that are native to the Eastern African Region where the semi-arid tropical zones clearly have a substantial legume flora. While some workers have been quite disappointed with the performance of the indigenous legumes (e.g. Sands et al. 1970), others had better results when the evaluation was done on the more fertile soils. Anderson and Naveh (1968), for example, found that one native legume from northern Tanzania (*Rhynchosia sennaarensis)* produced between 16 000 and 18 000 kg/ha of dry matter over a 27 month period at two of the drier sites they used. This suggests that some of the legumes, at least, are inherently quite productive. We understand that an FAO/Government of Kenya/NORAD project (FAO 1979) has made extensive collections of legumes in recent years and evaluated them at a network of sites in Kenya. This information should be of great value in assessing the worth of the indigenous legume flora for possible use in ley-farming systems.

To sum up, we believe that productive legumes for use in experimental ley-farming systems are either already present in the Eastern Africa Region, or could be readily introduced from comparable regions elsewhere in the world.

Finding a suite of potentially productive legumes is only part of the story. Our work at Katherine, N.T. has been based on the premise that the nutritional constraints of the soils (apart from N) must be removed if we are to produce as much biological N as the physical environment will allow. We can only speculate on the extent to which nutritional constraints have been responsible for the reported poor performance of legumes in some of the earlier work in Eastern Africa. It is clear, however, that there are important nutritional constraints on many soils in Eastern Africa (McCown et al. 1983). In our view, these will need much more attention if the true potential of legume ley-farming systems is to be realized.

Surface Soil Management

Now let us turn to surface soil management. How relevant is the concept of no-tillage/mulch retention to agriculture in the semi-arid Eastern Africa Region? The Region appears to suffer the same problems asociated with cultivation as west Africa and northern Australia. Cases of serious soil erosion from croplands have been reported from most countries in the Region. Another important constraint to crop yield is the loss of large proportions of the rainfall as runoff, before the profile is recharged. This is especially acute in areas of bimodal rainfall where rainfall is marginal in one or both seasons (Njihia 1979).

To date, the building of earth structures has been the main approach for controlling the movement of water and soil. Terrace banks have proved effective in checking gross soil loss (Thomas et al. 1980), but their high capital and maintenance costs seriously restrict their use. However, even where terraces are constructed, they are insufficient in annual cropping systems, since they do not affect the primary source of the problem, viz. the soil surface. Small ridges when 'tied' with cross checks have been reported to be very effective in preventing runoff and erosion (Njihia 1979; Stewart and Hash 1982). Njihia (1979) found however, that stover mulch on unridged land was just as effective, and recognized the advantages of the latter in enhancing soil structural integrity and water permeability. Further research in comparing the hydrological implications of tied ridging and no-till/mulch retention is needed.

Although we have seen no reports of increased yields as a result of a no-tillage/mulch retention approach, as has been the case in Nigeria and Australia, Huxley (1979) found yields at Morogoro in Tanzania only moderately lower than with conventional tillage. This is the experience in most places in the world where no-tillage has been evaluated, but benefits in savings of soil, water, energy, and time (particularly in the early part of the growing season) almost always more than compensate for slight yield losses.

For no-tillage to be successful, at least two conditions must be achieved. Firstly, a non-selective herbicide with low mammalian toxicity must be readily available at a price a farmer can afford. Glyphosate Roundup® has been shown to be very effective (e.g. Ndahi 1982) and is very safe. Real costs of Roundup® have fallen progressively over the last 10 years, and the patent is due to expire soon. The pressing question is 'how much further will the price drop?' For obvious reasons, it is virtually impossible at present to find out the inherent cost of the product. However, we are not aware of any evidence that would prevent its manufacture in Africa, in the medium term, and its subsequent sale to progressive farmers at moderate prices. A second condition is the willingness of farmers to forego some fodder for livestock in the interest of mulch to protect the soil surface,since it is the mulch that is the key to success in no-tillage crop production (Gurnah 1975).

As with the legume and soil fertility areas, a realistic appraisal of the prospects of a no-tillage approach in the Eastern Africa Region requires further research. Questions that warrant immediate attention are:

1. What are the benefits (in quantitative terms) of no-tillage on soil and water conservation, soil fertility, and crop yields?
2. What are the relevant costs of, for example, herbicides and animal fodder to replace that left as mulch?
3. What are the attitudes of farmers to both their existing problems and to the new technology?

Summary

Legume-ley farming systems have been highly successful in benefiting both crop and animal production in temperate areas of southern Australia. This paper explores the prospects for developing comparable legume-ley farming systems for the semi-arid tropics (SAT) of northern Australia and elsewhere.

Although technology now exists for improving the productivity of grazing lands in Australia's SAT by oversowing with legumes and applying fertilizers, it is generally not profitable, and the land is used mainly for extensive grazing of beef cattle. Dryland cropping appears to hold considerable promise, but the costs of the technology are high and the returns are relatively low.

The paper reports on the evaluation of a farming strategy in which net benefits are enhanced by synergies gained by integrating beef production and cropping. This strategy is stated as a hypothetical system with the following features:

* Self-regenerating legume-ley pastures of 1-3 years duration are grown in rotation with maize and sorghum.
* Cattle graze native-grass pastures in the wet or green season and leguminous pastures and crop residues in the dry season.
* Crops are planted directly into the pasture that is chemically killed at, or shortly before, planting.
* The pasture legume sward, which volunteers from hard seed, is allowed to form an understorey in the main crop.

The research program uses a systems approach in evaluating the biological feasibility of the strategy for this climatic zone. Emphasis is placed on elucidating dependence on climatic and eda-

phic variables so that the results can be extrapolated to other regions. Important early findings include:

1. One year of legume-ley has generally provided a succeeding crop with the equivalent of at least 50 kg/ha of fertilizer N. Longer leys have had greater effects and a longer residual effect.
2. Mulch retention and no-tillage has generally resulted in increases to maize grain yield of over 20%.
3. Herbicide and planting technologies have been developed to a stage where on-farm evaluation can proceed.
4. Cattle have gained weight during the dry season when grazing legume-leys and maize stover.

The prospects for developing related ley-farming systems for the SAT of the Eastern Africa Region are examined from the point of view of the availability of suitable legumes, the need to overcome soil fertility constraints, the relevance of the concept of no-till, and the availability of cheap herbicides to produce the mulch for the no-till system.

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Improving the Nutrition of Grazing Animals using Legumes, Fertilizer, and Mineral Supplements

R.J. Jones*

Nutritional stress, particularly in the dry season, is the major constraint to animal production in the subhumid tropics and subtropics ('t Mannetje 1982). In northern Australia various strategies have been, and are being, studied to alleviate the nutritional stresses to increase the productivity of the major livestock enterprise of this area, i.e. beef production. In this paper I review some of these strategies and the impact that they can make on beef production, and tentatively suggest strategies that may have relevance to the subhumid regions of Africa.

The Grazing Resource and its Limitations

The subhumid tropical area of Australia lies in an arc across the north of the continent extending down the east coast to the Queensland border at about 28° S (Fig. 1). This area lies to the north and east of the arid centre of Australia and inland from the narrow wetter coastal belt. Rainfall has a high summer (Dec-March) incidence but with a significant winter component in southern Queensland. Annual rainfall ranges between 500-1 000 mm with a high variability, especially in northern Queensland, resulting in marked variation in pasture yield from season to season (McCown et al. 1974).

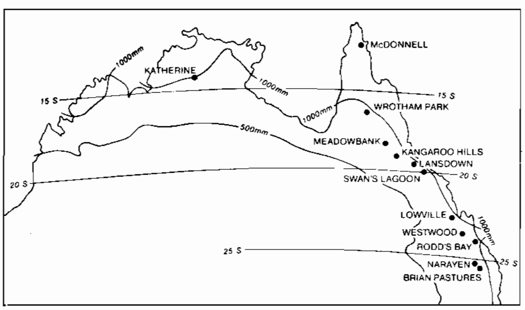

Figure 1. Location of some experimental sites in northern Australia together with 500 mm and 1000 mm isohyets.

The vegetation over much of this region is an open woodland, usually dominated by *Eucalyptus* species, although in the drier regions on more fertile clay soils, *Acacia*-softwood scrubs or natural grasslands may occur. The herbaceous understorey in these woodlands is essentially graminaceous, the major genera being *Heteropogon, Themeda, Bothriochloa, Dichanthium, Chrysopogon*, and *Sorghum*. In many respects these woolands have affinities with the savannahs of Africa. The formation and maintenance of these grazing lands has been strongly influenced by the burning of dry roughage, which has regularly occurred through planned or unplanned fires.

With few exceptions, the soils of the region have a low nutrient status with widespread deficiences of phosphorus and nitrogen and varying deficiencies of several other major and trace elements. In addition, many soils have poor physical conditions with surfaces that set hard on drying and tend to seal when wet (Hubble 1970). Soils are generally mildly acid with no serious problems due to high acidity.

The combination of low fertility soils and a prolonged dry season results in pastures that have a low nutritional quality for most of the year (Norman 1966, McIvor 1981). The high quality leafy forage present after the start of the rainy season, rapidly declines as the grasses become reproductive. Pastures are then essentially stemmy throughout the dry season, and in the subtropics may deteriorate further after frosting. In the dry season, even the most nutritious leaf component of perennial grasses may have a nitrogen concentration of less than 1%, a phosphorus content of 0.05% and a dry matter digestibility of 40-50% (McIvor 1981). Values for the dry leaf and the stem fractions may be even lower.

In addition to the low pasture quality, total dry

* Division of Tropical Crops and Pastures, CSIRO, Aitkenvale, (Townsville), Queensland, Australia.

matter yields, even in the absence of grazing, are also low (Table 1). Clearly animal production can only be sustained on such pastures if the stocking rates are sufficiently low to enable selective grazing of the most nutritious herbage in the dry season. On these native pasture ecosystems, stocking rates vary from 1 cattle beast to 3 ha in the better areas of SE Queensland to 1 beast to 25-35 ha in the northern tropics (Mott et al. 1981).

Cattle growth on these native pastures reflects the seasonal quality differences described above. Rapid growth following the start of the wet season continues until the pastures dry off. Cattle maintain weight over a transition phase, then lose weight toward the end of the dry season. Cattle may lose up to 50% of their wet season gain over the dry season. Consequently steers may take 4-5 years to reach a slaughter weight of 500 kg (Fig. 2).

In breeding females the low nutrient supply can result in delayed sexual maturity, poor conception rates, long periods of post-calving anoestrus and high mortality rates in animals that are lactating during the dry season. These problems are accentuated on pastures in far northern Australia where the dry seasons are more prolonged and where high temperature stress is greater. Under these conditions nutrition is probably the main factor influencing reproductive performance (Entwistle 1983).

In spite of these limitations a viable beef industry has been developed; this is based on the use of large areas of lightly-stocked land with large numbers of animals per property owner. This system is related in the north to the production of lean beef for the export market. It depends on relatively low financial returns per beast and hence precludes any but modest financial inputs per beast or per unit land area.

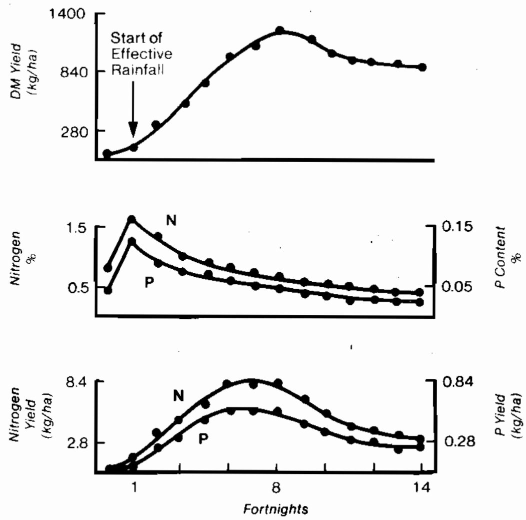

Figure 2a. Changes in dry matter yield, nitrogen content, phosphorus content, nitrogen yield, and phosphorus yield of native pasture at Katherine, Northern Territory, Australia.

Basic Principles for Improving Nutrition

Live weight change is generally a good indicator of the nutritional status of grazing ruminants. Exceptions can occur in the late dry season and early wet season when changes in gut fill can

Table 1. Yield characteristics of four native pasture communities in subhumid tropical Australia.

Site	Mean Rainfall (mm)	Maximum yields of standing herbage (kg/ha) DM	N	P
Katherine N.T.[a]	900	1 400	8	0.6
Lansdown Qld[b]	870	4 000	25	2.5
Redlands Qld[b]	600	1 500-2 000	11	1.0
Rodd's Bay Qld[c]	886	2 000	16	2.8

a. Norman 1966; b. McIvor 1981; c. Shaw and Bisset 1955.

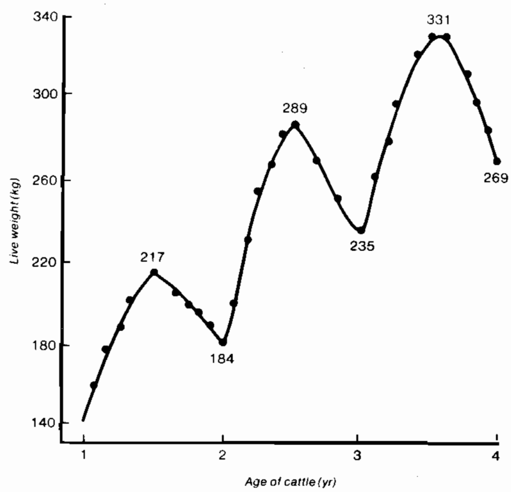

Figure 2b. Seasonal liveweight changes in 1-4 year old cattle grazing native pasture at Katherine. (After Norman 1966).

confound the empty body weight changes that are occurring. Rate of live weight change within any weight class reflects the intake of digestible dry matter (DDM) (Minson et al. 1976), which is an indicator of energy-intake. The relation between weight gain and digestible dry matter intake is usually linear over the range of live weight gain (LWG) encountered in grazing animals.

A decline in DDM intake with an associated decrease in LWG regularly occurs as forages mature. The DDM intake may be further depressed through deficiencies of protein or minerals or the presence of toxins. Correction of these deficiencies improves DDM intake but frequently the feed is of such maturity that even with deficiencies corrected, little production can be expected. Maintenance of high production would necessitate the use of energy or protein concentrates but apart perhaps for dairying and for very limited feedlotting of beef, such feeding is impractical and uneconomical in Australia.

With fibrous feeds, intake is limited by the need to reduce particle length to less than 1 mm to permit passage of material out of the reticulo-rumen (Minson 1982). Particle reduction occurs through chewing and through the action of rumen microbes. In the early wet season the selection of the more nutritious and readily comminuted plant leaf permits large intakes; as the plant matures, comminution becomes more difficult, partly through the resistance of the fibrous material to chewing and partly through the effects of nutritional deficiencies on the rumen microbes. Supplementation can ensure adequate amounts of ammonia and minerals for the microbes and hence permit the development of the microbial population that the forage is capable of supporting. However, in the grazing situation nothing can be done to improve the effectiveness of chewing in plant comminution; hence the physical composition of tropical forages is probably the major limiting factor to increased animal production.

The lower inherent digestibility of tropical grasses compared with temperate pasture grasses is associated with the differences in leaf structure between grasses with the C_3 photosynthetic pathway and those with the C_4 photosynthetic pathway (Wilson and Minson 1980). The latter have a greater proportion of supporting tissue of low digestibility and a lower proportion of mesophyll tissue of high digestibility (Wilson and Minson 1980). As a result of this difference, feed intakes, digestibility, and animal production are lower than from temperate grasses such as ryegrass. This is a fact of life and there is nothing that can be done to change this aspect.

However, factors other than the fibrous nature of maturing forages can limit the intake of dry matter and hence of digestible energy. In many situations nitrogen (protein) will be the primary limiting factor. If the dietary N concentration falls below about 1% then intake will be reduced (Minson 1982). As pointed out earlier, even the green leaf fraction of native perennial grasses can fall below this critical level throughout the dry season. Other deficiencies such as P, S, Na, or trace elements may be present although masked by the overriding N deficiency. Such deficiencies may only become apparent once the N deficiency has been overcome.

Critical concentrations of these nutrients in the feed below which deficiencies can be expected are given in Table 2. Where diets contain lower concentrations than those listed in Table 2, appropriate supplementation with the deficient nutrient may result in higher intakes. Responses may not be achieved if the energy supply from the roughage itself is limiting. If this proves to be the case the only alternative is to supply an available energy source such as molasses or grain, or to replace the base roughage by more digestible material of higher energy content.

Table 2. Dietary mineral requirements of cattle for growth (200 kg live weight; 0.5 LWG[a] kg/d); and lactation (500 kg live weight; 10 kg milk/d) (after Little 1982).

	Growth	Lactation
	(% in DM)	
Calcium	0.43	0.32
Phosphorus	0.12	0.30
Magnesium	0.15	0.18
Sodium	0.07	0.10
	(ppm in DM)	
Zinc	12.20	18-25
Copper	8-14	10-14
Manganese	10-20	10-20
Cobalt	0.11	0.11
Selenium[b]	0.03-0.05	0.03-0.05
Iodine[c]	0.5	0.5

a. LWG = live weight gain.
b. These levels regarded as probably marginal.
c. Probably adequate for all cattle and sheep in the absence of dietary goitrogens.

Stategies for Improving Nutrition of Grazing Animals

Before discussing the direct alleviation of the nutritional constraints on survival and production of grazing animals by introducing supplements or alternative feed sources, there are some management options that may be possible within the economic limitations to property development. Use of these options can result in better utilization of the existing feed resource.

Management Options

1. Use of Better Adapted Genotypes

In northern Australia the use of *Bos indicus* crosses has resulted in better survival and higher turn-off of fattened steers compared with *Bos taurus* cattle (Hodge 1980). Better resistance to heat stress, ticks, and internal parasites by *Bos indicus* cattle, together with lower maintenance requirements contributes to their superior performance. In the absence of environmental stresses *Bos taurus* cattle have higher feed intakes, higher growth rate, and higher fertility levels but these attributes cannot be fully expressed under the stressful field conditions in northern Australia and hence their full potential is unrealized (Vercoe and Frisch 1982).

In Africa the use of *Bos taurus* cattle for crossbreeding can increase the potential for higher production but unless they retain a sufficient level of tolerance to the stresses imposed by disease, ticks, internal parasites, and low quality of the feed supply, the potential benefits will not be achieved.

2. Controlled Mating and Strategic Weaning

Where rainfall is highly seasonal and predictable, management to match the nutritional requirements of the breeder herd with the nutritional quality of the pastures can be effective in reducing losses of both breeders and calves. In Queensland this entails mating for a prescribed period of the year (Jan-April) so that cows will calve before the wet season. This enables cows to lactate on an improving feed supply and for calves to be weaned before cows are severely stressed in the dry season (Rudder and McCamley 1972).

Early weaning of calves at three to four months of age can improve the nutrition of the cow and improve subsequent fertility. It is a management strategy particularly relevant in drought years to improve survival of breeders (Hodge 1980). It does, however, imply that a reasonable feed supply is available for the weaners deprived of milk.

3. Grazing Management

On every grazing property some areas are more fertile and better watered than others. Such paddocks are best used for stock with high nutrient requirements, e.g. weaners and fattening cattle. Conversely, poorer areas can be reserved for dry cows. Rotational pasture management is not practised in tropical Australia. Experimental evidence in different countries indicates that nutritional benefit to livestock from such management is minimal ('t Mannetje et al. 1976). Under some short duration grazing systems cows can experience greater stress and have lower conception rates than cows under a continuous grazing management (Jackson 1972). Furthermore, fencing and watering costs at current prices exclude multipaddock grazing systems for economic reasons.

The Use of Supplements

The aim of supplementation is to provide nutrients to improve the utilization of the low cost pasture to increase productivity or survival economically.

To be effective, supplements must be formulated to correct the deficiency or deficiencies that limit production. Pasture sampling is often ineffective in deciding which nutrients are limiting because animals selectively graze. For example, we found that steers were able to select a diet with about twice the phosphorus content present in the total pasture (K. Betteridge and R.J. Jones, CSIRO Division of Tropical Crops and Pastures, Davies Laboratory, Townsville, unpublished data). However, if the nutrient levels (in plucked leaves) are below the stated requirements, a deficiency can be suspected.

Accordingly to Kempton (1982) an effective supplement for animals on low protein diets should:

1. Be palatable to the animal.
2. Maximize the outflow of microbial protein from the rumen.
3. Provide a bypass protein, if necessary, to augment the supply of amino acids from microbial protein to meet the protein requirements of the animal (Egan 1965).
4. Increase the metabolizable energy intake to meet the energy demands for the desired level of production.
5. Increase the efficiency of absorption of nutrients from the rumen and intestines.

A primary aim of supplementation of tropical forages is to supply nitrogen (ammonia) to increase the activity of the rumen micro-organisms to digest the fibre fraction of the diet. Microbial growth may be impaired when ammonia concentration in the rumen falls below 20-50 mg N/litre (Satter and Slyter 1972). Provision of a soluble non-protein nitrogen (NPN) supplement such as urea will increase rumen ammonia concentrations although the effect may be transitory unless the urea intake is maintained. Lack of response to urea supplementation under grazing conditions has been attributed to discontinuity of ammonia levels in the rumen (Leng at al. 1973).

However, in tropical areas postive live weight gain responses to urea supplementation (20-30 g urea/d) given with molasses, or as dry licks with sodium chloride as the carrier, have been measured with young cattle on native pastures (Winks et al. 1970; Winks et al. 1979; McLennan et al. 1981; Winks et al. 1982). Live weight responses varied with years and supplement formulation from about 20 to 180 g/d during the feeding period. However, in most years compensatory gain of unsupplemented animals during the following wet season eroded the gains made in the feeding period. These field responses support the results of pen feeding experiments where urea supplementation improved the intake of low quality pasture hay. Nevertheless, in some pen feeding experiments sulphur supplementation was also necessary for a positive response to urea (Siebert and Kennedy 1972) indicating that the base roughage had insufficient sulphur for the conversion of urea into microbial protein.

With breeding cattle, which are subject to greater stress, urea supplementation has greatly reduced mortality rates and the need for survival feeding (Holroyd et al. 1977). However, fertility of cows supplemented with urea in the dry season was not improved when a restricted (in Nov-Dec) calving regime was used (Holroyd 1980). This was probably due to the lower stress experienced under this management system.

In most years the weight advantage obtained by urea supplementation in the dry season disappeared during the following wet. Unsupplemented animals of poorer body condition showed such compensatory gain during the wet season that the weights of both groups were much the same when the wet season finished. This consistent observation has limited the widespread use of such supplements. Provided an animal can be kept alive by judicious small-scale supplementation until the wet season is well established, compensatory gain will permit reasonable productivity.

However, the livestock manager finds himself in an quandary——to be effective as a dry season supplement, urea feeding should commence early in the dry season before the condition of the animal deteriorates. Molasses-urea feeding will not prevent deaths when cattle have become emaciated. Under these conditions supplements containing true protein and energy must be used (Lindsay 1980). Meat meal and cereal grains, or cotton seed meal and molasses can be used as effective supplements. Timing of the start of supplementation and decisions on the extent of supplementary feeding require judgment by the manager. Research is in progress to provide a better basis for such decisions.

On native pastures, responses to supplements other than N are less consistent, although responses to P, S, and Na appear to be more marked in the truly tropical northern areas where the dry season is more pronounced and when the overriding N deficiency has been alleviated. Deficiencies of S are more apparent on soils derived from basalt, whereas P deficiency is more marked on the red and yellow earth soils of northern Australia. Low Na levels are characteristic of some native and introduced species, e.g. *Heteropogon contortus, Themeda australis, Bothriochloa decipiens, Dichanthium sericeum, Cenchrus ciliaris, Stylosanthes humilis*, and *Macroptilium atropurpureum* (Gartner et al. 1980). Although the Na content of individual species varies with exchangable Na in the soil, the ranking of species remains the same (Playne 1970). Responses to Na supplementation of cattle grazing native pastures low in Na have been obtained with lactating cows (Murphy and Plasto 1973) and with steers (W.H. Winter, CSIRO, pers. comm.) and these responses occur both in the wet and dry seasons.

Most responses to P have been obtained in the wet season rather than in the dry season. For example, Winks et al (1977) increased daily LWG of steers in three wet seasons by 90-200 g/d compared with controls when phosphoric acid was used in the drinking water. In the following dry season, steers lost more weight on the supplemented treatments——possibly because of higher gains in the previous wet season.

On Birdwood grass (*Cenchrus setiger*) pastures, cattle supplemented with N, P, and S supplements in the drinking water lost less weight in the dry season and had higher gains in two of three wet seasons. Supplemented steers gained 31, 70, and 44 kg/head more than controls over the three years (Holm and Payne 1980). On *Themeda-Sorghum* pastures a combination of burning off half the paddock together with yearlong supplementation with N, P, S, Na, and trace elements has increased gain of steers stocked at 1 to 15 ha by 3 to 4 fold. Most of this gain occurred in the wet season (W.H. Winter, CSIRO Charles Darwin Laboratory, Darwin, pers. comm.).

In summary, supplements have given varied responses in grazing experiments. This can be expected as soils and pastures vary from area to area and moisture availability varies from year to year. Dry season NPN supplements have reduced mortality or the need for specific survival feeding and have increased gain or reduced weight losses in steers. However, compensatory growth of control groups eliminated much of this weight advantage. It is likely that where deficiencies of other nutrients are present, supplementation year long may be required for best results and supplements containing several minerals may also be necessary. Supplements only help to improve utilization of existing feed. If utilization is heavy, then adverse effects on the yields or botanical composition of native pasture could occur. Basically, production will ultimately be limited by the physical characteristics of the feed rather than by its mineral composition (Minson 1982); any further improvement will be dependent upon improvement of the pasture resource by means of sown pasture species of higher inherent feeding value.

Use of Improved Pastures

Feed quality of graminaceous pastures in the subhumid zone is stongly linked with climate and in particular with water availability (McCown 1980; McCown et al. 1981). Breaking this stong link is essential for increased productivity. In Australia adapted tropical legumes have been used in achieving this objective (Jones 1983). Legumes can effectively alleviate one of the dominant constraints to animal production, i.e. insufficiency of protein. In addition, and unlike grasses, digestibilty is not greatly depressed by high temperatures (Wilson 1982) and intake of the mature forage is higher than for grasses of the same age (Minson 1982). Furthermore, some legumes contain tannins that can protect proteins from excessive degradation in the rumen, so providing bypass protein, which may improve feed utilization (Kempton and Nolan 1978).

The presence of the legume not only improves the quality of the pasture, so resulting in better utilization of the feed grown, but may also increase total yields and permit a higher carrying capacity, often without increasing the risks normally associated with a higher stocking rate. Such legume based pastures overcome the major limitation of low yield and low nutritional quality of many native pastures.

On soils low in nutrients the use of single superphosphate (approximately 10% P, 10% S, 20% Ca) sometimes coupled with trace elements, has been an essential ingredient for success. In the subhumid zone, three legume genera have provided adapted legumes for commercial use in pastures, viz. *Stylosanthes, Macroptilium*, and *Leucaena*. Results from grazing experiments with these legumes will be used to illustrate the improvement in animal production that can be achieved.

From the data on steer live weight gains from grazing experiments with *Stylosanthes* in Australia compiled by Gillard and Winter (1983), the mean benefit from legumes plus superphosphate was calculated. From nine separate experiments (from 14°-26° S) mean gains were 76 kg/head/yr and 28 kg/ha/yr for the native pasture controls compared with 129 kg/head/yr and 96 kg/head/yr for the legume based treatments. This represents a 70% and a 242% increase in gains per steer and per ha, respectively.

In experiments where legumes or fertilizer were used separately, the benefits were less than when used in combination.

At Rodd's Bay on a shallow prairie soil deficient in N, P, K, S, and Mo, the effect of sowing *S. humilis* was greater than the effect of applying Mo superphosphate (Table 3).

In other experiments however, gains per animal have been similar to those on native pasture in the absence of fertilizer, although

Table 3. Effect of fertilizer and oversowing with the legume *Stylosanthes humilis* on live weight gain of cattle. Values are means over 7 years (Hacker et al. 1982).

Treatment	Spear grass			Spear grass and Townsville stylo		
	steers per ha	weight gain per hd	weight gain per ha	steers per ha	weight gain per hd	weight gain per ha
No Fertilizer	0.3[a]	83	25	0.7	121	93
	0.6	47	29			
Fertilizer[b]	0.6	100	62	0.9	149	148

a. Normal stocking rate for district.
b. Similar amounts of fertilizer (P, S, and Mo) were applied to the two fertilized pasture treatments.

stocking rate could be doubled. Under these conditions, pastures were *S. humilis* dominant.

Beneficial effects of fertilized *S. humilis* pastures have also been measured with breeding cows and their calves (Gillard and Winter 1983). Calving increased from 66-85% when 375 kg/ha superphosphate was applied (Edye et al. 1971), and in another experiment conception rates of lactating cows on *S. humilis* pastures fertilized with 125 kg/ha superphosphate were 70% compared with only 43% for cows on native pasture (Holroyd et al. 1977).

In the dry subtropics, pastures based on Siratro (*Macroptilium atropurpureum*) have produced gains of 153 kg/head and 167 kg/ha/yr compared with 113 kg/head and only 30 kg/head from native pastures over a 10 year period. Pure grass pastures of *Cenchrus ciliaris* fertilized with superphosphate and 168 kg N/ha/yr gave identical animal gains to legume-based pasture ('t Mannetje 1982). In the same environment, pastures based on Siratro produced four times the number of calves and five times the weight of weaned calves per ha as the native pastures ('t Mannetje and Coates 1976).

When grazed in conjunction with native pastures, areas of legume-dominant pasture can provide a useful supplement. The beneficial effects are then proportional to the length of time the animals spend on the improved legume-dominant area. Thus with fertilized *S. humilis* grazed in conjunction with native pasture, the LWG of steers over a 630 day period (y) was linearly related to the number of days spent grazing *S. humilis* (x) by the equation:

$$y = 0.377x + 55.5 \text{ kg/head } (r^2 = +0.94).$$

With dry season grazing only, the linear relation was:

$$y = 0.794x - 34.3 \text{ kg/head } (r^2 = +0.86)$$

where x is the number of grazing days on *S. humilis* out of a total of 112 (Norman 1970).

Shrub legumes may prove to be more persistent and easier to maintain weed-free than herbaceous legumes for supplementary feed. Most experience has been with *Leucaena leucocephala* (leucaena) grown in widely spaced rows. Unlike many other legumes it is better adapted to clay soils, particularly non acid clays, grows well in the subtropics and the tropics, and is extremely deep rooted. As a supplement, occupying 20% of the total grazing area, cattle gained 113 kg/head more than controls grazing only native pastures at the same stocking rate over a 33 month period (Forster and Blight 1983). These pastures were not fertilized and the leucaena was protected from grazing during active growth in summer in order to accumulate feed for the dry autumn-winter period. These results substantiate those obtained when leucaena was fed as a supplement in Fiji. There, steer gains were increased from 215 g/d to 300 and 500 g/d when 0, 10, and 20% of the native pasture was planted to fertilized leucaena (Partridge and Ranacou 1974). In that experiment the steers had access to leucaena for one to two days per week on the 10% treatment, and for three to four days per week on the 20% leucaena treatment. The contribution of 1 ha of browse in this experiment was calculated as 600 and 800 kg LWG/yr for the 10% and 20% leucaena treatments, respectively (Jones 1979).

The fear of leucaena toxicity resulting from ingestion of mimosine has contributed to the slow acceptance of this valuable grazing shrub. Better understanding of the effects of mimosine and its goitrogenic ruminal metabolite 3 hydroxy-4 (IH) pyridone (DHP) has reduced the concern once associated with this plant (Jones 1979). In addition, the use of specific rumen bacteria to degrade DHP could well remove any toxicity problems in the future (Jones 1981).

The use of nitrogen fertilizer on sown grass pastures can result in higher animal production than from native pastures in subhumid areas. However, the animal production obtained is similar to that achieved with adapted legume species ('t Mannetje 1982, and the author's unpublished data). Economically therefore nitrogen fertilized grass is an unattractive option and is not used commercially for beef production.

Use of Supplements with Improved Pastures

The need to use superphosphate on soils low in P (those with 15 ppm available P) to obtain good animal production is becoming increasingly apparent. With *Stylosanthes* spp this necessity is not related to the persistence of the legumes. In unfertilized grazed pastures of *S. hamata* and *S. scabra* the legumes are often dominant though steer gains are poor (Gardener 1983). This clearly indicates that the fertilizer is necessary to satisfy the requirements of the animal for the minerals (usually P and S) supplied by the fertilizer.

Where extreme P deficiency occurs in the pastures, cattle may avoid eating a high proportion of legume even in the dry season (McLean et al. 1981). This reduced percentage of legume in the diet in the absence of superphosphate is not however a consistent feature of unfertilized pastures since at Lansdown near Townsville, steers selected similar proportions of legume from unfertilized pastures and from pastures heavily fertilized with superphosphate (Freire 1981; K. Betteridge and R.J. Jones, CSIRO Davies Laboratory, Townsville, unpublished data). Detailed studies at this site have shown that the poor performance of steers is due to low intake of digestible dry matter associated with low P and S concentrations in the herbage and not to a reduced legume proportion in the diet (Freire 1981).

The cost of using fertilizer is a major factor in the economics of using improved pasture. Use of mineral supplements in conjunction with legume-based pastures, which require little or no fertilizer, is an attractive alternative. Only a few studies have been completed but the results support the predictions from pen feeding experiments that mineral supplementation of animals on unfertilized legume-based pastures wold be expected to increase animal gains. Thus Winks et al. (1977) increased the gain of steers grazing unfertilized *S. humilis* pastures over a three year period by a mean of 39% (range 20-69%) when 5-6 g P/head/day was fed. Spectacular responses to P and S supplementation were measured over one season at Katherine, Northern Territory on *S. hamata* cv Verano-native grass pastures. The supplements were incorporated in salt and were fed to steers grazing unfertilized or fertilized pastures (Table 4) (Winter et al. 1983).

A dry season response from steers grazing a *S. guianensis* cv Graham pasture on a sulphur deficient soil was only obtained when a supplement containing both Na and S was fed. There was no significant effect of either S or Na when fed alone, but in combination a gain of 26 kg was obtained over the 160 day dry season compared with a loss of 9 kg for unsupplemented steers (Hunter et al. 1979). Clearly these encouraging results offer possibilities for good animal gains from unfertilized legume-based pastures or pastures fertilized with low rates of fertilizer.

Although responses to other minerals such as Cu, Zn, and Co have not been measured in the subhumid tropics in Australia, responses have been measured in wetter environments (Gartner et al. 1980). It is likely that as beef production becomes more intensive in the subhumid areas, mineral deficiencies will become more apparent.

Relevance of the Research Findings to Africa

In Africa problems associated with the nutrition of grazing animals in the subhumid and semi-arid areas are far more complex than those experienced in northern Australia. Disease problems are greater as are the problems of ectoparasites. These indirectly affect the nutrition of grazing animals and in some areas, which are characterized by the prevalence of tsetse flies and trypanosomiasis, limit the numbers of animals that can utilize the resource. Average stocking densities in these wetter areas may then be less than in the arid zone (Mahadevan 1982). In other areas, problems of overgrazing associated with increased human and animal populations are encountered. Reduced stocking in these areas would undoub-

Table 4. The effects of supplements of P and S on steer live weight gain (kg) on *Stylosanthes hamata* cv Verano pastures stocked at 0.8 steers/ha in the wet season (from Winter et al. 1983).

Supplements (g/head/d)	Fertilizer Nil	Plus[a]
Nil	42	45
3 g S	29	74
10 g P	143	132
10 g P + 3 g S	167	218

a. Basal dressing of 100 kg/ha single superphosphate plus 15 kg/ha/yr maintenance.

tedly improve the nutrition of the remaining animals. However, such a strategy may be socially unacceptable. Where land is communally owned it would be difficult for motivated individuals to introduce improvements unless the community at large viewed these as desirable.

Furthermore, the profit motive, which is accepted in most developed countries, is not always seen as of primary importance in all African communities. Any progress towards improving the nutrition of grazing animals for the benefit of the peoples concerned must surely be made in the context of the existing social structures. It has often been said that the socio-economic problems in developing countries are far greater than the technological problems. Even though this may well be true, an awareness that some technological solutions are possible is at least a start!

In spite of the differences which exist between Australia and Africa, in both areas the principles of animal nutrition are the same.

The constraints to production will, however, vary from area to area as they do in Australia. The identification of these constraints is an essential prerequisite to the finding of potential solutions. In areas where there is adequate feed of low nutritive value, the use of mineral supplements to overcome identified limiting nutrients can improve the nutrition of grazing animals.

The specific nutrients required need to be identified so that soundly based supplements can be formulated. In the African situation the formulation and distribution of such supplements, even if deemed to be economically viable, could pose problems that may need to be tackled at Government level. In areas where the feed grown is already well utilized because of high stocking pressures it is unlikely that the use of mineral supplements alone will be of much value. Under these circumstances either the stocking rates will have to be reduced or pasture improvement measures adopted. Neither option will be easy to implement in Africa but unless some attempt is made to adopt greater control of grazing, with or without some form of pasture improvement, then any ideas of improving production by manipulation of grazing systems without any additional input will be wishful thinking.

In the majority of situations N is a major limiting factor to further production. As Pratchett (1983) has suggested in reference to the grazing lands of Botswana 'only by increasing the level of N in the system can major improvements in cattle performance and yields of beef per hectare be expected'. Increasing the N level can be achieved in several ways, viz. by the use of N fertilizer, N supplements, or legumes. Nitrogen fertilizer would appear to be an uneconomic option from the start in the drier areas.

Supplements may be an attractive option where individuals can provide supplements to their own cattle when held overnight in the boma.

However, apart from the economic considerations and the availability of supplements, the data relating cattle response to any given supplement or combination of supplements is lacking for many areas.

From Australian research the introduction of persistent nutritious legumes (with fertilizer) to provide the N has given the greatest and most consistent nutritional improvement to grazing stock, enabling both higher gains per animal and higher stocking rates. This search for and selection of suitable legumes has been a costly research exercise extending over more than a quarter of a century (Hutton and Henzell 1976). The vast majority of introduced legumes fail to persist under grazing and even after this long period of research the successful species for the subhumid areas number only five.

For reasons discussed more fully elsewhere (Wheeler and Jones 1977), most of these legumes would be unsuited for pastures in the drier higher altitude areas of Eastern Africa where night temperatures are low. However, this does not negate the principle that persistent, palatable legumes are the key to any realistic program for improving the productivity of grazing animals. It merely emphasizes the need to select the needed legumes under the existing conditions in Africa. The contribution from the legumes could be via herbaceous legumes oversown into native pastures, shrubs used as protein banks, or as trees to provide edible pods. Material for such an exercise can come from genetic resource collections held by CSIRO, EMBRAPA, CIAT, and more recently ILCA.

Direct transfer of technology from a developed to a developing country can rarely be immediately effective. However, the development of a sound principle within the existing system could be more effective.

In using pasture technology a major problem is associated with information transfer to people skilled mainly in handling livestock. This problem is not confined to Africa. Even in northern Australia cattlemen (graziers) are often unused to sowing crops. They know cattle, but have no previous experience with sown or improved pastures. The development of improved pastures in these areas is slow. In part this has been due to the fact that properties are large with a low labour input, a higher number of cattle per property, and low stocking pressure. This has resulted in adequate returns without pasture improvement. Other inputs at this stage of development, such as the sinking of bores, construction of fencing, and the introduction of better tick resistance and heat tolerance through the use of *Bos indicus* bulls have been given priority. Further increases in production will be dependent on improving the nutrition of the cattle by the use of supplements, the use of improved pasture, or a combination of both. Such development will depend very largely on increased demand for Australian beef, from overseas.

In much of Africa these conditions do not apply. The pasture resource is already well utilized, the cattle well adapted to the climatic conditions, herds are managed intensively in terms of labour input, and much of the meat produced is consumed locally. In many areas the pasture resource is over-utilized, production per ha is less than what could be achieved with lower stocking pressures, and the production potential of the resource is being reduced. The problems are indeed great, but unless stocking pressures on the resource can be controlled or some form of pasture improvement introduced, then increases in production are very unlikely——rather, production will decline as the pasture resource continues to be over-utilized.

In the African context a suitable starting point may well be with legumes in a mixed farming system. Here the benefits to the following grain crops and to animals utilizing both cereal stubbles and the legume ley, as described by Jones and McCown (1983) could provide the necessary stimulus for a closer integration of crops and livestock. An appreciation of the contribution of grazing legumes to livestock production in this system may then be extended to an appreciation of their worth in the freely grazed pastoral areas.

Summary

The major constraint to beef production in northern Australia as well as in most other tropical countries is poor nutrition. This is related to the low fertility of the soil on which the pasture resource is grown and to the low quality of the pastures, particularly in the dry season. Quantity of feed rather than its quality becomes the major limitation in overgrazed situations.

Options for improving the nutrition of grazing animals include reducing the stocking pressure, controlling diseases and pests, use of adapted genotypes, herd management to synchronize peak herd requirements to the wet season, supplementation of animals, fertilization, use of improved pastures, or combinations of these. The effects of supplementation and pasture improvement on cattle production in Australia are discussed.

Urea supplementation has improved steer grains in the dry season, but the benefits are usually lost during the next wet season through compensatory gain of control steers. Responses to P occur in the wet season when N concentration of the herbage is not a limitation. The magnitude of the response varies from season to season and on the P deficiency of the soil.

Year-long supplementation with N, P, S, and Na has given increased steer gains of 30-70 kg/yr when grazed at the same stocking rate as controls of *Cenchrus setiger* pastures.

Oversowing with *Stylosanthes* spp has enabled stocking rates to be doubled. Used in conjunction with fertilizer (P, S, Ca) gains/animal increased from 76-129 kg/yr and gains/ha from 28-96 kg/yr with *Stylosanthes* based pastures. In south east Queensland, Siratro based pastures have increased gains/animal from 113 kg/head on native pasture to 153 kg/head so enabling earlier turnoff. Gains/ha were increased from 30-167 kg on the improved pastures. Use of shrub legumes to supplement the native pastures is feasible. Where *Leucaena leucocephala* occupied 20% of the grazing area, cattle gains increased by 133% compared with controls on native pasture only.

Breeding performance and the gains of calves were also increased on the improved pastures.

With legumes capable of growing at low soil P levels a combination of low rates of fertilizer combined with mineral supplementation could

be an effective option for the future.

The relevance of the Australian results for African conditions is briefly discussed.

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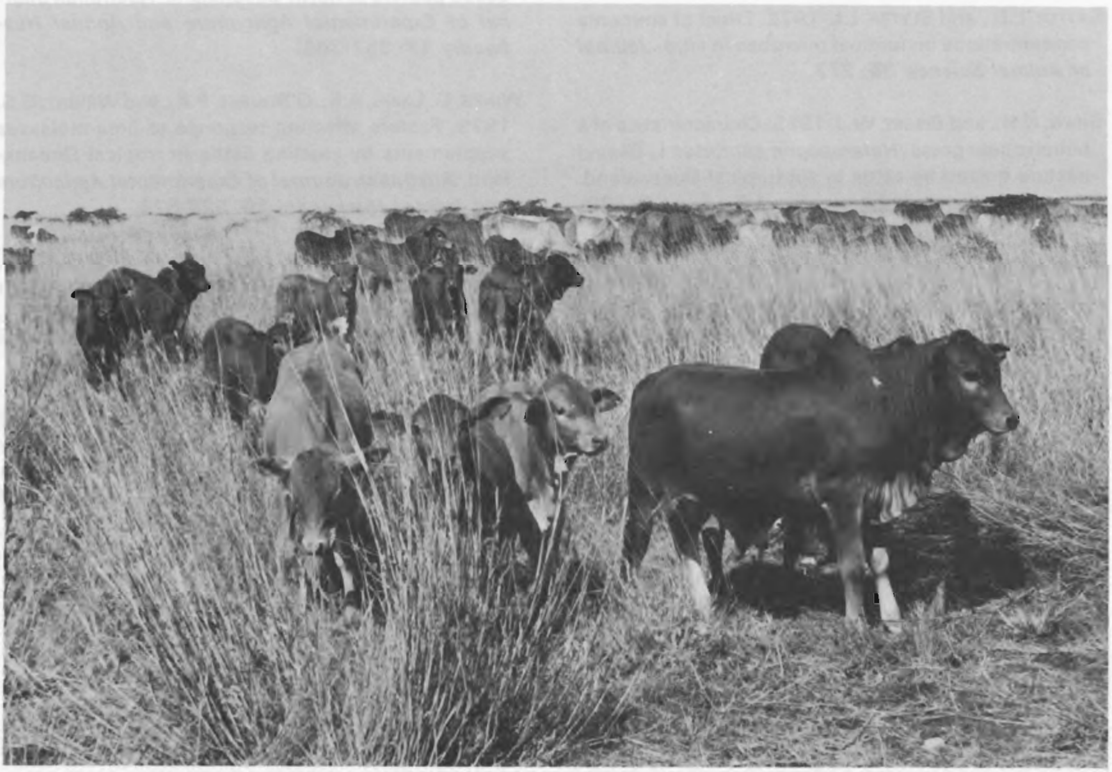

A herd of healthy young cattle grazing on native African pasture and showing freedom from the major production constraints in Africa, namely disease and malnutrition.

Animal Health Factors Involved in Livestock Production

J.W. Copland*

The animal, particularly the ruminant, is the key to the utilization of low-quality land and forage. Such land may be too steep, too arid or otherwise difficult for plant production, and in the absence of high-yielding crops, would normally be wasted as a food-producing source.

Animal diseases are a major constraint to livestock production in Africa, where many of the major infectious diseases of ruminants are present, such as rinderpest, foot-and-mouth disease and trypanosomiasis. Australia has been fortunate so far in preventing the introduction of these serious pathogens to its national sheep flocks and cattle herds. However, this does not mean Australian animal scientists are not interested, or unable to participate, in research into exotic diseases. The constant risk of the introduction of exotic pathogens demands that Australian scientists maintain an active and effective understanding of the major exotic diseases.

It is not often realized that during the last century Australia has had outbreaks of rinderpest and surra, three outbreaks of foot-and-mouth disease, fowl plague, rabies and other major diseases (Table 1). Most of these diseases were introduced by the importation of live animals and were contained by a mixture of drastic control measures and a relatively small population of susceptible animals at that time.

The importance given by Australian authorities to many diseases endemic in Africa and elsewhere can be gauged by the considerable investment in the construction of the Australian National Animal Health Laboratory (ANAHL), which is a maximun security laboratory to carry out research into many exotic diseases that potentially threaten the Australian livestock industry. Compared with Africa, Australia is relatively free of serious animal diseases, and its animal health resources are integrated into the broad front of livestock production. The approach is an extensive multidisciplinary exercise to address the many facets of livestock production.

The Livestock Industry in Northern Australia

A brief description of the livestock industry in Australia, with particular emphasis on the semi-arid areas, may indicate some of the similarities and differences between Eastern Africa and Australia.

The management of cattle in the semi-arid areas basically consists of uncontrolled breeding systems. In these areas, such as the Northern Territory, the Kimberley area of Western Australia, and northern Queensland, cattle stocking density is low and few sheep, if any, are kept. Further south in

* Co-ordinator for Animal Programs, ACIAR, Canberra, A.C.T., Australia.

Table 1. Exotic disease outbreaks in Australia that have occurred and been eradicated.

Foot-and-mouth disease	1803, 1871, 1872
Surra	1907
Rinderpest	1923
Bovine pleuro-pneumonia	1858-1973
Rabies	1866
Swine fever	1903, 1927, 1942, 1961
Newcastle disease of poultry	1930, 1932
Scrapie	1951
Fowl plague	1976

Source: Gee (1980).

the first named two areas, rainfall decreases and desert conditions prevail. Towards the southern coastal regions of both Queensland and Western Australia, the stock-density increases and more intensive management is practised (Fig. 1). The sheep numbers increase in the southern areas of northern Queensland.

The major constraint to animal health is the seasonal nutrition stress that can result in secondary diseases due to decreased disease resistance. However, the potential effect of the increased susceptibility is offset by the low stocking rate in this region. During the wet season, from approximately November to March, the land is inaccessible. Due to overriding nutritional problems and the extensive nature of cattle raising, there are few cattle diseases that require attention, but the role of infectious diseases requires further research. In the semi-arid region, water-holes as a disease-spreading environment have yet to be fully evaluated, although bovine tuberculosis is thought to be transmitted at water-holes. Mandatory treatment is required for tick control for any cattle moving out of the region.

A broad comparison of the African and Australian livestock industries is listed in Tables 2 and 3.

Animal Health Research Infrastructure

Research in animal health in Australia is carried out by three organizations, i.e. the State Departments of Agriculture, the Commonwealth Scientific and Industrial Research Organization (CSIRO), and the universities.

The responsibilities for regional research and the application of research results rest with the individual State Department of Agriculture. Each State has research facilities and, in general, concentrates on animal diseases of State significance. To carry out the research there is a Central

Table 2. Some major differences in livestock enterprises in Eastern Africa and northern Australia.

Description	Eastern Africa	Northern Australia
Owner contact	constant/frequent	low
Flexibility of management	little	moderate
Size of farm	small/nomadic	large commercial enterprises
Socio-economic factors	important, mainly social	important, mainly economic
Disease status	major problem	minor problem
Ticks present	several species	*Boophilus microplus*
Production restraints	disease/nutrition	nutrition

Table 3. Some important similarities in livestock enterprises in Eastern Africa and northern Australia

Description	Eastern Africa	Northern Australia
Species	cattle, sheep, goat camel, wildlife	cattle, buffalo, pig. Feral donkey and camels
Stocking rate	high to low	low
Nutritional status	low	low
Impact on environment	increasing/serious	increasing/ isolated
Tick fever	yes	yes
Reproductive failure	present	present
Reproductive mortality	present	present

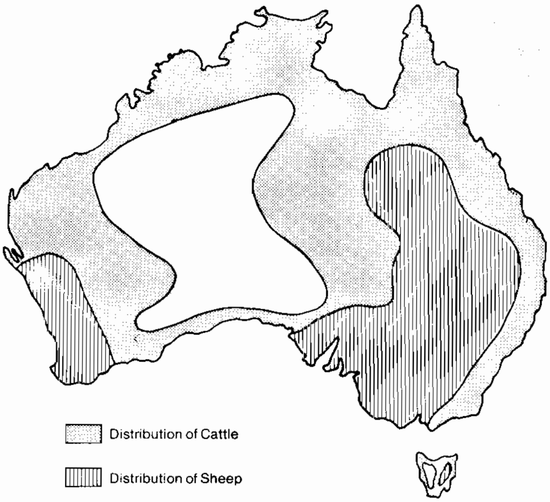

Figure 1. Map showing distribution of cattle and sheep in Australia.

Laboratory and often satellite laboratories. The scientific staff is likely to consist of veterinary graduates, microbiologists, biochemists, pathologists, serologists and others. A range of field staff utilize the scientific services and report disease-related information. Generally, the research is of a short-term nature, ranging from basic to applied, and responsive to the information that comes from the farmer/field staff interface. The difficulties in carrying out this diagnostic service and research in the semi-arid areas are the long distances between the laboratory and field staff. There are two laboratories in the northern region of Australia, one in Townsville and one in Darwin.

The CSIRO is the main national research organization; it concentrates on selected long-term research topics, ranging from basic to applied. It is divided into institutes in which there are several divisions. The Institute of Animal and Food Sciences undertakes most disease-related research, although the Institute of Biological Resources also has an important interest in animal pests and insects; the Divisions of Entomology, Wildlife Research and Rangeland Management are important in these areas (Table 4).

The bulk of the host-related work on animal diseases by CSIRO is carried out by the Divisions of Animal Health, Animal Production, and Tropical Animal Science of the Institute of Animal and Food Sciences. Each Division has several large laboratories and shared field stations. It is fair to say that the CSIRO is the most sophisticated research organization in Australia, and is able to bring a wide range of in-depth, multidisciplinary skills to individual research programs. As there are many common animal health problems in Africa and Australia, it is likely that some of the current research programs of the CSIRO will offer opportunities for collaborative research, particularly in the areas of immunological and parasitological aspects of animal diseases.

Table 4. The infrastructure of animal health research in Australia.

CSIRO	State Authorities:
Divisions of:	Western Australia
Animal Health	Queensland
Animal Production	Northern Territory
Tropical Animal Science	South Australia
Entomology	New South Wales
Tropical Crops and Pastures	
Universities:	
Sydney	
New England	
Melbourne	
Western Australia	
Murdoch	
Adelaide	
Australian National University	
Walter and Eliza Hall Institute	
Queensland	
James Cook	

To determine national research priorities and assist in their co-ordination, there are many multilinked advisory committees consisting of farmer representatives, scientists and government officials.

The universities, with four Veterinary Schools and several Agricultural Schools, carry out animal health-related research of a more varied nature. Certain schools (such as the Graduate Tropical Veterinary School at the James Cook University, Townsville, Queensland) have a long-term interest in the problems of livestock production in Northern Australia and other tropical countries. Often the direction of research is guided by the success of research grants and individual interests of the university staff.

The Multidisciplinary Approach to Animal Health Research

Most scientists are aware, or are becoming aware, of the complexities of the land-crop-animal system, and that production levels from this system are highly interdependent. For example, one of the limiting factors in the middle belt of the African continent is the disease trypanosomiasis, which is a serious production constraint. There are other areas where non-infectious factors are more prominent, such as inadequate nutrition and lack of water for stock and pasture. The latter two constraints reflect the situation in Australia. However, both infectious and non-infectious disease factors can effect the overall, animal health status of the livestock industry.

In Australia the view that is gaining momentum is that improvement of animal productivity in the overall agricultural production system can only be achieved biologically by modification of either the genetic and/or environmental factors.

No longer is the concept completely acceptable that maximum animal production can only be achieved by a single disciplinary approach; integration of all the relevant research components is required. Perhaps the most recent formal expression of this multidisciplinary theme is the recent formation of the Division of Tropical Animal Science by the CSIRO. It should be pointed out that there is still a need for intensive disciplinary research within a research program. An example where a strong disciplinary approach is required in Australia is the study of the arboviruses of cattle. A possible outline of the multidisciplinary approach to animal health research is shown in Figure 2.

Africa, as does Australia, has a livestock industry distributed over a wide range of climates. Of equal importance are the socio-economic fac-

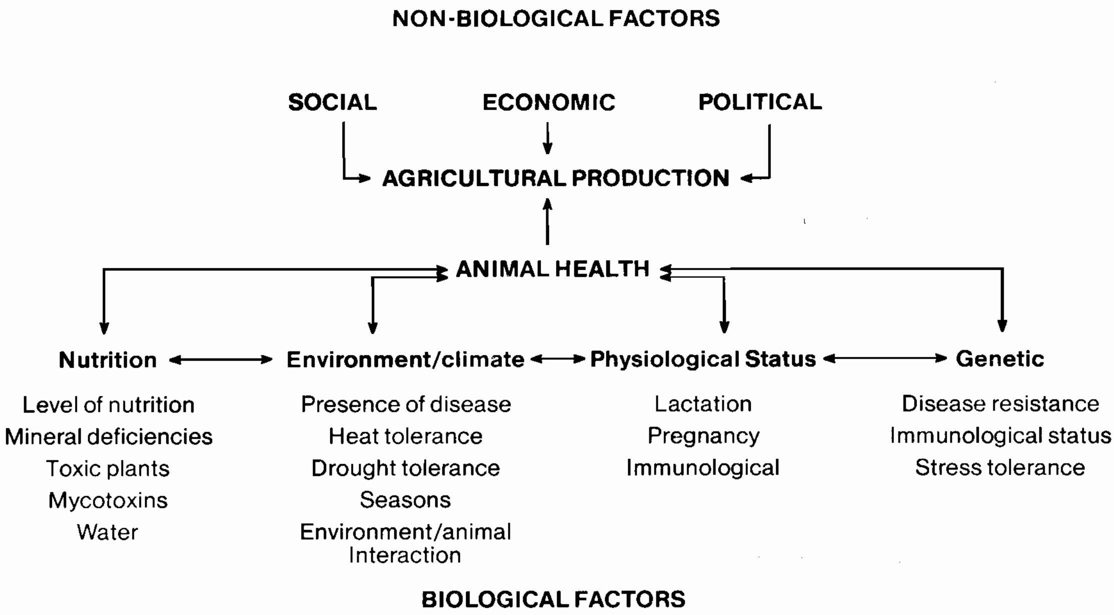

Figure 2. The inter-relationship of the major research factors involved in the health of livestock.

tors involved in animal farming systems, particularly in Africa. The richness of demographic differences in Africa is likely to require that greater emphasis be given to the socio-economic factors in animal health research planning than that in Australia. Attention has already been drawn to this important component of animal health research by Chema (1983). In both continents, the economic and political aspects of animal health research will play a decisive role in any national research programs.

Collaborative work by scientists in Africa and Australia should enable significant advances to be made into the biological aspects of animal health, such as nutrition, environmental impact, and in the areas of patho-physiological and genetic research. The topics of nutrition and genetics research are discussed by R.J. Jones (1983) and Howe (1983). Some specific topics in animal health research in Australia, which offer opportunities for collaborative research, are outlined below.

Major Research Areas

1. Research on Animal Disease Control and Eradication Programs

As stated earlier, Australia has been fortunate to be free of the major infectious diseases of the world. Also, despite the extensive management systems of cattle production in northern Australia, a successful eradication campaign has been completed against bovine pleuro-pneumonia. Currently, bovine brucellosis and tuberculosis are in the final phases of eradication, with large parts of Australia now being free from the two diseases. It is anticipated that bovine brucellosis will be eradicated in the next few years. The aim at present is to be free by 1992.

The experience in carrying out the three disease eradication programs and others mentioned earlier, has given animal health authorities considerable knowledge of methods involved in disease control management. To carry out an eradication plan, considerable research is required to determine the most suitable approaches. This can involve fundamental research into the prevalence of the disease in question, completion of the epidemiological models, development of suitable tests and the confidence levels of the test in question, seasonal factors and many other aspects of the animal disease that is under consideration.

The need for careful application of research to define the many parameters of the disease prior to commencing eradication is more fully understood and valued after the first successful disease eradication project. Throughout any eradication campaign, there is a constant need for a research input to answer unforeseen questions.

During the current brucellosis eradication, CSIRO and State Departments of Agriculture animal scientists are constantly reviewing and carrying out research to solve unexpected field problems. Examples are the role of 'fistulous withers' of horses as a source of spreading brucellosis, and non-specific serological reactions.

Disease control in extensive areas such as in northern Australia and perhaps Africa is difficult and expensive. Also, the scarcity of staff in these extensive areas prevents a broad all-encompassing approach. To overcome these problems, a trace-back system has been developed in Australia that allows for the detection and origin of cattle having particular diseases and thus enables the available scientific staff to concentrate on high priority herds (ABAH 1979). The trace-back used is a numbered tag attached to the tail for all cattle going to abbattoirs, or for sale. Such abattoir monitoring of disease status in the extensive areas of Australia has increased the effectiveness of the veterinary field staff. In order to carry out successful abattoir monitoring, suitable diagnostic tests are required, but as yet such tests are not available for all diseases. Areas for collaborative research in animal disease control revolve around specific diseases, development of suitable tests, vaccine control, and methods of disease data analysis.

2. Epidemiological Research

Australian veterinary scientists have made a major research thrust in identifying, modelling and interpreting epidemiological disease characteristics. Epidemiology is a study of the relationship between various factors that determine the frequency and distribution of diseases in animal populations.

There are many opportunities to gain a better understanding of common animal diseases of Africa and Australia, such as exist in the wide range of helminth parasites found in both countries. One reason why a study of epidemiological characteristics of a particular animal disease has attracted considerable support is because such a study provides a conceptual framework to evaluate and interpret all available biological knowledge of the infected host, the pathogen, and the environment. Availability of epidemiological analyses of diseases allows the establishment of research priorities when control or eradication plans are contemplated. The use of epidemiological models is further enhanced by the ability of agricultural economics to provide effective economic parameters of a particular disease and the cost-benefit ratio of proposed disease control measures (Roe 1982). As a result, in Australia an epidemiological approach to animal diseases is acceptable to the policy-makers, animal health scientists, and economists.

In an epidemiological study, the important parameters measured are concerned with the relations between (a) population of the animal host, (b) potential harmful agents within the host or the environment, and (c) time.

To understand the host response, considerable basic biological knowledge of the disease in the host is required, such as the innate and potential resistance status, genetic characteristics of host and pathogen, immunological state, nutrition, and many other parameters.

The biological parameters of the causative organism in the host and external environment have to be understood, particularly its pathogenicity to the host and antigenic stability. The latter characteristic, i.e. the antigenic stability, is particularly relevant to the epidemiology of bovine trypanosomes, which are able to evade the immune response of the host by their antigenic variability (Cross 1978). This presents a major obstacle in the production of a reliable vaccine.

All the biological information is evaluated and analysed using a variety of computer systems. Epidemiologists are constantly attempting to determine better ways of analysing epidemiological data in order to improve its relevance in the economic and scientific appraisals that are necessary. A path analysis has been suggested by Burridge et al. (1977) as an important epidemiological tool in the identification of important causal pathways in biological systems. The economic analysis of disease control systems is necessary to estimate the cost-benefit ratio of a particular approach on either a regional or national level. Methods involved in economic analysis have been described by Morris (1969). Once the economic analysis has been carried out, decisions can then be made on what disease control methods are best suited to the investment contemplated.

Epidemiological research is an important area for disease control in a country such as Australia where there are no obvious production-limiting diseases. Where there are serious animal diseases such as rinderpest and bovine trypanosomiasis, as in Africa, there is less need for an elaborate epidemiological study to determine the cost of the disease and selection of research priorities. However, an epidemiological study is suggested as a useful tool for the control or eradication of any important disease.

3. Vaccine Production Research-Biotechnology

The ultimate aim of disease control for most Australian farmers and veterinary scientists is to have a simple, one dose, cheap vaccine. To provide such a vaccine, large investments in research are frequently required. The areas of research range from basic immunological studies to applied biotechnological research of mass vaccine production. The largest producer of vaccines in Australia is probably the Commonwealth Serum Laboratory (CSL). Involved in the manufacturing activities of CSL are several research teams who aim to produce new and better vaccines. An example of the close collaboration between the biotechnologists of CSL and CSIRO scientists is the mass production of a vibriosis vaccine by CSL, which was developed by the Division of Animal Health, CSIRO. Should vaccine production or biotechnology require a research input in Africa, it should be possible to design research projects which utilize both African and Australian scientists, such as CSL researchers.

The high temperatures in summer are characteristic of both Africa and Australia and necessitate considerable care of all biological material, particularly vaccines. The use of non-viable vaccines has led to many incidences of disease control breakdown, resulting in embarrassment to both vaccinator and manufacturer. As a result, there is a constant research input by most vaccine producers to produce a heat stable vaccine. Successful collaborative research on relevant vaccines would have advantages and benefits for both countries.

4. Virological Research—— Arboviruses

As Australia is free of the serious endemic viral diseases, the main research has been on the detection and classification of what viral diseases we do have, in particular the arboviruses and their insect vectors (St.George and Kay 1982). Ephemeral fever, a viral disease also present in Africa, has attracted a considerable research input by the CSIRO and University of Queensland. The aim of the research has been to understand the viral taxonomy, the epidemiological characteristics, and pathogenesis of the disease. Areas of research that are in need of attention in ephemeral fever as listed by St.George (1981) are (a) biochemical methods to detect the virulence or virulence status of the virus, (b) biochemical changes and mechanisms of the action of the virus in the vertebrate host, (c) behaviour of the virus in the intermediate host, (d) identification of vectors in Africa and Australia, and (e) the study of ephemeral fever in tropical countries to determine the cost of the disease.

Collaborative research into any of the above aspects would assist a greater understanding of the disease, particularly the identification of vectors. Although ephemeral fever is important in Australia, African scientists will have to make a priority judgment whether it is important enough to warrant an African scientific resource input, in view of other disease constraints.

Bluetongue Infections of Sheep

In 1977, Australia was informed that a viral isolate from insects, CSIRO 19, was indistinguishable from bluetongue. Since that day, all sectors of the animal health community, both Commonwealth and State, have been involved in an active research program to identify the spread, significance, and pathogenicity of the 'new disease'. The impact of this news in 1977 on Australia's export trade was significant and it took 3 years before most trade restrictions were lifted.

Bluetongue is endemic in Africa. The discovery of the virus in northern Australia triggered off intensive research into the viral classification of bluetongue strains and of other closely related arboviruses in the orbivirus genus. The taxonomy of the virus is still under intensive investigation, using both biochemical and serological methods. The taxonomy of the intermediate host, a *Culicoides* sp, and its role in the spread of CSIRO 19 virus, is also currently under investigation.

Research on bluetongue in Australia requires a high security laboratory, as the only suitable laboratories are outside the endemic area. All bluetongue research is carried out at the Commonwealth Serum Laboratory, Melbourne and at the CSIRO Long Pocket Laboratory in Brisbane. For the record, 3 sero-types of bluetongue virus (BTV20, BTV1, BTV21) (Anon. 1982) and 7 other sero groups of orbiviruses are subclinically present in certain areas of Australia. The research emphasis on viral taxonomy is required, due to serological cross-reactions that are caused by orbivirus subgroup members in cattle tested for bluetongue. There are many field viral isolates that have yet to be identified.

Fortunately, the subtle relationship between bluetongue viruses and other subgroup members of orbiviruses is becoming clearer. One administrator involved in bluetongue investigations in Australia pronounced that the orbiviruses were 'conceived by biochemists, manufactured by virologists and promoted by entomologists'. Because of the antigenic relationship of bluetongue viruses to other members of the orbivirus genus, there will be a considerable ongoing research input to clarify the taxonomy. In spite of the fact that no clinical bluetongue disease has been associated with Australian viruses, the importance of bluetongue in other parts of the world, such as Africa, necessitates continued research and vigilance.

Research on Akabane Virus

Akabane virus is another arbovirus that is endemic in northern Australia without causing any obvious economic problems. However, in the southern, more productive areas, it has caused significant losses in cattle herds and sheep flocks due entirely to its adverse effect on developing foetuses. When akabane virus first appeared, it caused the loss of 5 000 calves due to abortion, stillbirth, and teratogenic effects, (Lehane 1982-83). At present, research is concentrated on the taxonomy of the akabane virus, and the pathogenesis of the disease in sheep and cattle with particular reference to the virus crossing the placental barrier.

5. Research on Bacterial Diseases

Foot Rot of Sheep

The most important infectious disease affecting Australian sheep is foot rot caused by *Bacteroides nodosus.* Other bacterial diseases, such as those caused by *Clostridia,* are routinely controlled by vaccination and are not important production-limiting constraints. The major bacterial disease of cattle, bovine pleuro-pneumonia, has been eradicated.

Intensive research on foot rot has resulted in the production of a commercial vaccine, which was based on the earlier immunological results of a CSIRO research project. There is considerable interest by State Departments of Agriculture and CSIRO for an improved vaccine, using purified antigen and a basic study of the humeral and cellular components of the ovine immunological reaction. Currently, there are three teams investigating which *Bacteroides nodosus* strains are present, in order to incorporate them in the vaccine. There is also a major research input into the differentiation of benign and virulent foot rot caused by strains of *Bacteroides nodosus.*

Bovine Trichomoniasis

Trichomonas foetus is a protozoan that causes infectious infertility in bovines resulting in low reproductive returns. The disease is endemic in Northern Australia and can cause significant losses through reproductive failure (Ladds et al. 1973). In some areas, the current management control is to use only 2-3 year old bulls, which show a much lower carrier status control than older bulls. However, under extensive management conditions, this practice is difficult. Research is underway to purify the antigenic fractions of the protozoan *Trichomonas foetus*. The chance of success in devising a protein vaccine is reasonable as cows appear to be resistant to adverse effects after initial infection.

Bovine Brucellosis Eradication Scheme

Bovine brucellosis has been a most expensive disease in Australia, with control measures having cost several million dollars to date, although it should be noted that on current epidemiological models, successful eradication is close. The research input for the scheme was carried out a long time ago. During the final stages of the eradication process, there is a demand for more specific, more sensitive, and cheaper serological tests by field operators.

The presence of non-specific serological reactions in bulls and calves has proved to be a more difficult problem than anticipated. The CSIRO and some State Departments have been investigating new serological procedures and their results suggest that the ELISA (Enzyme-Linked Immuno-Sorbent Assay) has many advantages over the current Complement Fixation Test. The low cost, opportunities for automation, and increased accuracy are attractive features of the brucella ELISA test.

6. Research on Parasites of Livestock

The Cattle Tick

The cattle tick is the major disease-associated problem of cattle in northern Australia. Its economic effects range from the spread of infectious disease to the depression of the host growth rates through general debilitation. The tick has previously been controlled by use of acaricides; however, chemical resistance has occurred. Crossbreeding between *Bos indicus* and *Bos taurus* has increased tick resistance, but physiological changes of lactation and pregnancy do lower such resistance levels.

As the tick is a major pathogen vector in Australia, research is currently being carried out by the CSIRO, State Departments of Agriculture, and universities. Current areas of research are:

1. Identification of tick resistant cattle—— the search is on for a simple immunological method to estimate the degree of tick resistance and the role of host compatibility antigens as genetic markers.
2. Immunization of vaccination against the cattle tick using natural tick tissue culture and adult tick antigens. The tick vaccines have shown some effect on the intestinal cells of adult ticks and have resulted in a lower tick egg viability.

Tick-borne Diseases

Vaccination methods against *Babesia* are well known; however, they do have considerable disadvantages, such as the spread of the organism, short-shelf life, and occasional breakdowns.

Research at the Long Pocket CSIRO Laboratories in Brisbane is currently directed to the possibility of using non-live vaccines. The approach is to use antigens from *Babesia*-infected cells and encouraging results have been obtained. However, further work is required to remove excess non-specific red cell antigen before the vaccine can be recommended for general use. Other research underway involves recombinant DNA methods, mono-clonal antibody techniques, and biochemical analysis of tick enzymes.

Internal Parasites of Livestock

Australian scientists have been aware of the importance of internal parasites as a cause of poor animal health status and resultant economic loss. Indeed, scientists such as Dr. Hugh Gordon have made a significant contribution to the 'knowledge bank' of parasitism. There are several laboratories where the ecology and population dynamics of helminth infections of grazing livestock are studied, ranging from a basic biological approach to that of an applied nature. The overall aim is to improve strategic control methods by manipulation of the susceptible stock and the infective stage larval population.

Anthelminthic Resistance to Helminths

Resistance by parasites to antihelminthic drugs has been of serious concern to the Australian livestock industry, particularly in the more settled subtropical areas of northern Australia. Currently, there are pockets of multidrug resistant populations of *Haemonchus* and *Ostertagia*, which have given urgency to the research efforts to gain an understanding of the mechanisms involved.

Current research endeavours are focused on the host-parasite mechanism of development of resistance and the intra-host regulation of nematode populations. Basic knowledge of the genetic make-up of drug-resistant *Haemonchus* species and genetic parameters of host susceptibility are being investigated by the CSIRO and University of New England, Armidale, New South Wales. In addition, there is a search for markers of resistance to parasitism of a relatively simple nature for animal breeding purposes. Preliminary results suggest that bovine lymphocyte antigens may be of use as such markers. Detection methods for anthelminthic resistance are the cumbersome drug response trials, however improved *in vitro* methods are also being intensively studied.

The current situation in Australia is that there are populations of trichostrongyles that are resistant to both of the available anthelminthic compounds, i.e. the benzimidazole and levamisole groups. The limiting range of available anthelminthics, plus the increasing animal populations in areas of Africa and Australia, have precipitated a considerable reallocation of research resources in this area. Fortunately, it appears that the new compound Ivermectin (R) may be effective against all current resistant populations. Another encouraging result is that infective larvae from resistant worm populations are found to be more susceptible to environmental desiccation than larvae from non-resistant populations.

Additional approaches to the drug resistance problem are (a) pharmokinetics of anti-parasite drugs, (b) host- physiological response to parasites, (c) respiratory mechanisms of developing nematode eggs and adults, (d) protein synthesis by the host and protein loss due to the parasites, and (e) hereditability of sheep resistant to *Haemonchus*.

In the northern areas of Australia, epidemiological studies have shown that the pathogenic parasites *Haemonchus placei, Oesophagostomum radiatum* and *Cooperia* sp are present all year round. The infective stage larvae survive in the dung pads, thus limiting the effect of control grazing. To offset the estimated 25% production loss due to parasitism, efforts are being made to stimulate artificially, the acquired immunity of cattle. Ultimately, it is hoped that a vaccine, possibly with antigens from irradiated larvae, may be developed.

Should parasitism be considered a priority for research by African scientists, there are many potential areas for collaborative research, which would be of importance to Africa and Australia.

7. Immunological Research

In the immunological field, Australia has a worldwide reputation for achievements made. The two centres that are actively carrying out immunological research are the Walter and Eliza Hall Institute and the Australian National University. The latter group has been involved in exploring the possibility of identifying immature cattle that have inherited protective immunological responses to specific factors such as ticks and internal parasites, and to establish the genetic patterns of such responses with the eventual aim of breeding fitter cattle. The association between inheritance of histo-compatability genes and susceptibility to diseases has been described (Dorf 1981).

The Walter and Eliza Hall, in conjunction with the University of Melbourne, has spent the last 5 years on a study of immunological processes of cysticercosis and taeniasis in domestic animals. This group have had considerable success in being able to reduce the incidence of *Cysticercus bovis* by using inert vaccine. This points the way to the possibility of immunizing stock against the intermediate stages of tape worms, and of protecting the meat-eating human population.

Other scientists have built on the knowledge gained from basic immunological research to develop improved diagnostic methods for infectious animal diseases. The ELISA test, which was mentioned earlier, appears to offer considerable advances in disease control schemes by providing a cheap, accurate test that has the dual advantage of being able to detect both the antibody as in a serological test, or the antigen, i.e. the disease-causing agent. Detection of the antigen by this system could remove the need to carry out the isolation procedures involved in bacteriology and virology.

There is considerable enthusiasm for this test in the more remote parts of Australia that do not have adequate diagnostic facilities or are too far away from a diagnostic laboratory. The benefits in terms of easier management and disease control of 'on the spot' ELISA tests for the extensive cattle systems of northern Australia are considerable. At present, research resources are being directed to establishing suitable test systems for viral diseases of poultry, and certain bacterial diseases of pigs and sheep.

In the framework of the disease priorities established by the African countries, there could be areas of collaborative research into an ELISA test for animal disease diagnosis that should be useful to regional laboratories and field staff. Provided adequate research inputs are available, the ELISA test has exciting prospects for the future control of animal diseases.

Conclusion

To sum up, the areas of animal health research areas in which collaborative programs may be of interest to both African and Australian livestock authorities and scientists are as follows:

1. Viral antigenic relationship as a taxonomic guide.
2. Immunological studies on internal nematode parasites and cattle tick.
3. Biotechnology——vaccine production, mono-clonal antibody techniques.
4. Methods of disease control.
5. Improved diagnostic methods and reagents such as the ELISA test.
6. Economic research on animal diseases, using the epidemiological model.

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Research and Development Aimed at Genetic Improvement of Livestock

R.R. Howe*

The recent establishment of the Animal Breeding and Research Institute in Western Australia and its program of research and development are indicative of the priority and nature of Australian applied research efforts in animal genetics. A discussion of its objectives and program with appropriate reference to other Australian work should therefore provide a useful background to this subject matter.

The Western Australian Animal Breeding and Research Institute (ABRI), universities and colleges, CSIRO, and all other State Departments of Agriculture are engaged in a significant research effort aimed at genetic improvement of livestock thereby indicating the potential that is still seen in this area. Cost-benefit analyses of animal breeding programs have been an important area of study because of the unique nature of genetic gains——small but cumulative and permanent over time.

Man has practised selection as a means of modifying the properties of animals from prehistoric times. Yet only in the last half century has a real study been made of the theory of inheritance (on which the selection theory is based). Attempts were being made in the late 18th century to explain heredity in mathematical terms. Little progress was made however until the concept of 'particulate' inheritance, based on the work of Gregor Mendel in 1865 was accepted. Little basic knowledge existed prior to the beginning of the 20th century. There was a period of some three decades during which Mendel's work was ignored due to the preoccupation with the theory of evolution and Darwin's work in relation to it. Furthermore Lamarckism (briefly, inheritance of acquired characters) was still in fairly strong favour relative to evolutionary theory.

Animal breeding practices up to this time involved the unconscious use of genetics and was aimed at the 'ideal' animal within a particular breed and species. This approach to animal breeding is still evident today.

Australian research in animal breeding really began only after World War II. A brief historical account of the history of animal breeding in Australia is given by Barker (1979). However, in general the nature of applied research in animal genetics has been either verification of the theory or the estimation of the many parameters required in designing or understanding breeding systems. While much of the work in both theoretical and empirical studies was motivated by the desire to understand evolutionary processes, increased productivity of domesticated species was also a major motivation. The latter is most relevant to this discussion.

In virtually all domestic species of livestock there is an aim to increase efficiency of production genetically per unit of food intake. In most cases this can be achieved by selection for high production per head without measuring intake. In either case, studies so aimed must be relevant to the livestock industry concerned. This discussion will concentrate on the sheep industry.

Institute Role and Objectives

The establishment of the Institute was based on the clear recognition that there could be substantial benefits from genetic improvement of livestock and that there was a substantial research and development requirement for this to be achieved.

The Sheep Industry

The Western Australian sheep industry, like the Australian sheep industry as a whole, is based on apparel wool and meat production. The former is largely an export industry high on the list of foreign exchange earners. The latter is about

* Director, Animal Breeding and Research Institute, Western Australian Department of Agriculture, Katanning, Western Australia, Australia.

equally balanced between local consumption and export, export being considerably expanded in recent years with the development of markets for mutton in the Middle East.

Wool, being largely Merino type (some 75% of sheep in Australia are Merinos) contributes largely to the high quality end of the market. Although wool yarn forms only a small proportion of total apparel yarn, its price on the world market has been reasonably maintained.

Meat production is essentially in two forms. First, specialty prime lamb production is based on a fecund, crossbred dam (Merino x British breed) and a meat-type terminal sire (British breed) where all the progeny are slaughtered. Crossbred dam production forms a secondary industry with male progeny also sold as prime lambs. Second, there is mutton producton from surplus stock in wool producing flocks, though the development of mutton exports has provided incentive for more specialized production for this market. A small carpet wool industry is developing, based on imported breeds from New Zealand. This is the only country from which live sheep, semen, or embryos can currently enter Australia although protocols are currently being examined at Government level.

The Australian sheep population of about 137 million is distributed in large flocks——the average being about 1 000 head. The most important aspect of its distribution though, is its breeding structure. Generally this is ideal for implementing genetic change programs, as only a small proportion of females are allowed to produce potential sires. These are the so-called 'stud' sheep which are either in parent or closed studs breeding their own sires, or in open studs which rely on parent studs for sires and are simply ram multipliers. With the exception of a proportion of sheep bred outside this structure, the genetic change in the Merino population is effectively in the hands of the small number of closed or parent studs (Short and Carter 1955; Roberts et al. 1975).

Recent developments outside this structure include house-breeding of rams on large properties, and co-operative breeding groups which are used in Australia and which could be especially valuable in countries where flocks are small. Group Breeding Schemes, as they are called, provide for superior breeding stock to be screened from many (small) flocks on a regular basis to form a ram breeding nucleus. Rams from the nucleus are supplied back to the contributing flocks. An optimum structure is about 5-10% of ewes in the nucleus and about half the ewe replacements come from contributing flocks but exact details depend on reproduction rates, age structure, male/female ratios, etc. Additional tiers for ram multiplication may be warranted in large populations. Such programs could be very useful within small nomadic flocks.

Past Research Results

Much of the important genetic theory has already been validated in sheep breeding. Also, studies in most of the important characters have provided estimates of parameters enabling design of optimum breeding programs and gains. Turner and Young (1969) provide a most comprehensive review of all aspects of sheep breeding research results. With only a few exceptions, favourable genetic changes of the order of 5-8% per generation are possible from selection in most economically important characters, provided these characters are measured. Some exceptions are low genetic variation (e.g. some fertility traits) and antagonistic genetic correlations (e.g. wool weight and crimp numbers, where this is used to estimate wool quality. If wool quality is judged on measure fibre diameter,the genetic correlation with wool weight is much lower).

Such responses are small compared with other typical input-output relationships (e.g. plant growth response to fertilizers). However, in the evaluation of a selection program, the cumulative and permanent nature of gains help the long-term benefits. Gains from each cycle of selection are additive and when selection is ceased the cumulative gains are not lost. In evaluating a particular program in dairy cows where costs per cow far exceeded the actual annual benefit, it was not until year 18 of a 20 year program that benefits were seen, but still the benefits of the whole program were very favourable.

Benefit-cost analyses of genetic research are thus more favourable than they might initially appear.

Breeder Acceptance

In addition to economic justification for such research and development, there is the benefit from improved adoption of optimum breeding programs. Studies of industry statistics suggest that the current rate of genetic improvement in wool production is low (Ferguson 1976). On the other hand, heritability estimates and selection responses in experimental populations suggest ample genetic variation. It would therefore appear that traditional breeding methods are relatively inefficient and adoption of modern, more efficient programs is poor.

Similarly, the more traditional objectives of breeding programs are based on show ring fashion rather than real economic benefits. However, the acceptance of economic breeding objectives might seem to be improving given the increasing proportion of rams that are measured for production (Savage and McGuirk 1976; Beetson 1976). Also the accuracy of selection using indirect characters and visual appraisal may be better than earlier thought (e.g. Napier and Jones 1979). The fact remains that selection differentials for the important characters are probably well below potential.

The industry itself would not equate this information to poor genetic progress but to the scientist's different concept of objectives. The scientist, on the other hand, would see this difference between so called 'traditional' and 'scientific' thinking as the major limitation to genetic progress in the industry. Continued research and development should provide increased credibility and thus adoption by industry.

Technical Limitations

Limitations of a technical nature are those that prevent optimum design and efficient operation of breeding programs. Research aimed at reducing these limitations is warranted:

1. Genetic Parameters

Optimum selection program design requires good estimates of phenotypic and genotypic parameters such as heritabilities and correlations. Estimates are available for many important traits but the range of estimates for each is large and high standard errors apply to most. There are other traits of importance for which only few or no estimates are available (e.g. staple formation, fertility, and skin morphology traits).

The sensitivity of selection programs to changes in these parameters warrants attention (Ponzoni 1979). Considering the poor precision of estimates available and the relevance of these to widely varying environments, flock management systems, and seasons under which the ram breeding flocks operate, there is cause for concern. In particular, knowledge of differences in the parameters among breeds, strains, and individual flocks, not to mention changes over time (several generations) is even more limited.

2. Genotype By Environment Interaction

The flocks making up the ram breeding industry operate over diverse environments, management systems, and seasons. Of particular importance is the fact that a high proportion of rams are bred under more favourable conditions than the commercial flocks purchasing them. Improvement in ram breeding flocks may not fully carry over to the less favourable environments of commercial flocks.

Some evidence exists for significant interactions in sheep (King and Young 1955; Dunlop 1962) but Turner and Young (1969) concluded that they are unlikely to be important in animal breeding plans. On the other hand, they have been implicated in apparent plateaux in selection response in some experimental flocks (Pattie and Barlow 1974).

3. Measurement Procedures

The accuracy of selection is clearly increased where objective measures of a character are available. Resistance by breeders to measurement *vis a vis* visual appraisal is a complex problem but it is greater where expensive and complex measurement techniques are necessary.

Although measurement of mean fibre diameter is now reasonably cheap, a quicker and cheaper method would increase its acceptance. Interest in skin morphology and other characters such as wax/suint ratio, staple diameter variation, etc. will not become widespread while their measurement is so expensive.

4. Production Traits

Ponzoni (1979) points out that selection objectives in ram breeding flocks should include those characters influencing monetary returns in commercial flocks since the latter produce virtually all the wool and sheep meat.

Given the absence of obvious faults, such as pigmented fibres, a simple list of characters is fleece weight, fibre diameter, number of lambs weaned, and adult body weight that would apply to varying forms and combinations depending on breed. The acceptance of these by the ram breeding industry is low but a wide range of other characters are accepted. Research continues in some of these. For example, characters such as crimp definition and staple formation may be important in fleece protection (Turner 1976).

Most of these 'traditional' characters however, are either only indirectly related to production objectives or are concerned with the aesthetic appearance of the sheep or fleece. Their importance in the industry has been strongly reinforced by the show and sale ring as well as by the trade (both wool and meat), which itself has only recently adopted objective marketing technology. However, both breeders and the trade are changing.

The Australian Merino Society and the Association of Performance Recording Merino Breeders represent significant bodies of breeders adopting a more objective approach. Also, in the last wool selling season about 90% of wool was sold on measurement of fibre diameter and yield, encouraging objectivity in breeding programs.

The Major Research Projects

A brief description of the major projects either in progress or planned at the Institute will serve to illustrate the nature of Australian animal breeding research.

Fertility Screening Project

Using the technique of endoscopy, the project team screened maiden ewes within the top ram producing studs to identify those with twin ovulations at mating. Only stock considered suitable by the breeder with regard to body size, wool quality and production, conformation, etc. are selected.

Twin ovulating ewes are transferred after mating to the Animal Breeding and Research Institute where individual lambing records are obtained. The four-tooth ewes are joined with high fertility rams selected on the basis of dam fertility record (ovulation at 18 and 30 months of age), testicular development, wool production, and growth rate.

A nucleus high-fertility breeding flock of 600 ewes has now been established at the ABRI from the flocks of 76 co-operating Stud Merino breeders (about 20% of registered Merino breeders in Western Australia). This establishment phase has been extremely successful.

The next phase of the project involves selection of ewes to form the studs' own 'fertility families' and infusion of fertility nucleus genes into these families so that they can offer for sale, flock rams bred for high fertility.

Twin bearing ewes from within each stud flock are identified using the ultra sound technique to form the studs' own 'high fertility' family. The best rams from the fertility nucleus flock will be used in these families by intra-uterine artificial insemination (laparoscopic) of frozen semen.

In 3 years, the 'fertility families' within each participating flock will have been established and will essentially be self-replacing. The artificial insemination program will be the only remaining service to be offered to the participating breeders on a regular basis.

Measurement of genetic difference achieved by screening and subsequent selection has yet to be made but even if heritability is low (say 10%) the 'elite' flock should be well above the average due to its intensive selection.

Base Merino Flocks

Twelve of Western Australia's biggest studs have each provided 100 stud ewes that although run as one flock will remain linked to the stud by annual purchases of sires. The 12 flocks are made up of 4 in each of the major Merino strains——Peppin, Bungaree, and Collinsville. Those flocks will provide the basis for:

1. Estimation of heritabilities and phenotypic and genetic correlations in all the important traits with sufficient precision to examine differences between strains in these parameters.
2. A study of the relative magnitude of between strain and stud differences.
3. Monitoring genetic change, if any, being made at stud level.

Complete pedigree records are kept from these flocks.

Strain x Environment Interaction Studies

A genotype x environment interaction (GEI) occurs when different genotypes respond differently to changes in environment or where their relative performance alters in different environments. Here 'response' refers to the actual phenotype in a particular character. 'Environment' in this context can cover a myriad of factors affecting phenotypic expression but we are concerned here with external physical influences such as nutrition, temperature, and the presence or absence of any stressful condition.

The GEI can be in the form of either a change in ranking of genotype or a change in the difference between genotypes. Whichever type of interaction is present, there will be some influence on the effectiveness of selection decisions. If GEI is significant in important characters then the present ram breeding system may be suboptimal.

Investigations of GEI have not been attempted in Western Australia, hence advice to breeders can be extrapolated only from other results. The climate in this State is more Mediterranean than elsewhere in Australia and therefore recommendations based on Eastern States' research where GEI has been shown to be relatively insignificant, may be inappropriate.

Ewe flocks of each strain will be established in each of four widely differing locations. Sires of each strain will be sampled from rams bred in the base flocks, and distributed to each location. The rams will either be rotated to each site in sequential years, or lambing will be staggered within years to allow the same rams to be used at all locations.

Selection for Dermatophilosis Resistance

Dermatophilosis (mycotic dermatitis or lumpy wool) is a condition that can be important in predisposing Merino sheep to fly strike.

The objectives of this work are:

1. To determine whether the culling of dermatophilosis- affected sheep is effective in reducing the incidence of this disease in affected flocks. It would be necessary to clarify whether culling is effective because of the removal of susceptible types or simply because of the removal of reservoirs of infection.
2. To derive values for the realized heritability of resistance to dermatophilosis and measure correlated changes in production characters (e.g. fleece weight, reproductive performance, liveweight, etc).

The condition occurs following wet, warm conditions but the nature of infection is not well understood. The condition being an all or none trait, with a level of incidence variable between seasons and locations, an artificial procedure was used.

A flock of 700 ewes and 100 rams from a very dry environment and thus no previous contact with the condition were treated. The first 20% infected were chosen as susceptible and the 20% remaining when 80% became infected, were chosen as resistant. Differences in the incidence of the condition in the progeny will indicate a genetic response and will provide an estimate of realized heritability.

Body Weight Screening

The objectives of this project are:

1. To screen stud Merino flocks for superior genotypes based on 12-month body weight and to use outstanding sheep as the basis of a selection flock. Establishment of a control flock will enable estimation of the initial genetic difference caused by screening at a defined intensity.
2. To provide a source of superior 12-month body weight sires for participation, hence enabling them to supply rams designed to meet a specific marketing requirement for young, heavy lambs.

The heaviest 2% of one year old ewes together with a random sample will be chosen from each contributing flock. Rams with the highest deviation in standard units will be chosen from among all flocks. An elite flock of about 300 breeding ewes will be established over three years with a similar control flock.

The areas of study are:

1. Correlated Responses

Comparisons between the control and selection flocks will enable the estimation of correlated changes in other productive traits; for example, some breeders believe that concentration on body weight will lead to poorer quality or quantity of wool. The correlated response in reproduction rate is also an important and obvious study area.

2. Parameter Estimates

Genetic and phenotypic parameter estimation will be possible in the control flock. In particular, the genetic correlations between part records and full records are of interest, where full record is 12-month weight.

3. Components of Efficiency

Selection at 12-months of age should have the effect of identifying those animals that are most efficient at maintaining body weight during the dry summer period.

Booroola Project

Breed development is one of the major functions of the ABRI. Within this context, improvement of reproduction rate is seen as a high priority. Improvements in the State lambing percentage (70) can be achieved by crossbreeding using known high fecundity breeds. In Australia, the outstanding breed available for this purpose is the Booroola Merino, with a reproduction rate similar to the best of the exotics from Europe (Turner 1978).

Research reported by Piper and Bindon (1981) strongly suggests that a single dominant major gene (named the F gene) is implicated in the outstanding reproduction rate of the Booroola. It should therefore be possible to isolate the gene in a non-Booroola background genotype. Wool production and live weights of Booroola crosses have been shown to be inferior to non-Booroola Merinos.

The objectives of this project are therefore to:

1. Isolate the Booroola gene in a non-Booroola background genotype by backcrossing.
2. Provide animals homozygous for the F gene but differing in the proportion of non-Booroola background genes, as a resource for studies into genetic components of wool and growth production parameters.
3. Breed F gene carriers, which are registerable and hence acceptable to the stud Merino breeding industry.

Booroola rams will be crossed over Merino ewes to produce F_1 progeny. These progeny will be *inter se* mated to generate F_2 progeny, a quarter of which are homozygous for the F gene and half will be heterozygous. Ram lambs that are progeny tested will be mated to large numbers of ewes (up to 100 each) by artificial insemination. The top 25% of rams on progeny test will be used to initiate round 2 that follows the same pattern as round 1. Round 3 sees the production of crossbreds that are only one-eighth background Booroola genotype.

Wool Growth Studies

Tenderness in wool is a particular problem in Western Australia, accounting for losses of $5-$10m per year. Tenderness is probably caused in Western Australia by poor nutrition over the later summer/autumn period coupled with the trauma of low temperature following the break of the season.

There is no information on the relationship between other wool characteristics and tenderness, nor is it known what proportion of differences between sheep in resistance to tenderness are genetic in origin. Heritabilities and the correlation structure are required before selection against tenderness can be included in formal breeding programs. Also, stud flocks are bred under conditions of ample nutrition through supplementation. The nutritional conditions that determine the incidence of tenderness may not be imposed and selection would therefore be ineffective.

Two flocks of 300 ewes are to be established, one managed under stud conditions, the second run similarly to a commercial flock. The same rams will be used in both flocks so that genotype x environment interactions can be assessed. Full pedigree records will be maintained. Periodic wool growth will be measured by dyebanding at 2-monthly intervals, and a wide range of other wool traits recorded including fleece weights, yield, fibre diameter average and distribution (at each dyeband and along the staple), tensile strength, wool growth, etc.

The Future

All of the areas of research, current and planned, referred to above fit the pattern of verifying genetic theory or measuring parameters or responses in breeding systems. It is all based on genes that are already available in Australia (and New Zealand).

There have been reports on the potential importation of exotic genes for most of the livestock industries. In sheep (Anon. 1979) a wide range of breeds currently unavailable in Australia have been recommended should current import restrictions be lifted. This Institute is particularly interested in studying some fat-tail breeds and their crosses with the Merino as a means of improving mutton production. Where such studies are prevented by import restrictions some studies could conceivably be carried out in the country where the required breeds exist if no import restrictions exist there. That is, Australian breeds, which would be crossed to exotics, would be taken to the country of origin, although this would leave some uncertainties, particularly in the area of genotype x environment interaction.

This possibility would provide mutual benefits in both countries and thus provides a basis for collaborative research.

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Australian Broadleaved Species in Fuelwood Plantations and Agroforestry Systems

L.D. Pryor*

Australian woody vegetation consists mainly of endemic species some of which are in large genera such as *Eucalyptus* and *Acacia*. In other groups, Australia is the centre of species diversity and is thus the main source of propagating material. This flora has developed over a long period and in isolation from the rest of the world. It possesses features that are not shared to the same extent with trees of other continents, and is especially adapted to resist water stress and fire, and to endure conditions of low nutrient status.

In the past, use has concentrated particularly on *Eucalyptus*, which has been highly successful in cultivation in many parts of the world providing a range of produce such as fuelwood, building poles, sawlogs, industrial wood, and other products.

Not only is it possible to extend the use of species in this genus, but there are other important genera that have scarcely been examined at all, and two of these, namely *Casuarina* and *Acacia*, are able to fix atmospheric nitrogen actively. To the extent that they have been used, species in these genera have been found to grow quickly and produce fuelwood, especially in places where there is a shortage of fuel and building material.

The correct identification of species, the collection of seed true to label and from specific provenances as well as establishing the best silvicultural practices are areas in which considerable research is necessary to permit the full use of this resource, which can play a highly significant role in meeting the woody plant needs of the developing countries.

Fuelwood

Fuelwood used directly or as charcoal is a basic need upon which enormous numbers of people depend for cooking, warmth, and thus survival in many parts of the world. Great shortages are predicted before the end of the century (Spears 1978), which will add to the markedly deficient situation that already exists, especially in developing countries in warmer regions (Arnold and Jongma 1978). At present this material is derived largely from overcutting in accessible woody vegetation either forest or woodland, leading to accelerating degradation of the land producing it, diminishing supply, and pushing the surviving resource beyond the limits of accessibility to many communities.

Fuelwood is relatively heavy and of low value. Most users cannot afford the price that results from long haulage distances and many communities are limited to exploiting an area within a radius determined by the distance of half a day's walk.

Unless there are some radical innovations in present practices the situation can grow only rapidly worse as populations increase and resources become still more limited. To this must be added the loss resulting from the deflection of animal dung and agricultural wastes from further crop production, to fuel. Some reversal of the trend has been achieved here and there by the establishment of plantations aimed solely at producing fuelwood. Since these must be near the users, small community forests or farm woodlots are often appropriate and close integration with the practices of the society concerned is essential. Agroforestry methods also offer considerable promise in meeting this need.

Some Essential Features of Fuelwood Plantations

In order to fill the need, fuelwood plantations must be quick growing species and produce wood of reasonable calorific value bearing in mind that generally the denser the wood and therefore the higher the calorific value, the more slowly the tree grows.

* Forestry Adviser, ACIAR, Canberra; and Department of Forestry, Australian National University, Canberra, A.C.T., Australia.

It is important that the wood produced should have good burning qualities and especially be free of spitting and noxious smoke. Some adjustment from preferred traditional needs by the users may be possible and desirable, according to circumstances.

Usually, crop renewal by coppicing for at least several rotations is essential. Also, several other features are often desirable such as resistance to eating by domestic stock, adaptability to a wide range of sites, ability to thrive on sites of low nutrient status or on difficult habitats, and other features.

Ideal conditions seldom exist and most adopted practices will be a compromise aimed at securing the best available result in the prevailing circumstances.

Agroforestry

The development of agroforestry practices, often by the extension of traditional methods, offers considerable promise in helping to alleviate shortcomings in some areas (B. Lundgren, pers. comm., 1982). There is no sharp boundary between community or social forestry and agroforestry, but the latter gives special emphasis to using multiple purpose woody plants and includes shrubs and trees. Nitrogen fixation is likely to be especially important in this situation.

In one way or another, woody plants in agroforestry systems can contribute to soil stabilization, provide shade, shelter and fodder, produce some fuelwood and building poles, and add to the nitrogen balance. Some species yield products such as honey, tannin, essential oils, fibre, etc. Of course not all things will be provided by all species at all times.

The Eastern Africa Situation

The foregoing generalized statements can be applied without modification to many parts of Eastern Africa. Translation to programs of development must of course take account of specific regional conditions in deciding on the precise steps for implementation. In many cases, foregoing research is still necessary before developmental operations can be properly planned and implemented.

The Role of Australian Germplasm

Australian material has a special place in future fuelwood and agroforestry programs. Past experience has shown that many Australian species perform particularly well as exotics in other countries. While this role has often been directed to industrial wood production and involved the use of certain *Eucalyptus* species, there is no doubt that similar benefits will continue to flow from the use of additional eucalypt species as well as from species of other Australian genera.

The larger genera of Australian trees display a great range of adaptation to different environments, both in climatic and soil conditions in which they thrive. Australia, which is continental in extent, ranges from tropical regions to cool temperate zones and from well watered places to very arid sites. The soils are often sandy and acid, sometimes are calcareous, other sites are saline, and a number are swampy. Often within this array there are species adapted to particular sites that may suit the needs in developing countries.

The reasons for the excellent performance of the Australian material are believed to involve their ability to thrive on sites of low nutrient status (like so much of their homeland), their freedom from parasites in exotic environments (which may not last forever), and the fact that in a given ecological situation large plants result from Australian material in comparison with local species. In many parts of the world, local species in particular sites are smaller and grow slower than their Australian counterparts.

Although the Australian species in their homeland often have parasites and pests, they are in balance and are seldom of critical importance for successful growth. When introductions to other countries are made by seed these pests are always left behind. It is important to avoid introductions of vegetative material except under the most stringently controlled conditions, and national plant quarantine services should take account of this situation. Where insect pests have been introduced there have been some spectacular instances of later biological control but this is costly and not always immediately applicable. It is wise to avoid situations that may require biological control. It is comforting to note that there is very little attack on Australian plants by pests indigenous in other countries.

There are strong reasons for taking advantage of the benefits offered by such species. At the same time, the view expressed in the National Academy of Sciences publication Firewood Crops (1980) as to certain risks involved in the introduction of exotics is acknowledged. However, the dictum therein that 'In any trials of fuelwood plantations local species should always be given first priority' should be viewed with reserve. It would seem more appropriate to suggest that indigenous species should be given equal priority in trials. In this context it is worth noting that where there has been extensive site degradation, exotics at present are often by far the best species to use in rehabilitation programs even though the indigenous species may take a place finally as the preferred species once a degree of stability has been established.

Australian species are pre-eminent for their fast growth, general healthy condition, nitrogen fixation, yield of other products, and provision of shade and shelter.

While most experience to date with Australian species relates to *Eucalyptus* there are many other species, especially in the genera *Acacia* and *Casuarina*, that offer great promise for such use (Boland and Turnbull 1981).

Eucalypts

Australian trees are probably best known internationally through eucalypts (FAO 1979). The genus is large, with some 500 species, the majority of which have been tested at least once experimentally outside Australia. The primary purpose has usually been the search for industrial wood with other uses taking second place.

In many species there is a considerable geographic distribution in natural occurrence and thus marked provenance differences within the species. This variation has been examined in a few species but for the genus as a whole, it is a study in its infancy. Further research is warranted not only with species but also on provenances within species. For fuelwood production, the genus is less explored since the species with a higher wood density and therefore in general better burning qualities have (as a rule) a slower growth rate in volume. Partly for this reason they have been set aside in the search directed to ends other than fuelwood production.

The significance of this aspect is illustrated by a recent paper (Kaumi 1983) on trials at Mugugu, Kenya. In a study of two eucalypt species over two rotations, *E. saligna* was found to be nearly 10% higher in wood density than *E. grandis*, which has been favoured because of its value in producing industrial wood. In selecting species for fuelwood production, the benefit of higher density makes the same volume production more valuable in the species with the higher density so that some growth loss can be accepted without that being inferior economically. There are also benefits in the transport of higher density material because it occupies a smaller volume. In this particular experiment, volume production was also found to be higher in *E. saligna* than *E. grandis* in the fourth rotation (reversing earlier trends) so that on both grounds *E. saligna* was indicated as the species.

However, neither of these two eucalypt species is top class as fuelwood and if more species were investigated along the same lines it is likely that distinct advances would be made in selecting other species and other provenances for particular locations. For example, on the site where the above species are favoured, both *E. microcorys* and *E. decepta* would thrive and produce wood of considerably higher density. There are a limited number of trials with these species but their unsuitability for industrial wood has generally led to their being ignored for extensive use. However, for fuelwood they could well be superior, especially if an adjustment for density difference is made when assessing the economic situation.

As a group, the eucalypts have great value not only because of their desirable features for use in fuelwood plantations, but also because they are especially suited by their physiological characteristics for growing in the drier and warmer tropical and subtropical regions of the world, in which fall the broad climatic characteristics of many developing countries.

Apart from a closer survey of the genus in its natural habitat and from complementary experimental work under managed plantation conditions, there is a future prospect for still greater developments via tree improvement methods. Although these methods have been established, they are still probably beyond the reach of the facilities available for many urgent undertakings. These developments will often involve interspecific hybridization and vegetative propagation of planting stock. These procedures have already begun in plantations for industrial use where the value of the product is higher than in fuelwood production. However, basic need may establish an economic value of wood for this purpose when produced from plantations properly located that is high enough to merit fully the use of such techniques.

The special needs of agroforestry, particularly as they are more precisely defined, are likely to be especially responsive to such improvements. An examination of the economic elements involved in such possible developments would be worth exploring in-depth. Amongst other things, it may lead to central specialized nurseries associated with appropriate storage and transport systems.

Eucalypts have many advantages for the previously mentioned uses, but they also have shortcomings. For example they do not fix nitrogen so far as is known. Their water consumption is high although it is believed that (a), wood production per unit of water consumed is also high and (b), they are amongst the most efficient plants in wood production in relation to water consumption. Planning the use of resources should allow a balanced decision as to the extent of eucalypt planting in any given situation in order to keep water consumption to appropriate levels. In some agroforestry situations, species other than eucalypts will be favoured on this ground alone so that combinations of tree and crop plants will be more practical than would be the case if such mixtures were attempted with eucalypts alone.

Casuarinas

As with eucalypts, the casuarinas are almost an Australian biological monopoly but not quite to the same extent because there are more *Casuarina* species outside Australia than is the case with the eucalypts. Casuarinas have already attracted considerable attention, but their use to the present has been concentrated largely on three or four species and on limited provenances of those species, whereas the resource is very much broader.

The importance of *Casuarina* has been recognized in various ways including at the international workshop that was held in Australia in 1981 (Midgley et al. 1983). Apart from being a vigorous grower (although not quite to the extent that is shown by the eucalypts) it actively fixes nitrogen and rivals that of herbaceous legumes and the best of other tree species in this category. As a group, *Casuarina* produces superb fuelwood and in its native habitat it was preferred in earlier years by bakers for fuelwood for the exacting process of bread-baking. Special contracts were arranged for supplies of wood for this purpose in eastern Australia at least until 1939.

The selection of species for these uses presents special problems, the first of which is the basic taxonomy. Recent treatment proposes that the genus be separated into four separate genera each of which stands in considerable genetic isolation from the other. Moreover several of the potentially most important species extend into regions of Australia (some are in Papua New Guinea). They are relatively little explored and are not readily accessible. The result is that a considerable amount of research remains to be done on screening and exploring provenances of the best adapted species.

To date only about four or five species have been widely used and of these *Casuarina equisetifolia, C. cunninghamiana* and *C. glauca* are the most widespread in plantations. Amongst these, *C. equisetifolia* has been especially important. It has been very successful as a sand binder and wood producer on coastal sands in many areas in India near Madras and on the central coast of Vietnam.

In Thailand a single clone, which is derived from *C. junghuhnuana*, has been widely planted while in Egypt a spontaneously occurring hybrid of *C. cunninghamiana* and *C. glauca* has shown considerable promise for agroforestry use in that country (El-Lakany 1974). Examples such as these, point to some ways in which future development may proceed with benefit.

Some species can be propagated readily by stem cuttings (as in Thailand), which is a method that opens the way for clonal culture and which is likely to be of special importance in agroforestry situations. Traditional use of *C. oligodon* in Papua New Guinea has exploited this feature and there is a related practice in Timor with the local species.

The extent to which interspecific hybridization will be feasible remains to be explored. It is known that marked chromosomal differences occur between different groups and that there will certainly be barriers to interspecific hybridization between some pairs of species.

The capacity of species of *Casuarina* to fix atmospheric nitrogen has been known for some time. This is mediated by the actinomycete *Frankia* in association with root nodules. All species have been found to possess nodules, but they are not invariably present on all sites and it known that nodules can be present without there being much active nitrogen fixation. Sometimes, poor performance of seedlings and young plants has been observed, which suggests that either *Frankia* inoculation is absent or that the strains available are inappropriate. In view of the importance of nitrogen fixation, especially in agroforestry, the benefits of a thorough understanding of the biology of the system in *Casuarina* is very desirable and would help in planning more effective use of this group of trees.

Apart from this characteristic, some species display a capacity to tolerate considerable salinity. *C. glauca* and other species will withstand quite calcareous conditions; however genotype habitat interactions have not yet been systematically studied.

Various *Casuarina* species range in size from shrubs to 30 m trees. Many will coppice readily and the well known ones are easy to handle in the nursery either as seed or cuttings. Many provide fodder for stock when needed under conditions of stress although this feature may make problems for protection during establishment. Not all species share all these characteristics and this calls for further research.

It is evident that *Casuarina, sensu latus*, is a genus of great importance for fuelwood and agroforestry programs in widespread areas of the developing world.

Acacias

As defined at present, the genus *Acacia* extends round the world in the warmer latitudes. From taxonomic studies, some persons consider that most of the species occurring in Australia, and which are mostly phyllodinous, merit elevation to a genus of their own. Whether this view has universal support or not, it does emphasize that as a group they have features that separate them from other species in the genus and especially from those that occur naturally in Africa and Asia.

The Australian group is a very large one with some 700 species——larger than *Eucalyptus*. The distribution of some acacias extends further from Australia than eucalypt species, e.g. as *A. koa* in Hawaii and *A. confusa* in Malaysia. In Australia, species are still being described at a rapid rate. Acacias in Australia are predominantly shrubby, but a few species grow as trees to 30 m high.

In the main, Australian species develop phyllodes instead of normal leaves; these leaf-like structures are derived morphologically from petioles associated with a largely complete suppression of the pinnate foliage characteristic of the genus as a whole. The phyllodes are often remarkably similar to eucalypt leaves so that acacias and eucalypts in Australia tend to have a somewhat similar appearance in the mature trees in the field. Almost everywhere in the natural habitat where there is a species of eucalypt there is an accompanying species of acacia.

A few species have been planted extensively outside Australia. In this regard, *Acacia mearnsii* (syn. *mollissima)* is widely known as a producer of tanbark and latterly of useful wood either for fuel, pitprops, or pulp. In common with other Australian species this has grown very well as an exotic in suitable localities——there are extensive plantations in east and southern Africa. *Acacia melanoxylon* has also been quite widely used in various places as a timber producing tree and at times reaches more than 30 m in height. Other species have been sought as ornamentals of which one of the most striking is the mimosa of southern France, which is based on a hybrid of the two species *A. podalyriaefolia* and *A. baileyana*. This in turn has been grafted as a clone on to stock of another phyllodinous species, i.e. *A. retinodes*, which is resistant to calcareous soils that are characteristic of much of the region in which its cultivation is sought on the Mediterranean coast.

This historical experience in relation to ornamental horticulture indicates the possibilities for further domestication of the genus as its use is extended.

In tropical areas *A. auriculiformis* has been used and more recently, *A. mangium*. The latter is somewhat larger and has a better stem form than the former. Some provenance trials with this species are presently being commenced on an international basis.

It is known that a range of species exists that merits introduction to cultivation, a first step in which is field survey and seed collection where they grow naturally. Such collections will commence in 1983. Acacias of these types are generally very fast growing when young and are often short-lived, viz. 10-20 years. Others grow much longer. Many produce excellent fuelwood as well as timber of high value. Some will coppice and some also make good animal fodder. The position is that the value of the resource is recognized but at present is being little tapped.

In common with other legumes, the phyllodinous acacias fix atmospheric nitrogen and display root nodules. However, less is known about the details of the process, its efficiency, and implications in cultivation. Research to provide more information in this aspect is desirable.

The potential for use of *Acacia* species is great, both in meeting fuelwood needs as well as in agroforestry situations.

Melaleucas

Interest in this genus of paperbarks centres on the species that were known formerly as *M. leucadendron* but which are now spread over a dozen or so species, which are confined to the Australian region, with one or two closely related ones in SE Asia.

Basic taxonomic work in the group is still incomplete but there is evidence that trees in a range of sizes, which endure adverse conditions such as swampy sites, salinity, and aridity, are found. In some localities, species of the group have become weedy in exotic habitats and this feature must be assessed when their use is contemplated.

Compared with the foregoing groups, assessment of their potential is still at an early stage but there is considerable promise implied from the existing information.

Other Australian Species with Potential for Use.

The biological resource in Australia is unique, diverse, and of incalculable value where needs for fuelwood and agroforestry are to be met in much of the developing world. This is not confined to the four groups mentioned above but extends to considerably more genera, each with a few species. Some that are likely to be significant have been mentioned recently by Boland and Turnbull (1981). Further reviews of such species are to be expected in the future.

The opportunities for taking advantage of this resource will be extended by programs of the Australian Centre for International Agricultural Research (ACIAR) in the cooperative programs that it is developing.

Summary

The demand in developing countries for fuelwood and for introducing the benefits of developments in agroforestry is large and urgent. Australia has a biological resource of major value in these fields and one which is still largely unexplored in *Eucalyptus, Casuarina,* phyllodinous *Acacia, Melaleuca*, and other genera. Research to employ this resource more fully is a need of high priority and one which should involve especially the nitrogen fixing role of both *Casuarina* and *Acacia*.

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Flooded Gum, Eucalyptus grandis, coppiced i.e. cut for fuelwood at 7 years of age, in Eastern Africa.

An Assessment of the Current and Potential Use of Australian Woody Species in Conventional and Non-conventional Forestry Systems in Kenya, Tanzania, and Zimbabwe.

S. J. Midgley*

Australian tree species have become an integral part of the rural landscape of Kenya, Tanzania, and Zimbabwe since plantings were first made there towards the end of the last century. These trees are now grown in the three countries over a wide range of soils and climates——from fertile uplands at 2 000 m to infertile semi-arid areas and to the tropical coast. There have been introductions of probably 150 species of Australian origin and the eucalypts, the wattles (*Acacia* spp), and *Grevillea robusta* are the best known (Anon. 1957; Perry and Willan 1957; FAO 1979; Mullin 1982). The Australian Centre for International Agricultural Research (ACIAR) realized the increasing social importance of Australian species in the region and commissioned an assessment from June-September 1983 of their current use and potential so that better use can be made of the Australian genetic resource.

Eucalypts

They were first introduced as fast-growing trees to meet projected demands for railway fuelwood and, until replaced by oil and coal, they made a significant contribution to the development of Zimbabwe and Kenya. Today the eucalypts are a vital source of domestic fuel in many areas of the Eastern Africa Region and are commonly used as posts, poles, and small-scale building material. In Kenya and Zimbabwe they are also being grown for industrial cellulose. They are widely grown in commercial plantations, in small villages, on farm woodlots, and for ornamental or amenity plantings. Total areas under eucalypts are given in Table I. Most plantings are on the better quality lands at higher altitudes and are dominated by *E. grandis* and *E. saligna* but many plantings, mainly *E. camaldulensis* and *E. tereticornis*, have been established on harsher sites. Other species planted commonly include *E. paniculata, E. microcorys, E. globulus* and *E. citriodora*. Evaluation of other eucalypts for the more marginal sites in the Region is in progress.

The prime reasons for continued popularity of eucalypts among the rural populations include fast growth, superior form of production of building materials, great coppicing ability, ease of management, lack of weediness, and their value as a fuel. In some quarters concern is being expressed as to possible environmental consequences of eucalypt planting, including soil impoverishment, increased erosion, disturbance of the soil-water regime, and possible allelopathy. Although some eucalypts on some sites under particular conditions of management may contribute to such problems, the benefits of planting eucalypts clearly outweigh such shortcomings.

Acacias

The most successful and widely planted Australian acacia, *Acacia mearnsii* (wattle), is grown primarily for tannin, which is extracted from its bark. A decreasing world demand for tannin has prompted extensive conversion of wattle plantations to other land uses over the past 20 years but significant areas remain (Table I). Wattle cultivation benefits rural employment and provides significant quantities of fuelwood and charcoal, posts, and building materials. From one district with some 8 000 ha of wattle plantation, the East African Tannin Extract Co (EATEC) of Kenya produces about 10 000 tonnes of charcoal annually with an estimated wholesale value of 6 million Kenyan shillings i.e. approximately US$440 000

* Experimental Officer, Division of Forest Research, CSIRO, Canberra, Australia.

Table I. Current total areas (ha) under eucalypts and *Acacia mearnsii* in Zimbabwe, Tanzania, and Kenya.

Genus	Zimbabwe	Tanzania	Kenya
Eucalypts	30 970[a]	3 000[b]	24 000[c]
A. mearnsii	13 920[a]	23 300[d]	14 000[e]

a. Forestry Commission, Harare.
b. Estimated total, Forestry Division, Dar es Salaam.
c. Forestry Dept, Nairobi, pers. comm.
d. Sherry (1971). (Figures now out of date and possibly an overestimate).
e. Heuvelop et al. (1982).

(M.J. Gichuru, pers. comm. 1983). In populated areas a maize crop is sometimes grown between the rows of wattle during the first year of the rotation. EATEC has also recorded nitrogen fixation rates of 50 kg ha^{-1} yr^{-1} under vigorous stands of wattle (Kirit Patel, pers. comm. 1983).

Despite its obvious success in many areas, the use of wattle is restricted by its inability to coppice and its potential to become a weed under some conditions. In areas converted from *A. meanrsii* to *Pinus patula* it has, in some cases, taken up to 10 years to totally remove the wattle from the site. In Zimbabwe, because the wattle plantations are remote from the centres of populations and the people have no cultural affinity towards charcoal, some 70 000 tonnes of wattle are burnt to waste annually (J. Wiltshire, pers. comm. 1983).

Other Australian acacias introduced to Africa are *A. decurrens* and *A. dealbata*, which are closely related to *A. mearnsii* and *A. melanoxylon* (well known as a furniture timber), but these are not as widely used as is *A. mearnsii*. Acacias from an expanded range of Australian environments will be included in future species-assessment trials. Fast growing species, from arid, semi-arid, and seasonally dry tropical zones, that can compete with weeds, fix nitrogen and provide fuelwood and charcoal are of particular interest.

Other Australian Genera

Grevillea robusta was introduced to East Africa early this century primarily as a shade tree for tea and coffee crops. Although there is a technical question as to the future of shade crops for tea and coffee, *G. robusta* will continue to be planted at many sites as an ornamental, in shelterbelts, in boundary plantings, and intercropped with agricultural crops. Small plantations of this species in Kenya and Tanzania suggest that its reputation for autotoxicity when planted in monoculture is not fully deserved. It is currently a much sought-after tree for inclusion in agroforestry systems in Eastern Africa as it produces a favourable mulch and does not compete strongly with agricultural crops (ICRAF, pers. comm. 1983).

Other Australian genera, which have been planted to a lesser extent, include *Araucaria, Callistemon, Callitris, Casuarina, Melaleuca*, and *Macadamia*. They are more commonly planted as ornamentals in arboreta or in small trial plantations. *Casuarina equisetifolia* is an exception in that it has become almost naturalized in coastal sites of Eastern Africa. It is said to have been introduced by Arab dhow captains to mark harbour entrances (Perry and Willan 1957) and produces straight strong, durable poles highly prized for building and firewood, and occasionally used as masts. The ability of this casuarina to fix nitrogen, to help stabilize dunes, and to establish on impoverished sites has made it very popular on the coast of Kenya, and indicates that further trials of the casuarinas, particularly *C. cunninghamiana* and *C. glauca* are warranted. Both these species have demonstrated a potential for success on semi-arid, saline, or waterlogged sites.

Management of Australian Species

Australian species have presented few problems in the nursery, planting, or establishment stages.

Propagation material (primarily seed) is readily available and easy to work with, and the species have generally offered flexible silvicultural and management options. Their properties are such that it is possible to utilize the timber, whatever the size, at almost any time during the rotation. This is well demonstrated in Uganda where, over a period of 50 years, the end use target of the *E. saligna* plantations changed six times (Marten 1981). Thus, if priorities in end-use change, the management of these species, particularly the coppicing eucalypts, can be altered accordingly. Their regeneration capacity from either seed or coppice is such that re-establishment after harvesting is generally cheap and technically straightforward.

Future Directions in the Use of Australian Trees

Forestry authorities in the countries visited have expanded their objectives from an almost total commitment towards industrial wood production to a substantial additional commitment towards domestic fuelwood supply. This conscious policy shift will have far-reaching effects upon the future utilization of Australian tree species. The governments in all three countries have firm policy commitments towards forestry in general and to village afforestation in particular. As a consequence of enlightened political patronage, this commitment is supported by generous resources in Kenya through the Rural Afforestation Extension Scheme (RAES), in Tanzania through the Village Afforestation Scheme (VAS) and in Zimbabwe through the Rural Afforestation Scheme (RAS).

The prime objectives of all three schemes are to provide for the wood needs (primarily fuelwood and small building materials) of a rapidly growing rural population and to maintain a suitable environment for sustained agricultural production. The estimates of annual fuelwood consumption for Kenya of 20 million m° (Speich 1983), for Tanzania 40 million m° (Kaale 1983), and for Zimbabwe of 5 million m° (Banks 1980) are placed in perspective by comparing them with total roundwood removals from Australian forests in 1981-1982 of 16 million m°, which included wood for paper, building materials, reconstituted products, and chips for export.

Agricultural demands upon the better quality highland areas of Kenya and Tanzania are increasing rapidly and plantation forestry, which has been a prominent land use in these areas, is being pushed to more marginal sites. There is now an urgent need to identify species that can grow in harmony with intensive agriculture or can better utilize marginal and arid, or semi-arid sites. It is for these reasons that research in afforestation on arid and semi-arid lands and on farm forestry (including social forestry, community forestry, and agroforestry) is being given high priority and has attracted support from foreign donors (IDRC, USAID, World Bank, FAO, NORAD, GTZ, Swiss Government, SIDA and others).

In this new direction for forestry, all the ingredients for success are present including funds, expertize and political and administrative commitment. However, there are constraints. Many rural inhabitants are not yet convinced of the gravity of the fuelwood problem and there are shortages of suitably qualified staff to implement projects. Technical questions, the main one of which is the choice of suitable species to meet local objectives, still have to be answered.

Those called upon to implement fuelwood or agroforestry programs find that many of the traditional forestry constraints to species choice are no longer relevant. Attributes such as stem form, fibre length, wood colour, and sawing qualities become subordinate to qualities such as fast growth, burning properties or mulching ability and the range of potentially suitable species is consequently increased. The end result is that the tree planter is confronted with a bewildering array of largely untried species from which to make a choice. It is no coincidence that many projects are concerned with species assessment. There are two projects in Zimbabwe, four in Tanzania, and in Kenya the problem is tackled by four ministries, twelve donor agencies and probably twenty non-government organizations. Lack of coordination and communication between these projects is leading to duplication and fragmentation of effort.

In the past, problems in seed procurement have limited many species trials (Nkaonja 1980). The Canadian IDRC has recognized the problem of communication and duplication of effort especially with regard to supply of tree seed and has proposed to support a Regional Tree Seed Centre based in Zimbabwe (Scott, pers. comm. 1983).

Such a centre will be a natural focus for information on species assessment and would overcome many shortcomings of tree seed supply.

Kenya, Tanzania, and Zimbabwe have climatic and soil conditions that are likely to suit many of the 1 300 Australian species of eucalypts, acacias, and casuarinas. Some of these are suitable for fuelwood and agroforestry (Boland and Turnbull 1982) and can often tolerate particularly harsh site conditions including aridity and high levels of salt and soil alkalinity. Mullin (1982) concluded that 'with this vast array of species to choose from, and the already proven success in Zimbabwe of many eucalypts and one casuarina, there seems little reason to look beyond Australia for trees to meet our fuelwood needs'.

Despite long experience in dealing with Australian species, many foresters in Kenya, Tanzania and Zimbabwe particularly the first two named were unaware of the enormous variation that exists between provenances (different seed origins) of some Australian species. Lack of experience in the taxonomy of Australian species has led to problems associated with incorrect identification. This inexperience with the Australian flora is seen as a major constraint to its effective use. There exists in the region a wealth of data, literature, and experience with a significant, but by no means exhaustive, range of Australian tree species; however, much of this information is not readily available.

Conclusions and Recommendations

The crisis of domestic energy supply will ensure that forestry activities are afforded high priority in the future development of Kenya, Tanzania, and Zimbabwe. Australian species have the potential to play a unique role in the future of African forestry. Careful introduction, systematic trial work, and careful assessment are essential to ensure the effective use of these species.

This would be facilitated by establishing projects designed to:

1. Increase the local expertise and knowledge of Australian woody species.
2. Assist in the selection and evaluation of additional species.
3. Encourage effective use of successful Australian species through efficient distribution of authentic seed and positive support for the proposed IDRC-sponsored Regional Tree Seed Centre.
4. Gather, evaluate, and publish relevant data on the performance of fast growing species for fuelwood or agroforestry in the eastern and southern regions of Africa.

Summary

Current use and management of Australian woody species in Kenya, Tanzania, and Zimbabwe are discussed. A shift of emphasis of governmental policies from forestry for industrial wood supply to forestry for domestic energy supply is noted. Future directions in rural reforestation, the role that Australian species may play and constraints to their effective use are described. Recommendations for donor assistance are made.

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Session 3

Farming Systems and Socio-Economics

Concept and Practice of Farming Systems Research

J.L. Dillon and J.R. Anderson*

One could easily gain the impression, given the spate of recent literature, that the farming systems approach to research was only discovered in the past decade or so. Until the 1970s, little was heard of it. Since then it has had no shortage of either powerful proponents or opponents in those various national and international forums where the organization, programming, and budgeting of agricultural research are decided——a sign, no doubt, that farming systems research (hereafter FSR) is significant and revolutionary. Yet, farming systems have necessarily existed since farming began. Likewise, it is inconceivable that agricultural research can ever have been conducted without some appreciation of the farming system context to which it related. Indeed, with hindsight, one may argue that much successful agricultural research historically has been that which was conducted with an implicit farming systems orientation. Nonetheless, it is also a fact that institutional research specifically organized in terms of farming systems is relatively new, dating perhaps from no earlier than the 1950s. Only in the past decade has FSR gained formal recognition via the sanctioning of budget appropriations and designated program activities within a variety of research agencies and in terms of the research literature. For instance, the journal *Agricultural Systems* only began in 1976.

As a formal framework for the conduct of agricultural research, the farming systems approach is still, for many people, ill-defined and unproven. Certainly, being so new in its modern formal incarnation, it is true that the concepts, terms, and methods of FSR are young and evolving. Thus some have found it:

1. To suffer from problems of definition.
2. To involve activities that seem to lack specificity of purpose.
3. Not to have a codified set of methods for its implementation.
4. To involve a bewildering array of activities.
5. To be difficult to evaluate in benefit-cost terms.

Perhaps heroically, against such a background, in this paper we attempt to outline the farming systems approach, appraise its relevance and consider its implications for research organization and management in the context of agricultural development.

The Farming Systems Approach

What is the farming systems approach to research? Certainly it does not imply the use of some new independent science. Rather, it involves the application of knowledge available from the physical, biological, and social sciences (i.e. from the standard pool of knowledge used in traditional agricultural research) but with the difference that it uses a systems approach (Couger and Knapp 1974) in its inquiry. Thus FSR is holistic in outlook and is both multi and interdisciplinary. Reflecting its systems orientation and consequent need for realism and practicality (expressed in part by an understanding of farmers' existing systems), the activities of FSR include both working at the farm level and at the research station level, often with less control than is usual in traditional research with its focus on a particular discipline or commodity.

Basic to FSR is an appreciation of the farm as a system whose *modus operandi* is specified by some particular farming system of which the farmer is an integral part. Defining what is meant by the term 'farming system' is not easy, as is indicated by the following statement (Dillon et al. 1978, p.8.):

> 'A farming system is not simply a collection of crops and animals to

* Professor and Head, Department of Agricultural Economics and Business Management, University of New England, Armidale, N.S.W., Australia; Associate Professor, same Department, respectively.

'which one can apply this input or that and expect immediate results. Rather it is a complicated interwoven mesh of soils, plants, animals, implements, workers, other inputs and environmental influences with the strands held and manipulated by a person called the farmer who, given his preferences and aspirations, attempts to produce output from the inputs and technology available to him. It is the farmer's unique understanding of his immediate environment, both natural and socio-economic, that results in his farming system'.

More directly, Shaner et al. (1982, p.16) have defined a farming system as:

> 'a unique and reasonably stable[1] arrangement of farming enterprises that the household manages according to well-defined practices in response to the physical, biological, and socio-economic environments and in accordance with the household's goals, preferences, and resources. These factors combine to influence output and production methods. More commonality is found within the system than between systems. The farming system is part of larger systems——e.g. the local community, and can be divided into subsystems——e.g. cropping systems'.

Thus a farming system involves complex interaction between a variety of interdependent components both physical and psychical which, in turn, may often be viewable as subsystems. Central to the system is the farmer himself.

Following Norman (1980), Figure 1 is a schematic representation of the determinants of a farming system. The environment is seen as having two elements; human and technical. The technical element, specified in terms of available technology and climate, defines production possibilities. The human element involves exogenous factors (including the socio-economic and cultural environment) that influence the farmer's decision making as to what farming system he will use in the face of the technical and resource constraints that he faces.

In such terms, FSR can be viewed as research that: (a) views the whole farm as a system; (b) is conducted with a recognition of and emphasis on the interdependencies and interrelationships that exist among elements of the farm system, and between these elements and the farm system's environment; and (c) is aimed at enhancing the efficacy of farming systems through the better focusing of agricultural research so as to facilitate the generation, testing and adoption of improved technology.

To these ends, the major activities involved in FSR oriented to a particular target group or region are:

1. To develop a clear statement and agreement on initial objectives of the team.
2. The collection and analysis of base line data.
3. The study of existing farming systems.
4. The design of new system components, subsystems, and/or farming systems.
5. Farm systems experimentation.
6. The evaluation and monitoring of new components and/or new or modified farming systems.

Some Examples of FSR

The span of application of FSR, ranging from simple system adjustment through revision to replacement by a virtual new system, is illustrated by the following three examples.

1. System Adjustment in Brazil

Wheat, which would otherwise be very well suited, suffers from the high aluminium level of the soil in the Cerrado of central Brazil. Recognizing this, EMBRAPA and CIMMYT are cooperating on a wheat breeding program to develop wheat varieties resistant to aluminium toxicity. When available, this new germplasm will, as a simple adjustment to the prevailing system, replace the existing wheat germplasm.

1. A referee has expressed the cogent view that a feature of many farming systems in upland areas (e.g. Ethiopia, Nepal) is that they are becoming inherently unstable under sustained resource 'pressure'.

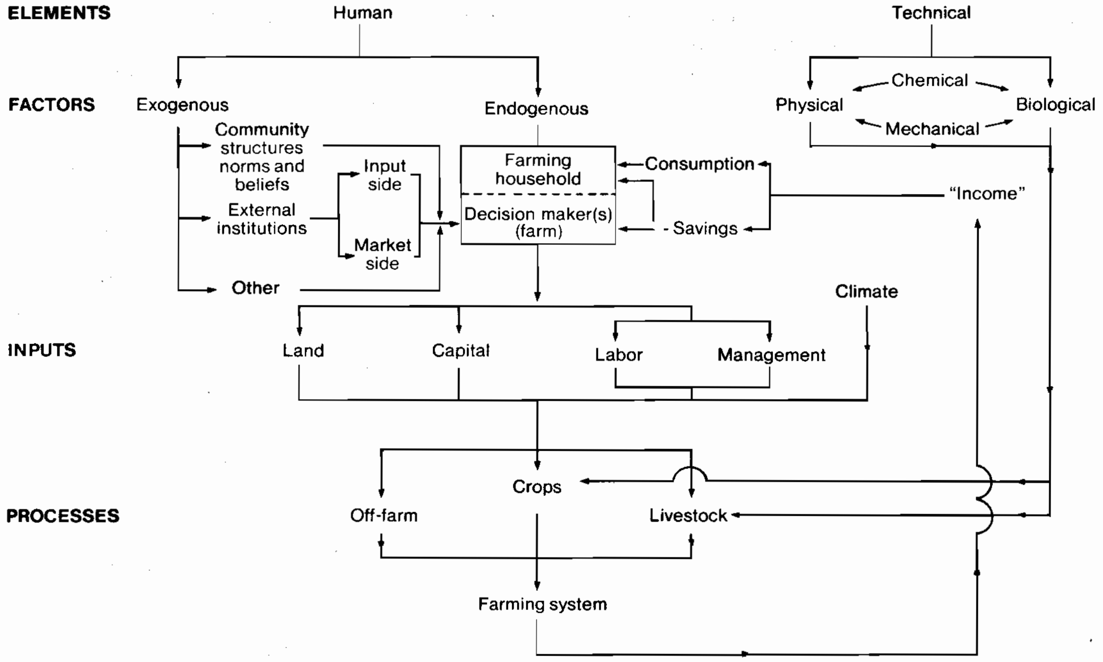

Figure 1. Schematic representation of some determinants of a farming system (After Norman 1980).

From a FSR view, this is not a complicated matter——though the breeding research may be quite complicated (as may also be the research needs opened up when Cerrado farmers, through the income generated from the new wheat germplasm, have the potential for further elaboration of their farming systems).

2. System Revision in the Philippines

IRRI's Cropping Systems Program has focused on rice-based systems of small farmers in rainfed areas. One avenue of assistance to these farmers was seen to be increased cropping intensity (Zandstra et al. 1981). For areas with a growing season of intermediate length, appraisal indicated that the effective growing season might be lengthened. The following methods, either alone or in combination, were proposed: (a) the use of shorter duration varieties, (b) techniques allowing earlier planting at the start of the rainy season, (c) overlapping of growing periods by relay cropping and intercropping, (d) use of drought-tolerent crops, (e) improved soil moisture usage, and (f) use of supplementary irrigation.

Thus, for example, research into rainfed rice systems in the Iloilo region of the Philippines showed that new short-duration rice varieties in combination with direct seeding techniques would enable other upland crops to be planted before or after rice and, in lower-lying areas, the production of two rice crops in a single season. When IRRI began this work in 1975, 82% of the rainfed land in the Iloilo region was planted to a single-crop rice fallow pattern. Today, in contrast, some 75% of the region produces two or more crops per season. With this revision to the farming system, a significant increase in the region's cropping intensity was achieved in two years.

3. System Replacement in India

Perhaps the most significant application of FSR to date has been ICRISAT's development of virtually a new farming system for the Vertisol sub-region of India having a soil depth of at least one metre and a mean annual rainfall above 750 mm. The new system appears suited to implementation on at least 5 million and perhaps as much as 12 million ha of this subregion of 73 million ha in India's semi-arid tropics. Currently, this area of rainfed agriculture is left fallow during the rainy season and cropped for wheat, chickpea, sorghum or safflower in the postrainy season.

The essence of the new system (Swindale 1981; Kampen 1982; Reddy and Willey 1982) is the growing of an extra rainy-season crop on the lands presently left fallow, thereby raising cropping intensity from its present level of around 100% to around 200%. Development of the new system has involved multidisciplinary on-station team research at ICRISAT Center near Hyderabad since 1974. Central to this work has been the use of operational-scale watersheds and subwatersheds of from 1-5 ha in size. The technology options considered have been of a moderate-input nature based on bullock power and, assuming that some economies of size can be achieved in the manufacture of implements, lie within the reach of the small farmer. They are based on the concept of the small watershed as the basic resource management unit. They are technology options that will create employment and are thus socially relevant.

Within the context of the small watershed (which will typically involve some 6 to 20 farmers), components of the new system are (Ryan et al. 1982):

(1) Cultivation of the land immediately after the previous postrainy-season crop when the soil still contains some moisture and is not too hard.

(2) Improved drainage with the aid of field and community channels and the use of graded broadbeds and furrows constructed with a bullock-drawn wheeled tool carrier.

(3) Dry seeding of crops (such as sorghum or maize in a sequential or intercropping system with legumes, such as pigeonpea or chickpea) before the monsoon rains arrive.

(4) The use of improved varieties and moderate amounts of fertilizers.

(5) Improved placement of seeds and fertilizers; and attention to improved plant protection, particularly for legume crops.

While any one of these components, with the exception of fertilizer, gave only a small effect on production, all of them together produced spectacular results. This is shown in Table 1 from Ryan et al. (1982, p.8) for the case of a maize-pigeonpea intercrop system in 1976-77——a system, which in research station trials over the years 1976-77 to 1980-81, gave an average annual yield of 3.85 t/ha of food grain production without irrigation. Economic analysis of these on-station experiments has been made by Ryan and Sarin (1981). The new improved system using all the devised technology gave annual profits averaging US$365/ha, compared with only US$50/ha from the simulated traditional system. The ICRISAT Center study suggests that, for an extra annual cost of US$120/ha, a farmer changing from the traditional to the improved system can earn an additional profit of about US$310/ha per year. This represents a rate of return on the increased operating expenditure of 260%.

To provide on-farm verification of the proposed new system, ICRISAT conducted a farmer-managed trial in 1981-82 in a village chosen to be representative of the deep Vertisol region with assured rainfall. A watershed of some 15 ha involving 14 farmers was used for the experiment. Some assistance by way of wheeled tool carriers, power sprayers and surveying of the watershed was provided but other required resources were paid for by the farmers. Advisory input from ICRISAT scientists amounted to 1.4 man years. The farmers were also guaranteed that they would not earn less than they could have expected by using the traditional system. To this end, nearby plots representative of the traditional system were also monitored. Using information provided by ICRISAT, the farmers made their own crop choices——this resulted in nine different crop combinations, including the crops of one farmer who decided not to change.

The results of this farmer-managed trial have been summarized by Ryan et al. (1982) and Ryan and von Oppen (1983). Averaged over the nine cropping systems on the improved watershed, the profits were US$306/ha compared with US$165 for the traditional system. This implied an average rate of return of 240% on the farmers' extra annual expenditure and confirms the experience at ICRISAT Center (even though atypically high prices for postrainy-season sorghum grain led to unusually high profits in the traditional

Table 1. Synergistic effect of variety, soil management, and fertilizer application in a maize-pigeonpea intercropping system on a deep Vertisol at ICRISAT Center, Patancheru, A.P., India, 1976-77.

Treatment	Yield (kg/ha)	
	Maize	Pigeonpea[a]
Maize variety: Local		
Traditional inputs and management	450	320
With improved soil- and crop-management alone	600	610
With fertilizer application alone	1 900	450
With improved soil-crop management and fertilizer	2 610	840
Maize variety: Improved/hybrid		
Traditional inputs and management	630	500
With improved soil- and crop-management alone	960	640
With fertilizer application alone	2 220	540
With improved soil-crop management and fertilizer	3 470	600
L.S.D. (5%)	470	220

a. Pigeonpea variety was the same in all cases.

system in 1981-82).

As typical of on-farm FSR, particularly when dramatic changes are made to the existing farming system, this farmer-managed trial threw up a variety of problems for further consideration. These included difficulties with *Striga* weed in sorghum, pod borer in pigeonpea, threshing and storage, bullock power availablility, markets for new crops, credit requirements and mechanisms, fertilizer sales distribution, implement availability, and skill development in farmers and extension personnel.

Some of these problems imply further research station trials; others imply policy and institutional considerations. Also, with the extension of on-farm trials to a further eight representative sites involving a total of 57 farmers on 120 ha across the deep Vertisol region in 1982-83 and the implementation of the technology by official agencies in four States in 1983-84 with the development of some 4 000 ha involving 1 700 farmers, there is no doubt that further problems will be discovered.

The Need for a Farming Systems Approach

If agricultural reseach aimed at the improvement of technology is to be fruitful, it must generate knowledge that is actually used by agricultural producers. Otherwise, if the research has no impact, it implies wasted effort and loss of other opportunities (including those foregone because research has earnt itself a bad name).

The need for FSR and its usefulness lie in the degree to which traditional research approaches of a disciplinary or commodity nature fail to produce results that are actually used by farmers. Such failure of traditional research can be usefully related to the FSR concepts of system adjustment, revision, and replacement. Traditional research whose impact, from the farmer's view, is merely system adjustment has *ceteris paribus*, the greatest chance of adoption. Thus we have the success of well adapted new, especially Green Revolution, varieties since they only require the farmer to make minimal adjustments to his existing farming system. In contrast, system revision is more difficult to implement, and system replacement, from the farmer's view, is the most difficult of all.

Traditional disciplinary or commodity research results whose potential impact lies in system replacement are highly unlikely to be adopted because, by the nature of traditional research, such results will have been generated without due regard to the realities of the farmer's situation and the difficulties he faces in system replacement. Thus it is inconceivable , for example, that the current implementation of ICRISAT's Vertisol technology could have occurred without its having been developed in an FSR context. Indeed, it is most unlikely that a traditional research approach would have been able to generate such a technology.

The results of traditional research may fail to be adopted for two reasons: on the one hand, the research may be misdirected because the researchers misperceive the farmer's situation through lack of understanding of his desires, perceptions (especially of risk) and constraints or, on the other hand, because the farmer cannot perceive the relevance of the research results due to inadequate information. Through its orientation to the farmer, emphasis on the understanding of his existing farming system and its context as its starting point, and its follow-up activities, FSR aims to ensure that these two difficulties are overcome, in turn ensuring more rapid adoption of the new technology that it generates than would otherwise be the case. At the same time, because of its system orientation, FSR is more likely to ensure consideration of the whole system within which agricultural production takes place, and thereby give due weight to both the needs of farmers and of society at large, as well as more effectively identifying and suggesting solutions to institutional constraints to agricultural development.

Without doubt, the greatest need for an FSR approach is in the development of improved technology for the masses of small farmers in the less developed countries. This opportunity arises, first, because such farmers, who are of overwhelming numerical importance in the Third World, generally do not have either the education or information services to enable them to act as good integrators of new scientific information; and, second, because traditional research in such countries (a) has generally overemphasized biological potential and yield considerations without sufficient attention to other relevant criteria, (b) has been based on priorities decided by government or by researchers without the involvement of small farmers, and (c) has been carried out on experiment stations in isolation from small-farmer conditions. To a significant degree, these difficulties reflect the inadequacies of traditional institutional arrangements for agricultural research——a matter to be further pursued below.

To the extent that farmers are capable integrators of new scientific information, have influence in the choice of research that is to be conducted, and rely on sole cropping and monoculture, the need for a formal FSR approach is reduced. There still remains, however, the argument that FSR, by virture of its holistic approach, provides a more complete approach to agricultural research than the traditional disciplinary or commodity approaches with their reductionist philosophy of research (Dillon 1976). Thus it can be argued that most successful agricultural researchers have, in fact, had an appreciation and understanding of the farming systems relevant to their work, even though their research was conducted with a disciplinary or commodity focus.

Methodology of FSR

While there is still much discussion over various points of detail, the general methodological framework of FSR is no longer a matter of contention as evidenced by the general consensus to be found between, for example, Collinson (1982), Dillon et al. (1978), Gilbert et al. (1980), Norman (1980), Shaner et al. (1982) and Zandstra et al. (1981). In this section we follow these authors in suggesting what sould be done in FSR without elaborating precisely how it should be done. There is much ambiguity about tha latter and the unresolved questions about it constitute a prevalent weakness in the practice of FSR.

Following Collinson (1982), Figure 2 depicts the overall framework of FSR. Broadly, seven activities are involved. To a degree, particularly in the initial stages, these activities will be sequentially cyclical as shown in Figure 2. However,

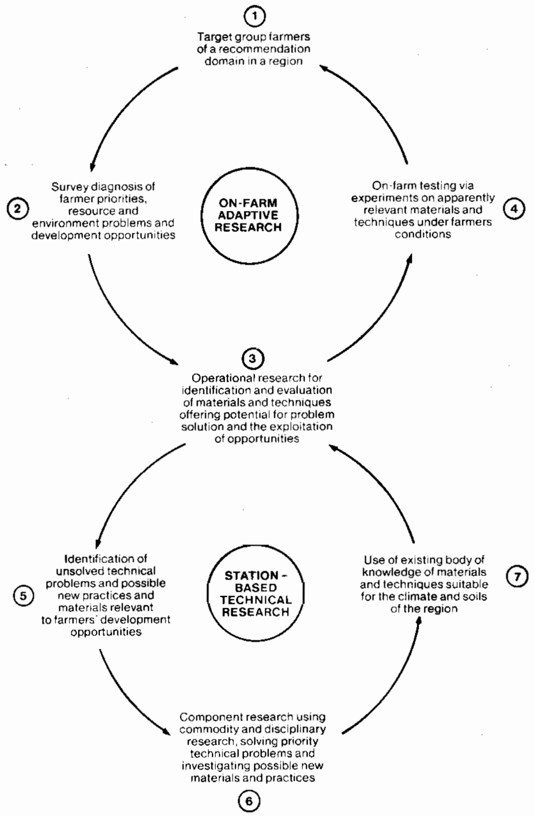

Figure 2. Schematic view of FSR method (After Collinson 1982).

once an ongoing FSR program is established, all the activities will likely be going on simultaneously with forward and backward interactions across them all. Relative to each activity, the following points may be made:

Choice of Target Area or Group

Selection of the target area or group (sometimes referred to as the recommendation domain) should: (a) attempt to be compatible with social needs and priorities, (b) be such as to give a fair chance of obtaining tangible results in reasonable time, and (c) be broad enough to spread costs (Perrin et al. 1976). The most satisfactory delineation is likely to be based on the relative homogeneity of the farming system currently used or, in terms of potential, on the basis of agroclimatic zoning. The aim should always be to strike a satisfactory balance in terms of the economic trade-off between decreased intra-group variability (or increased inter-group variability) and the problem of location specificity, which reduces the domain of impact (Menz and Knipscheer 1981).

Both in the delineation of the target area and in its further specification once chosen, there will be a need for base line data analysis. Time and cost considerations may often imply the use of secondary data. The relevance of data should be judged in terms of their contribution to the delineation and understanding of existing farming systems, their constraints, and opportunities for modification. Base line data will involve both physical factors such as land, soil and climate, and socio-economic factors such as population, culture, and infrastructure. Generally, base line data analysis will be carried out as a desk study. It will, of course, also make use of any micro information that is already available from prior surveys or research into existing farming systems.

Diagnostic Survey

Having delineated a target area or group, it is necessary to gain an understanding of the existing farming systems and farmers' motivations in using them. The main aim of this activity is to provide an assessment of farmers' priorities, decision criteria, resource availabilities, constraints, and possible development opportunities. The survey will also, if need be, provide a basis for delineating separate recommendation domains of farmers within the overall target area group. These domains may be based on natural factors such as soil or topography; cultural factors such as food preferences; or institutional factors such as tenure and market access.

Two broad types of surveys have been used for diagnostic purposes, i.e. reconnaissance or exploratory surveys, and formal surveys (Byerlee and Collinson 1980; Byerlee et al. 1980; Gilbert et al. 1980). The former are relatively informal and of low cost. They typically involve a week or so of field travel through the target area by a small multidisciplinary FSR team (e.g. an agronomist and an economist) who talk with representatives of policy-making and farmer-contact agencies, community leaders, and a small sample of farmers and their families. Formal surveys, in contrast, typically involve some considered form of sampling and prespecified sample sizes, designed questionnaires and an orientation to traditional scientific standards of accuracy. In contrast to informal exploratory surveys, they are likely to be time consuming and costly. This will be particularly so if the formal survey is of a multi-visit panel nature with field recording of production factors.

If time and resources permit, and the need is seen, both exploratory and follow-up formal surveys will be conducted. In terms of gaining an understanding of existing systems and opportunities for change, they are complementary and perhaps best seen as relating to different stages of an FSR program. Initially, the rough and ready information of an exploratory survey may suffice; later, particularly if systems modelling (e.g. mathematical programming analysis) is used, more detailed information obtainable only via formal survey procedures may be needed.

Identification of Possible Changes and Operational Research

From appraisal of the survey information (and also from operational research), judgements can be made as to system changes that might be feasible and relevant. This experiment-station (or sometimes farmer's-field) based design, and operation research activity should generate a few sets of improved practices for possible testing at the farm level and suggest a number of technical problems or more major system changes needing deeper research. More risk-averse researchers may want more rather than a very few sets.

Criteria suggested as relevant (Gilbert et al. 1980) to the initial choice of possible changes for farm-level testing have been that they:

(1) Involve, as experimental variables, practices in which farmers' management is flexible (perhaps due to underutilized resources) and where *ex ante* evaluation suggests the possiblity of increased productivity (perhaps due to limiting resources).

(2) Assume few changes in the existing institutional framework relating to input supply and product marketing.

(3) Take as parameters in the experimental process those factors not potentially subject to manipulation, their level being set so as to be as representative as possible of practical farming conditions.

In the longer term, more drastic system changes become more feasible and the above strictures may be relaxed.

The design stage of indentifying possible system changes for on-farm testing may involve experiment station trials of an operational research nature and should always involve *ex ante* economic appraisals as, for example, discussed by Anderson and Hardaker (1979), Banta (1982), Ghodake and Hardaker (1981), and Ryan et al. (1979). Generally, the greater the body of existing knowledge pertinent to the system under study, the shorter will be the time required on the experiment station to complete the design stage and the more valuable is panel survey work.

System changes considered at the design stage may involve incremental or 'single trait' changes or more extensive 'packages' of practices. While incremental changes are doubtless easier to design and extend, packages will often have the advantage of capturing complementary or synergistic effects between components.

On-farm Testing

Farm-level evaluation via both researcher-managed and farmer-managed trials is a crucial element of FSR methodology. The evaluation criteria should be the same as those used by farmers, whatever they may be, as ascertained in the diagnostic survey. Performance of the improved technology, of course may drop as it is moved from the artificial conditions of the experiment station to the farm level, particularly under farmer management where it is being fully tested for compatibility with the existing system.

Research-managed farm trials can cover more treatments than farmer-managed trials and should be aimed to screen proposed technologies from the design or experiment-station stage, to fine-tune them to local conditions, and to evaluate their potential for local and regional coverage. All this is, of course, easier said than done, and refinement of the operational details for successful practice remains the key challenge in FSR.

Farmer-managed trials are the strongest form of testing. These trials should be on sufficently large plots and involve as many farmers on a continuing basis as is practicable to provide valid information on the new technology itself and on its compatibility with other parts of the farmer's system, and should be replicated over time with any modifications deemed necessary from the ongoing appraisal.

Choice of farms for farm-level testing is important as it bears on the question of farmer-research team interaction and technology transferability. To foster transferability, sites should, if possible, be representative of large areas, particularly with regard to landscape position. To foster farmer-researcher interaction, the more cooperative better farmers will tend to be preferred as collaborators. However, these are not representative farmers. Use of 'average' farmers, while decreasing interaction, may give a more satifactory appraisal of the proposed system changes.

Associated with and growing out of the on-farm testing activity are extension, monitoring, and evaluation activites. Extension workers should be involved directly in the on-farm testing activities so as to be fully informed. They, along with other member of the FSR team, should monitor the spread and evaluate the performance of the newly introduced technology so as to provide feedback to policy makers and sponsors, if there are any, on any relevant issues. In this sense, monitoring and evaluation should be made from the various perspectives of farmers, researchers, and society as a whole.

Identification of Technical Problems

Arising out of the diagnostic survey and identification of possible system changes, a variety of technical problems (e.g. diseases, market difficulties, etc.) can be identified. The feasibility, potential benefits and priority of attacking these problems need to be established as a prior step to undertaking research aimed at their solution.

Component Research

Having decided on the portfolio of technical problems to be researched at greater depth, commodity or disciplinary research on the relevant system components can be conducted on the research station. This research may be oriented to single or multiple components and may involve quite basic research, although to ease subsequent transfer, conduct on farms will be preferred where possible.

Single component research, which aims at improving individual components, will generally help elucidate 'principles' and 'processes'. It includes such topics as, e.g. identifying suitable genotypes for a particular cropping system, examining factors effecting runoff, etc.

Multi-component research constitutes the initial integration of modified or new components developed from disciplinary research into the system. It includes aspects such as the integration of cropping systems with labour availability, soil fertility management, and watershed management.

Use of Existing Scientific Knowledge

Particularly in the experiment station sequence from component research to operational research, use will be made of the existing body of scientific knowledge of both a general nature and specific to the target area or group and its farming systems.

Organization of FSR

The broad organizational lines of FSR spanning on-farm adaptive ('downstream') research and station-based technical ('upstream') research are depicted in Figure 2. Much debate has occurred over the separation and overlap of these activities——see, e.g. Dillon et al. (1978), Norman (1980), and Gilbert et al. (1980). Such debate, however, has been rather fruitless. A complete FSR approach will involve full integration of on-farm and station-based research with the same researchers working, as appropriate, in both activities. Thus ICRISAT, for example, has emphasized the complete integration of on-farm and station-based research via its designated Farming Systems Research Program which, as shown in Figure 3, exists alongside and interacts with the ICRISAT commodity (germplasm) and economics programs (ICRISAT 1983). A similar approach has been taken at ICARDA.

Compared with a traditional organization of research on the basis of disciplines and/or commodities, FSR has strong implications for research organization and management.

By virtue of its holistic approach to the problems of agricultural production, FSR is mul-

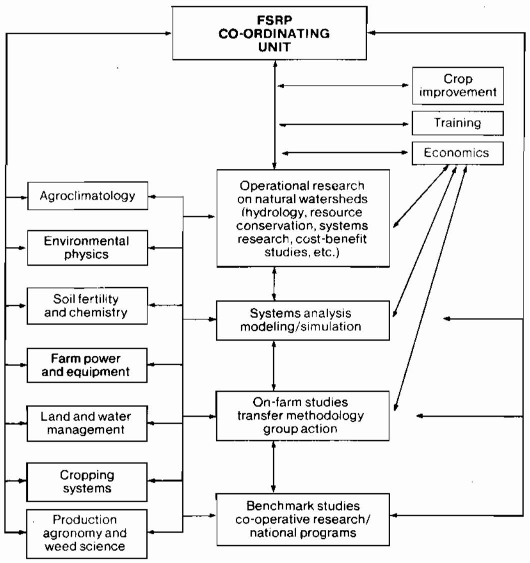

Figure 3. Organization chart of ICRISAT's Farming Systems Research Program (After ICRISAT 1983).

tidisciplinary in nature. It should be organized so as to provide a means by which multidisciplinary teams of researchers can examine problems of the relevant farming systems, including the complementary and competitive relationships between enterprises. The characteristics of FSR thus transcend those of conventional disciplinary research, in that FSR through a multidisciplinary team effort with a systems orientation, aims to develop new technology that is compatible with farmer goals and that will enhance system productivity.

The organization of FSR should thus be such as to encourage effective interdisciplinary interaction, which is the key element in FSR and is best encouraged by purposive leadership and voluntary cooperation rather than by attempted institutionalization through structure and formalities. Flexible procedures and mechanisms have to be developed to facilitate interdisciplinary research. Individual initiative in the competition for ideas should not be sacrificed. Sharing of experiences through networks can be very helpful and, as IRRI has shown through its cropping systems research network, can be especially useful in training FSR workers.

The successful operation of FSR programs places great demands upon the scientists involved. Coordination must be frequent and be undertaken by the people directly concerned. Team work is essential. Most importantly, the intra-institute organizational structure for FSR must be flexible; as the research task changes, so too, if need be, should the team and its leadership also change. Team leadership should not respect seniority. A high standard of professionalism is required which, in turn, requires that personal professional goals must be realizable within the system and the team.

One implication unique to FSR is that scientists should be involved in all steps of agricultural research. Scientists do not stop at one stage and hand over their research product to someone else for its further development and testing, but rather should participate in all stages of the problem-oriented research. Research with a conventional approach is usually much more compartmentalized across time and space.

At the more macro institutional level, the implementation of farming systems approach implies significant changes to the organizational structure of research found in many developing countries. First, it implies a shift away from commodity or disciplinary-based research institutes or divisions to a multidisciplinary farming systems orientation. In many countries this would perhaps be best expressed by a shift away from a system of research institutes or stations each having responsibility for a specific commodity to a system emphasizing regional responsibilities (but within which, of course, component research would still be undertaken as needed). Second, it implies a high degree of flexibility in the research, with considerable devolution of decision making and responsibility to those actually doing the work. Third, it implies a far higher degree of integration between research and extension activities than is usual. Extension personnel should be part of the FSR team and, ideally, there should be no institutional break between research and extension. Otherwise, the adoption of an FSR approach may lead to a new set of extension activities being carried out, and the consequent isolation of the traditional extension agency. Fourth, FSR implies a far greater role for farmers, through both formal and informal avenues, in the determination of research agendas. Fifth, through its orientation to farmer reality and the total environment of agricultural production, FSR implies an integral role for social scientists, particularly agricultural economists, in its activities. So important and so often misunderstood is this role that we take it up separately.

FSR and the Social Scientist

In the post-euphoric phase of the Industrial and Green Revolutions, the importance of human, social, and economic factors in farming systems is so widely recognized that it does not need further elaboration here. Research administrators, whether they be in regional, national, or international organizations have generally responded by ensuring that social scientists are represented in research structures.

The form of their representation varies widely, reflecting such things as the prejudices of the administrators and their influential scientific advisers (especially from other than the social sciences) and the availability of social scientists with backgrounds and interests in agriculture. The range extends from a token and peripheral appointment or two, through specialized service divisions of social sciences, to complete integration of social scientists in multidisciplinary research and problem-solving teams. In spite of the diversity, we might chance the generalization that the institutional incorporation of social scientists becomes more haphazard, the more local is the level of organization. Thus, for example, social scientists are pervasively involved in the International Agricultural Research Centres but, at the other extreme, can be almost non-existent at the regional agricultural research stations of the Third World where priorities have usually been given to activation of biological research. Perhaps it is the political sensitivity of socio-economic research findings (e.g. on income distribution issues) that have slowed the advancement of social sciences in Third World agricultural research[2]. Fortunately, however, the situation is improving rapidly in most such countries.

What is it that social scientists have to offer in farming systems research? Surely, it is not simply informing someone that beans have a higher market price than barley, or working out costs of production! It can be many things, and will doubtless vary from scientist to scientist, accordingly to disciplinary training and experience. Among the most important matters that will be addressed are: (a) the social milieu in which farm decisions are made, including customs of sharing and bequest, (b) the institutional setting and policy environment in which farming is conducted, including land reform, credit, and taxation, (c) the economic environment of farms, including long-term market prospects for inputs and outputs and, most importantly, an understanding of the opportunity costs and transactions costs faced by farmers, and (d) the attitudes and personal constraints of farmers, including their desire or otherwise for change, for leisure, for education, for different foods, and so on, and their human and other capital.

Data on such matters are not assembled for their own sake nor for the professional gratification of the social scientists concerned. Rather, the purpose must be to assist in the identification of effective changes to and designs of practices, techniques, enterprises, activities and policies that are acceptable to and appreciated by the target groups in FSR. The days of the 'quick' technological 'fix' have probably gone and progress now must be won in the context of the full reality.

Understanding the wider reality of farming systems does not come easily. Ideally, social scientists glean their knowledge of such systems through long and close contact with the people of the systems. Horton (1983) documents such a recent successful endeavour in Peru. The ideal, however, rarely obtains and more formal methods of description and understanding must be sought. The most widely used approach is a survey that garners detailed information on what happens in the village and on farms, to whom and when. Profiles of labour availability, cash flow, work demands, prices received, etc, can be built up in this way and, if the collections run for a sufficiently long period, the variability over time, especially in reponse to natural hazards like flood, drought and fire, can also be quantified.

Many elements sought in survey activities are subtle and/or sensitive. Particular skills are required to ensure faithful description of reality. For instance, some transactions costs such as bak-

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2. A referee has suggested another possibility, namely, that biological science administrators see a contribution from social scientists as being less useful than that from biological scientists!

sheesh to public irrigation managers or to fertilizer distributors may not be readily forthcoming in simple interviews but may involve considerable inflation of factor costs. Production levels may be systematically understated if farmers fear linkage between FSR workers and taxation authorities. For a final example, attempts to elicit information on farmers' attitudes to risk are fraught with the danger of interview bias clouding the sought information. Such anecdotes underscore the costs of reliable FSR survey work. In short, it is (a) time consuming, involving repeated contact both to develop confidence on the part of farmers and to gain an understanding of intertemporal effects, and (b) demanding of a high degree of professionalism on the part of those in direct contact with the farmers. Senior social scientists themselves must be actively involved in the direct contact, even if this is (perhaps linguistically) difficult. Minimally, interviewers should be conversant with the theoretical underpinnings as well as the empirical applications of the collected data.

The roles charted above for social scientists in FSR could be interpreted as a blueprint for integrative scientific supermen and it is as well to reflect on just how well such roles are executed, at home and abroad. To focus on Australia for the moment, a distinguishing feature of most social scientists engaged in work that could be broadly described as FSR is their basic facility in the technology of agriculture. Following British tradition, most of them have a first degree in agricultural science (or agricultural economics), which makes for their ready appreciation of the technical issues in FSR, as well as predisposing more ready peer acceptance from their colleagues in physical and biological sciences. This contrasts with, say, the situation in the U.S.A. where most economists, sociologists, etc. who work in agriculture do not have the same sort of background in agricultural sciences, and may explain, in part, the fairly high proportion of Australians among FSR social scientists working in the International Agricultural Research Centres.

On the organizational side, FSR-type work is conducted primarily in the Australian State Departments of Agriculture. These are partitioned into research and extension units and the structure of research is typically on disciplinary lines. However, there is usually a high degree of collaboration across disciplines, and between research and extension workers. Sometimes the cooperation is formalized in problem-solving teams but usually it works from bottom-up joint activities——especially at regional research centres. Such free-wheeling farm-level interdisciplinary research contrasts strongly with the prevalent arrangements and practices in most African countries, for example, where typically research agencies are rigidly structured and administered so that there is little collaboration between social and other sciences, and extension services are relatively weakly staffed and are bureaucratically and operationally divorced from the research agencies.

Given the rigidity of African bureaucracies, perhaps the best way to foster FSR generally, and its social science components in particular, is to introduce new bureaucratic entities such as 'FSR Coordination Units' wherein the leads being facilitated by, say, CIMMYT in East Africa, ILCA in Ethiopia, and ICARDA in Tunisia might be implemented in national programs of rural research and extension.

Problems in Adopting the FSR Approach

A variety of problems must be met in implementing the FSR approach. First, commitment of scientists to the approach is essential. To be effective and to operate successfully, the systems approach requires participants to adopt a more altruistic attitude to their work than is conventionally required. Unless participants are committed to the approach, there may be problems in generating the attitudes required for its successful operation.

Second, scientists may often be inadequately prepared to operate effectively in integrated research, either because they did not receive a formal 'systems' training or because the training was theoretical and/or inadequate for practical use. Because most agricultural research units are shortstaffed, the temptation may be merely to shift 'conventional' researchers to an FSR group without restaffing the more conventional disciplinary areas. This 'robbing Peter to pay Paul' philosophy should be avoided if at all possible, even granted the shortage of research resources in developing countries.

Third, there may be problems relating to the evaluation and reward of scientific merit. Conventional evaluation and reward systems that do not adequately recognize the scientific ability of an individual in terms of his or her contribution to the achievement of group, rather than individual research, are not conducive to integrated research of the type required in FSR.

Fourth, there may be problems of definition and focus. In its efforts 'to do good', FSR may run the risk of becoming too loosely focused and degenerate into overly site-specific research characteristic of 'rates and dates' agronomy. At the other extreme, as exemplified by Nielsen and Preston (1981), FSR may be excessively systematic and attempt to design ideal farming systems that have little probability of adoption. A practical farm-oriented perspective has to be maintained throughout the conduct of FSR. As already noted, the difficulty of implementation increases significantly as the research orientation moves from system adjustment, to revision, and to replacement. Concomitantly, the development of completely new systems will be much more demanding of research resources and a far more difficult research task than the development of system adjustments or revisions.

Fifth, there is the question of who sets research priorities and for whom. The establishment of formal forums for the interchange of ideas for setting up research priorities and discussion of multidisciplinary tasks is essential. Determination of priorities is not an easy matter and the scientific staff must be well informed if they are to participate effectively in the decision-making process. There may be political obstacles to overcome in some instances, since some governments maintain a deliberate bias against some groups, e.g. against small farmers outside cooperative groupings. If resource reallocation should become necessary, extensive background briefings will be needed. As noted above, it may be necessary for an institution to establish a coordinating unit for its FSR. The functional nature and composition of such a coordinating unit need to be clearly defined. Steps should also be taken to ensure effective liaison and equilibrium between any such FSR coordinating unit and the subject matter areas of research. The unit should continuously evaluate the present status of the FSR multidisciplinary effort and formulate goals and priorities for the immediate future. Additional means to assist this unit may be required.

Sixth, established reward systems based on equating only reductionist activity with good science may cause difficulty. In the context of FSR, such difficulties are aggravated by problems associated with multidisciplinary targeted research. Reporting and presentation of FSR data tend to follow a step-by-step and seemingly fragmented structure that often times provides little stimulation for evaluating the integrated results of the program as a whole. No doubt due to the relative newness of FSR, there are as yet an insufficient range of forums for presentation, discussion, and evaluation of FSR research. It also seems that insufficient importance is attached by FSR workers to such activities. All members of multidisciplinary research teams must be especially cognisant of the need to accord recognition to those who contribute to the scientific success of such teams. Clear guidance for administrators that effective participation in multidisciplinary projects is recognized would seem to be very important.

Seventh, in terms of implementation problems, there is the question of whether FSR can be superimposed on an existing conventional program. The answer is definitely yes. FSR and conventional research are not mutually exclusive. They are complementary, as implied in Figure 2. To be successful, any FSR program requires both basic and applied research. Conventional research programs are often 'project-oriented' or 'departmental-oriented' with individual scientists attached to each department carrying out a specific piece of disciplinary research relevant to the project under consideration. In this approach, which is akin to component research in FSR, individual components are not, however, defined relative to some holistic view. FSR would enable such precise definition and provide for time-bound achievable goals. However, the following organizational needs related to the structure and conceptual framework of FSR should be clearly understood:

1. There should be a satisfactory mechanism for establishing the goals, priorities and allocation of resources within the FRS program.
2. The definition and coordination of research activities, particularly those of an integrated nature, designed to meet FSR goals should be as complete as possible.
3. Sufficient flexibility to respond to chang-

ing circumstances and the introduction of new ideas should be well ensured.

4. Adequate encouragement of activities and communication among subdisciplines, and between FSR and other major activities of the institute, is desirable and necessary.

In terms of introducing the FSR approach into a conventional research institute, the best first step would probably be to introduce or foster on-farm testing as a normal activity of researchers, perhaps through encouraging them to take greater interest in work outside their particular specialities. The second step would be to provide a flexible institutional structure within which researchers can come together to tackle problems on a systematic basis. The third step could be to provide locii for base line analysis, base line surveys and diagnostic research which, along with on-farm testing, would generate enhanced awareness of the need for a FSR approach.

Finally, in terms of implementation problems, some points of caution are necessary. First, it must be recognized that FSR is, to a greater or lesser degree, location-specific (Kalirajan 1981; Menz and Knipscheer 1981). The more complex the system under study, the more location-specific it is likely to be. The constraints defining location-specificity are physical, biological, economic, and social. Physical and biological constraints are the most intractable. They define the limits of improvement that are possible. To define these limits, to assess physical location-specificity and to enable technology transfer, certain minimum sets of data must be obtained on-station and on-farm. Social and economic constraints are less intractable than resource constraints and are more time-dependent. Second, multidisciplinary research can tend to be 'weak in theory and soft in quality' (Schultz 1979). It may be easy to jump on the bandwagon but it is important for the disciplines concerned to steer the wagon in the right direction and at the right speed. Third, and most important of all, it must be recognized that FSR is no more than one of many facilitators to development. Of itself, it is not a panacea.

With particular reference to African farming systems, two features of most systems contribute to their complexity in a very significant way. It happens that they are both strongly paralleled in most Australian farming systems so that Australian experience and expertise may have particular value in collaborative work. First, livestock play a central and pervasive role in the functioning and success of such systems. Second, climatic variability (especially rainfall amounts and inter-temporal distribution) is high on world standards, (but not Australian). Witness the present devastating drought affecting southern Africa.

The conjunction of these features is a greatly under-researched field. FSR workers face the prospect of many surprises and insights as they untangle and comprehend the many complementary interactions among livestock and cropping activities and the buffering effects that these have in assisting farmers to cope with turbulence in their environment, whether it arises from natural, economic, or political sources. One of the challenging aspects of such work is to discover and deal with the attitudes towards risk, food insecurity, and wealth held by African farmers. These must be understood much better than they presently are before investigators could, with any confidence, presume to propose 'improved' tactics and strategies for farmers managing in such highly variable environments.

Perhaps the greatest single problem in FSR for Africa, and, indeed, for any alternative model of agricultural research, is the diversity of farming systems. We have alluded to this above in the context of location-specificity. Another issue for researchers to grapple with is the allocation of their scarce investigatory resources among so many competing systems of diverse importance, especially when importance is judged by such things as the contribution to the economic growth and welfare needs of more or less neglected groups. We know of no easy solution to this difficulty but, minimally, research decision-makers must be sensitive to the tendency to concentrate resources on farm people already favoured relative to those in less accessible areas. The price of social relevance may be that work that is more difficult and less scientifically satisfying should take precedence over opportunities that are easier and more comfortable. Special funding may be required in some instances and, with the growing recognition of FSR among donors, this may be increasingly obtainable.

Summary

The FSR approach can be summarized (Shaner et al. 1982, p.4) as farmer based, problem solving, comprehensive, interdisciplinary, complementary, iterative and dynamic, and socially responsible. It is:

1. Farmer based because FSR teams seek an understanding of farmers' conditions and integrate farmers into the research and evaluation process.
2. Problem solving in that FSR teams seek researchable problems and opportunities for improving existing farming systems.
3. Comprehensive in that FSR teams consider the whole farming system in the context of all its environmental influences so as to learn how to improve the farmer's welfare while evaluating results in terms of both farmer and societal interests.
4. Interdisciplinary in its team approach involving scientists and extensionists with different disciplinary backgrounds who work together to identify problems and opportunities, to search for solutions, and to implement and monitor the results.
5. Complementary because it draws on and feeds back to disciplinary and commodity-based research.
6. Iterative and dynamic in that FSR follows a cyclical pattern of research and testing that leads on to further research and testing.
7. Socially responsible in that FSR teams aim to keep public interests, both present and future, in mind, as well as those of the farmer whose farming system is being studied.

Many of these features are, of course, common to the more traditional approaches of disciplinary and commodity research. The combination of them all, however, distinguishes the FSR approach.

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Eastern African Farming Systems and some Indications of Research Priorities

M. P. Collinson*

The paper focuses on small-farm systems. The justification for ignoring commercial farmers is that small farmers make up 80-90% of the total populations of the Eastern African countries, and their development dominates national political and economic priorities.

Figure 1 models the characteristics of a farming system. The farmer reacts to his circumstances by decisions to allocate resources to crop and livestock enterprises that meet his priorities. Natural circumstances, particularly of climate, but also of soil and biology, bound the production opportunity set open to him. Economic circumstances, marketing systems, prices, and policy modify the usefulness of this opportunity set to the farmer. His resource base dictates how, and how far, he can exploit these sets of circumstances and how well his activities satisfy his priorities. Differences in circumstances, in farmers' resource bases, or in farmers' priorities can result in different farm systems represented by different patterns of crops and animal enterprises and different methods of production. With wide diversity in climate, social background, and market development in Eastern Africa there is a parallel diversity in farming systems. The paper attempts to identify only the most important sources of variation, to discuss the effects of these sources on East African farming systems, to example two common types of systems and, finally, to discuss priority areas of research for these two types.

Farmers' Exogenous Circumstances

Natural Circumstances

Categories of circumstances that can influence farm systems are listed in Figure 1. Fundamental to dryland farming is rainfall, and this is the dominant natural source of variation between farming systems in Eastern Africa. Quantity, pattern, and reliability are key characteristics dictating cropping opportunities. Table 1 shows the relative importance of different rainfall patterns in Eastern Africa (Kenya, Uganda, and Tanzania).

Many stations in Eastern Africa have recorded maximum annual rainfalls more than four times the minimum. Such variation gives low levels of reliability in many areas and Table 2 summarizes, for Kenya and Tanzania only, the land areas receiving various levels of reliable rain.

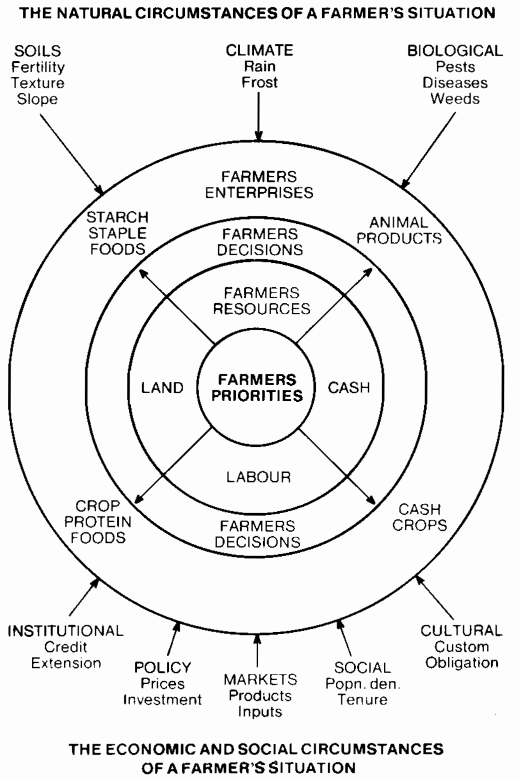

Figure 1. The characteristics of a farming system.

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* Economist, CIMMYT, Nairobi, Kenya. The views expressed in this paper do not necessarily represent those of CIMMYT.

Table 1. Areal distribution of given rainfall regimes in Eastern Africa (Morgan 1969).

No. wet months	Land area %	No. Wet months	Sequence of seasons							Land area %
			Wet season		Dry season		Wet season		Dry season	
12	1.8	7	4	–	1	–	3	–	4	0.2
11	3.7	7	4	–	2	–	3	–	3	1.0
10	3.5	6	5	–	2	–	1	–	4	0.2
9	6.9	5	2	–	2	–	3	–	5	2.3
8	3.2	4	2	–	2	–	2	–	6	1.3
7	12.3	4		–	2	–	3	–	6	1.4
6	16.4	4	2	–	3	–	2	–	5	2.0
5	22.7	3	2	–	3	–	1	–	6	3.5
2	2.6	Unidentified								0.2
1	14.8									
	87.9									12.1

Table 2. Percentage of land area receiving selected amounts of annual rain in 4 years out of 5 (Morgan 1969).

Rainfall	Kenya	Tanzania
< 20" (< 500 mm)	72	16
20-30" (500-750 mm)	13	33
30-50" (750-1 250 mm)	12	47
> 50" (> 1 250 mm)	3	4

Thus Kenya, much the most poorly served of the East African trio, receives a reliable 760 mm over only 15% of its land area. Altitude differences affecting the length of the growing season, are an additional, important natural source of variation in East African farming systems, though secondary to rainfall. Maize, for example, will mature in 100 days at sea level but will occupy land for 300 days at 2 500 m. The effect of this extreme variation in the length of the growing season on farming systems is tempered by the fact that most of the East African land area has only a single annual growing season, and over 50% has a 5-7 month dry season. Thus the sheer length of the growing season at high altitudes is not an extraordinary disadvantage. Though, when combined with prolonged exposure to hazards of frost and unreliable rainfall in particular situations, it greatly compounds uncertainties.

Economic and Social Circumstances

The dominant socio-economic source of variation between farming systems in Eastern Africa is population density.As Figures 2 and 3 (Kenya and Tanzania only) demonstrate there is a close correlation between rainfall and population. On the whole the best rainfall areas were farmed first and populations have since been pressured out into poorer conditions. This general pattern is modified by historical tribal dominance, and by low population densities of the relatively well watered areas in the west and south east of Tanzania.

Overall population densities are modest but irrelevant, due to the large proportion of land areas unsuitable for agriculture. Local specific populations reach very high densities for dryland farming, e.g. over 500 persons (70-80 families)/km^2 in parts of western Kenya in the higher rainfall areas of the Lake basin. This contrasts with very low densitites, i.e. below 10 persons (1-2 families)/km^2 in well watered parts of west and south east Tanzania (760-1 270 mm per year, 4 years out of 5). Such variations in population density are closely related to other economic circumstances, especially market opportunities and

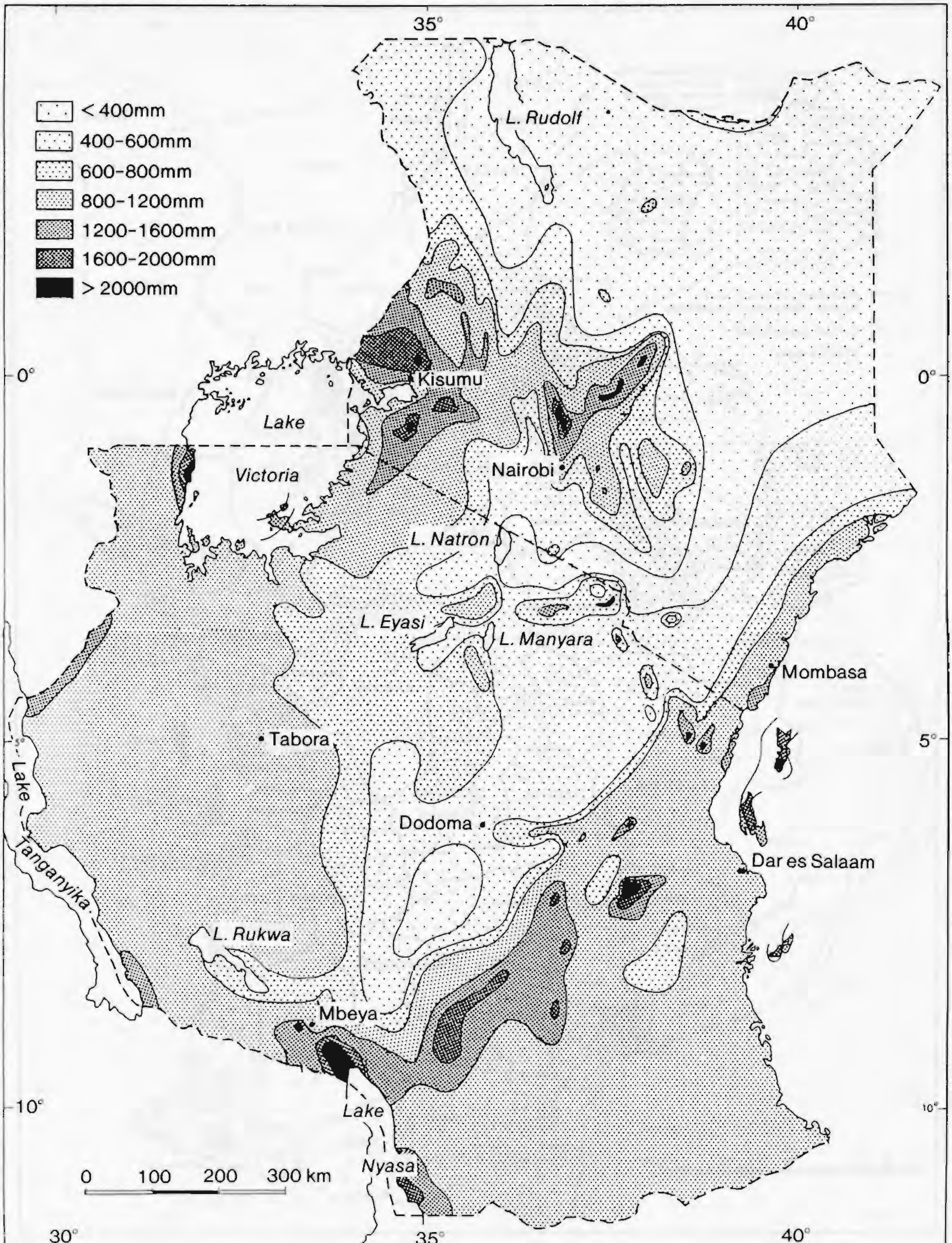

Figure 2. Zones of average annual rainfall (mm) in Kenya and Tanzania (Reproduced with the kind permission of B. Lundgren, ICRAF, Nairobi, Kenya).

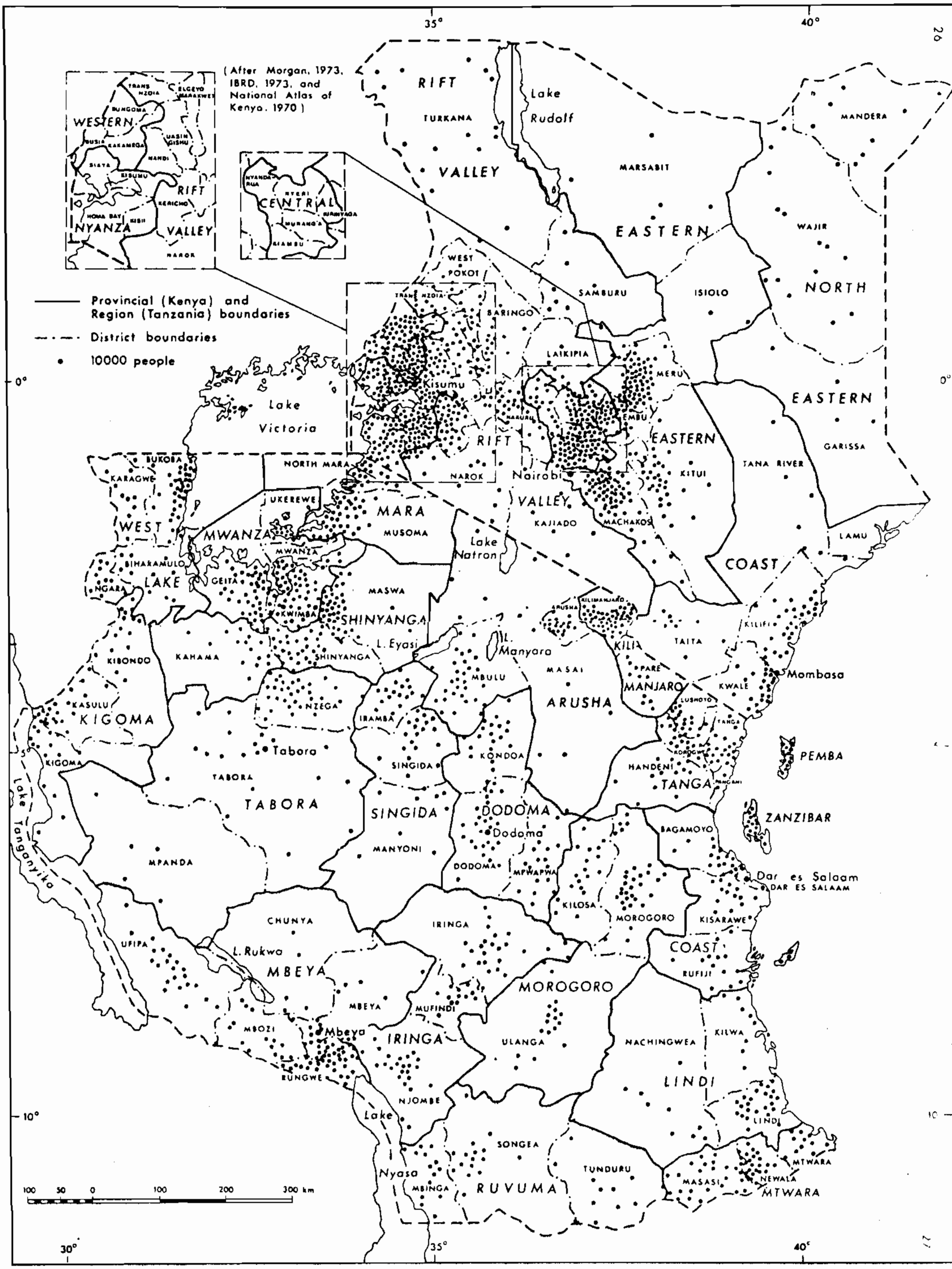

Figure 3. Administrative boundaries and population density in Kenya and Tanzania (Reproduced with the kind permission of B. Lundgren, ICRAF, Nairobi, Kenya).

infrastructure development. High densities form market opportunities and allow the cost effective development of roads and assets to service the concentrated populations. As a corollary, some of the most successful re-settlement efforts have been based on the principle of providing infrastructure and market opportunities to motivate people to settle in the area.

Finally, specific basic starch foods are often a strong tribal tradition. Where subsistence foods are a major part of the farming system, variations reflecting different cultures are a strong modifier to the pattern. There are over 120 recognized ethno-cultural groupings in Eastern Africa and basic starches include grain, plantain, and root crop types.

A wide range of natural, economic, and social circumstances make up the farmers' production environment. Rainfall, altitude, population density (and related features of market opportunity and infrastructural development), and traditional tribal starch foods seem the most important exogenous sources of variation between Eastern Africa farming systems.

Farmers' Endogenous Circumstances

Farmers' Priorities

Farmers' priorities change as they develop. The smaller the farm, the more limited the resource base and the more do subsistence needs dominate resource allocation. Farmers with limited means place an overriding priority on producing food, day in day out, for their families. Increased market contact and exchange are a prerequisite for farm development. As contact increases, production rises and the farming system expands until output for the market parallels and then overtakes subsistence production. During this process, production for the market will begin to dominate resource allocation.

Further steps in this sequence of changing priorities are the farmer turning to the retail market to purchase food for his family, and specializing in cash crop production. While all stages of this development sequence can be found among Eastern African small-holders, home food production probably dominates resource allocation in the majority of small-holdings in the region. Four stages are listed below with the second stage being the dominant one:

1. Wholly subsistence production with surpluses locally exchanged or used for increased social activity when available.
2. Dominant subsistence priorities with (a) deliberately produced surpluses for sale locally or centrally, and (b) with a cash enterprise 'tacked on' to the subsistence system and management subordinated to food supply priorities.
3. Dominant cash enterprise(s) but with basic food requirements still produced on the farm; food shortfalls or special preferences are supplemented by purchases.
4. Wholly cash enterprises and mainly family goods purchased (except for specialities).

Stage 1 is characteristic of systems in areas of low population density with poorly developed infrastructure. Such situations are limited in Eastern Africa. Most of Eastern Africa'a small-farmers probably fall into Stage 2. Table 3 is a list of farm enterprises that are managed for subsistence and for the market, in the region.

In subsistence priority systems, the energy requirements of the family dominate resource allocation and the starch staple is usually the largest enterprise. The management requirements of cash crops are subordinated to those of the foods. Where rainfall reliability is low, farmers' management strategies centre on ensuring a family food supply. Market reliability also plays a major part in the development sequence. Farmers in areas where purchased food supplies are unreliable or for which prices are highly variable continue to grow foods. Similarly, where cash crops markets are unreliable, where there is no guarantee that crops will be purchased, or where cash may not be available on crop delivery, farmers will persist in subsistence production.

Very few small-farming systems have reached Stage 4 where farmers rely on cash earnings for food purchase. This may be limited to some densely populated areas in the central highlands of Kenya with effective and reliable marketing channels for coffee, tea, and dairy. In such cases, where cash flow problems are minimized by the nature of the enterprises, some but by no means all farmers, under pressure from population increases, have begun to specialize in these cash crops.

Most Eastern African farmers operate systems

Table 3. Major farm enterprises of Eastern Africa.

1.	Major Source of Energy——Starch Staples: Maize, sorghum, millets, cassava, Irish potato, sweet potato, plantain, wheat, rice.
2.	Major Vegetable Protein Sources: Beans, cowpea, groundnut, chickpea, gram, pigeon pea, bambara.
3.	Major 'Relish' or 'Food Flavour': Groundnut, cabbage, kale, tomato, onions; and fruits and/or leaves of cowpea, bean, cassava, pumpkin.
4.	Cash Crops: Export and Local Industry: Cotton, coffee, tea, sugar, pyrethrum, tobacco, cashew, sisal, groundnut, sunflower, sesame, soya, castor, coconut, fruits. Urban Food Supplies: Maize, wheat, beans, groundnut, cassava, plantain, sugar, fruits.
5.	Livestock: Milk, meat for subsistence and sale, draft power, manure, security, traditional uses.

oriented to family subsistence. Innovations, to be relevant and thus acceptable, will have to be focused in one of three ways:

1. To improving the efficiency of resource use in food production, without sacrificing food supply reliability, and releasing farmers' resources for market production.
2. To improving the reliability of food supply and releasing resources from food insurance management strategies for orientation to market production.
3. To improving the efficiency of resource use for marketed crops without jeopardizing the supply and reliability of food supplies.

Small-holders' Resource Base

Relative land scarcity is the most important resource factor causing variation between farming systems in Eastern Africa. A direct effect of population density, it can be related back to differences in rainfall. Land is scarcer in the areas most favourable for farming. Availability ranges from about 1 ha per family in some of the very high potential areas, to 50 ha per family in some low medium potential areas. (This range excludes those semi-arid and areas occupied by pastoral people dependent on their herds and nomadic in character).

Two other resource factors interact with land scarcity to cause variations between farming systems, i.e. cash availability and power resource. Small holders spend between 10-25% of their gross cash revenues on farm inputs ranging from hired labour and tractors through to the intensifying inputs of fertilizers and insecticides. Farm expenditure on the majority of small holdings is in the range of US$10-250 usually reflecting the level of market contact of the system. Cash requirements and the returns to cash are often key criteria in the selection or development of innovations because of low cash incomes, and low farm expenditures, in many Eastern African small-farm systems. Returns to the use of cash can be very high in small farm systems——well over 10:1 on the early increments. This falls off as extra cash is invested. Table 4 shows the levels of cash costs and the returns to cash found on local farms and experienced on a trial smallholding in Tanzania in the 1960s. Returns on new technology that demand cash outlay have to compete with returns to existing uses of cash in the system for the innovations to be attractive to small farmers.

Power source for land preparation is a further resource factor interacting with land scarcity in Eastern African small-farming systems. Methods of seedbed preparation range from the handhoe, requiring 50 plus man days per ha, through oxen, requiring 5 team days per ha, to tractor hire, that is used on a limited scale to supplement hand or ox power. Small farmers often continue preparing and planting lands for two or three months at the start of the rainy season. If we assume three work units per family and take an average work period of 50 days at the start of a season, this limits families working with handhoes to 3 ha cultivated, and families with a single ox team and plough to some 10 ha cultivated.

Table 4. Returns to increasing levels of cash expenditure on a trial small holding (US$) (Collinson 1969).

Factor (US$)	Local farmers		Trial Farm		
	Average	Best	1962-3	1963-4	1964-5
Level of farm costs	17	23	22	82	135
% net returns on all cash used	793	1 130	766	326	162
% net returns on extra cash used	–	1	725[a]	122[b]	96[b]

a. Over that used on the average local farm.
b. Over that used in the previous year.

Three points for research relevance emerge from these generalized scenarios; they focus on the extensive or intensive use of land as a production factor:

1. Although fertility maintenance problems emerge much earlier on most soils, land does not become absolutely scarce (i.e. there is less available than farmers could cultivate during the season) until population density has reached about 200 people/km^2 of cultivatable area under handhoe systems and about 50 people/km^2 under ox plough systems.
2. Even when land becomes absolutely scarce and the 50 days work period assumed for planting reduces, crops will continue to be established at suboptimal times because of the low rates of work for both ox draft and particularly hand power.
3. With long periods taken for seedbed preparation the initial areas prepared need weeding before later areas are planted. With dual demands on limited labour, weeding is often subordinated to further land preparation.

Research and extension have failed to recognize that the extensive use of land is logical and will persist until holding sizes are very small due to the low levels of power at the disposal of small farmers. It has often been said that small farmers are irrational by not planting at the right time as it a 'costless' recommendation. Nothing could be further from the truth. Exhorting the small farmer to 'plant everything in the first week of good rains' is tantamount to asking him to reduce his production levels by 80%. Even on holdings with 1 ha of cultivated area, where the traditional hand seedbed preparation sequence is used, the last plantings will be 3 weeks after the start of the rains. Experiments have shown that yield potential may be halved by such a delay. Clearly the economics of fertilizer use alter radically.

If we look at 'the extra acre' prepared by hired power at modest yield levels, the return to cash employed is very high. (Say US$20 for a hired tractor for an acre realizing 800 lbs of cotton at US$0.20 = US$160 or 8:1 on the investment). It takes major crop responses to intensifying inputs to equal such returns and this is why the extensive working of land persists. The delayed times of planting forced by lower power availability, the choice of further seedbed preparation over early weeding, the low quality of seedbed preparation and rapid methods of seeding to offset labour scarcity, all interact with the classic intensifying inputs and inhibit their efficient use. (Farmers have said 'we need high levels of fertilizer to make sure the demand from weeds does not take too much away from the crop!'——they may right).

Two Common Types of Eastern African Farming Systems and some Research Implications

Two common types of farming systems are described and implications are drawn for some research priorities in the light of the needs of these systems. The examples used are dictated by areas in which CIMMYT's Economics Program has cooperated, relatively recently, in diagnostic survey work and which are representative of difficult situations for increasing numbers of Eastern African small farmers.

First, from the south part of Chibi District in Zimbabwe, an example of the type of system with a single season of unreliable rainfall and the use of animal draft under increasing population pressure is described. The example highlights the importance of food security in local farmers' resource allocation decisions, and the increasingly common clash between human and animal food needs in Eastern and Central Africa.

Second, from Kakamega in western Kenya, an example of systems in better rainfall areas with very high population densities, dependent solely on the handhoe for land preparation, is outlined.

Semi-Arid areas, Unreliable Rainfall, Animal Draft Dependence and Increasing Populations——a Zimbabwe example (Collinson 1982).

Rainfall and Soils

Annual average isohyets in south Chibi range from 600 mm in the north to 850 mm in the south. Rain falls from mid-October to mid-April. There is a 20% probability of a 15 day period with less than 45 mm of rain at most times in the growing season. This mid-season dry period is devastating when it occurs while maize is tasselling and silking from late December to early February.

Soils are granitic sands, do not retain moisture well, and have a poor nutrient status. Table 5 shows how dry periods occurred in the 1981-82 season, the first catching early maize plantings at 3-4 weeks and delaying later plantings until January. Then the second dry period subsequently devastated these with the season virtually finishing in late February. Rainfall totalled less than 470 mm for the season.

Population Density and Market Infrastructure

Population density is about 75/km^2. With eight persons in the average family this is about 11 ha of land per cultivator. Probably below 50% of the available land is arable; farmers presently cultivate some 3 ha each. Although the area is bisected by a main tarmac road, feeder roads are few and poorly maintained. Some local retail storekeepers have been appointed as Maize Board agents but there is no Board depot in the area. The nearest reliable source of purchased inputs is 100 km from most of the area. Exchange transactions are dominated by the informal market within the community.

Increasing population pressure has created a clash between arable needs to produce human food and grazing needs to feed animals. It has reached a crucial stage reducing livestock numbers and consequently squeezing draft animal resources.

Farmers Resource Base and Performance

Table 6 sets out the resource base and some rough measures of performance for our two groups of farmers in south Chibi; cattle owners and non-owners, this difference in control over power source has been used to separate the groups.

Significantly, as is common in Zimbabwe, parts of Zambia, Malawi, and southern Africa, most cash is earned from non-farm sources. At these low levels of cash income, farmers priorities are to achieve enough food production to meet family requirements. Surpluses of maize and groundnut are sold off locally. Finger millet is either sold for local beer making or brewed on the farm and sold as beer. Although farmers are not cultivating all the land available, new families are being forced to crop poorer land that was formerly used only for grazing. This is growing to a crisis for the area.

Constraints on the System

Historically the major challenges to farmers have been the unreliable rainfall and the low soil

Table 5. Rainfall (mm) at the Chibi District Office, 1981-82 (north of and drier than the actual project area).

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
34	130	29	140	91	4	34	4

Table 6. Resource base and performance in two farmer groups, i.e. 46 owner group and 50 non-owner group, south Chibi, 1980-81.

Resource or parameter	Owners (46) ha	Owners (46) % growing	Non-owners (50) ha	Non-owners (50) % growing
Land: Area cultivated (ha)	3.23	100	2.40	100
of which — Maize	1.40	98	1.00	98
— Finger millet	.31	70	.34	86
— Sorghum	.19	39	.16	44
— Groundnut	.65	87	.30	80
— Bambara nut	.13	70	.13	62
Labour: Size of family	9.0		6.5	
% Hiring labour	52		26	
Av. spent on labour hire ($/yr)	6.0		1.3	
Power: % Owning 2+ draft animals	96		0	
% Owning 4+ draft animals	30		0	
% Hiring machinery	22		90	
Average hire costs ($/yr)	1.2		7.7	
Output: Bags of grain produced	25.7		9.4	
Bags retained for food	14.7		8.4	
Average cash income ($/yr)	240		105	
Sources of income ($):				
Trade & other	70		19	
Off-farm (Casual labour	12		32	
(Family work away	42		15	
Farm (Maize + G/nut sales	57		12	
(Millet + beer sales	29		23	
Other sources	30		14	
Cash spent on farm inputs ($)	34		16	
Cash spent on food ($)	39		25	

Note: Variations between the groups are reduced, but not eliminated, when related to the difference in family size.

fertility of the granitic sands to be managed in a context of very limited and costly market contact. Farmers' strategies had been geared to these circumstances. Unreliable rainfall has been countered by two main food insurance devices, i.e. (a) two or three plantings of maize, staggered to reduce the impact of a mid-season drought on any one planting, and (b) the growing of finger millet, a traditional grain that can be stored for several years, or brewed as beer for social activity, or for cash sale once it is clear that current crops will be good.

Low fertility of the granitic sands has been countered by crop rotation around an area of fallow and the use of animal manure in the fields. The increased population pressure, by reducing the available fallow and grazing areas, and thus cattle numbers and the quantity of manure, has undermined soil fertility maintenance strategies. By reducing draft power availability, population pressure has reduced farmers' flexibility to handle rainfall crises, and threatens general management standards. These semi-arid areas are becoming the classic famine relief cases as populations increase.

Only 45% of households now own cattle. Among owners, herd size is too small to replace oxen. Farmers must choose between keeping cows, as a source of milk and more animals, or oxen. Their answer is to keep the cows and use them for ploughing. This in turn reduces fecundity and threatens domestic milk supplies, and the downward spiral takes another turn. The 45% of households plough for virtually the whole community and this prolongs the time taken to establish crops, lowers the quality of work on the seedbed and puts heavy pressures on the cows being used. Table 7 shows the problem of this downward spiral in cattle resources over the last five or six years. (One should bear in mind that the civil war over the period will have accelerated the trend).

Seventy two percent of cattle owners reported using cows, and 20% donkeys, either as a substitute for, or to supplement their oxen for ploughing. The effects of this loss of draft capacity to the community are far reaching:

1. Owners show more thorough seedbed preparations, e.g. 60% of their maize plantings are winter ploughed compared with 20% by non-owners, and 40% of plantings are harrowed compared with 15% by non-owners.
2. Ninety percent of owners reported using cattle manure compared with 15% by non-owners.
3. Owners show a high proportion of maize and groundnut planted earlier than non-owners (40% and 58% before November 10th, c.f. non-owners 20% and 26%).

These differences help to explain differences in reported maize yields from the two groups with 21 bags/ha for owners and 10 bags/ha for non-owners, and a much lower failure rate for groundnut among the owners.

Extrapolating the downward spiral in cattle holdings indicates increasing problems in timely cultivation, in weeding and in the quality of all work, and a reducing flexibility on the part of Chibi farmers to handle both the unreliable rainfall and declining soil fertility. The ultimate question is whether draft animals can be held in the Chibi system over the long term.

Research Indicators

It is clear that increased market contact and infrastructural development are prerequisites for any improvement in the situation of Chibi farmers. New ideas brought by research will imply new means and materials that require a distribution system. New materials need cash for their purchase, which implies better marketing channels. Within this context our particular interest is the research implications of this situation common throughout Eastern, Central, and Southern African countries.

Farmers in south Chibi are adapting to the growing pressures on their system, e.g. the use of cows for ploughing, increasing use of winter ploughing at a time of the year when their animals are in good condition, the use of maize stover for dry season feeding, and very late plantings of maize and bulrush millet to provide standing

Table 7. Trends in cattle holdings in part of the Chibi District, Zimbabwe, over the last 5 years.

Parameter	About 5 years ago	1981
% of whole sample owning cows	56	45
Number of cows owned by farmers	204	138
Average numbers of cows per herd	3.78	3.21
% of whole sample owning oxen	50	33
Number oxen owned by sample	209	100
Average number oxen per herd	4.35	3.12
% of owners with 4 or more oxen[a]	36	14

a. Four oxen were normally used as the ploughing team.

fodder are all devices to counter the increasing animal nutrition problems. As such, they provide leads for research. Re-inforcing farmers adaptations often allows an easy entrée for new technologies.

The research thrusts outlined below are grouped around four problem areas of great importance to increasing numbers of small Eastern African farmers in semi-arid areas who are dependent on animal draft power and are working relatively infertile granitic sands, with low cash incomes and low levels of cash available for purchased inputs:

1. Improved reliability in starch staple food supplies at increasing levels of production.
2. Maintaining draft animals in the system as a community resource.
3. Spreading the demand for labour and draft power away from the start of planting rains.
4. Providing alternatives to fallowing, and the use of animal manure for fertility maintenance.

Improved Reliability in the Starch Staples

Stability in the supply of starch staples is the priority objective for small farmers. While the basic problem is an unreliable rainfall regime, it is exacerbated by other pressures building up in the system, i.e. falling fertility reduces yield stability, falling draft capacity reduces farmer's control over timeliness in operations and their ability to react to seasonal contingencies as they arise. Research thrusts on all four identified problem areas will help enhance starch staple reliability.

One way to tackle the problem, which is largely ignored at present, is to provide a good retail distribution network and an assured supply of the starch staple at a controlled price. Grain starches are usually longer-term crops and thus most susceptible to rainfall variation. Currently, retail distribution is often unreliable, (retail maize prices may vary five-fold pre- and postharvest) and farmers are being wholly rational in trying to supply their own, avoiding dramatic seasonal price fluctuations; or at worst no retail supplies.

Research thrusts towards staple reliability concentrate on the manipulation of maturity period and planting dates in maize, sorghum, and finger millets to improve farmer's flexibility in the face of rainfall uncertainty. Multiple plantings are a valid strategy in the face of a mid-season drought. It is clear, because of the short period of rain available for later plantings, and the marked time of planting effect in much of Eastern Africa, that starch grains planted in say late October and early January should probably be of different varieties, often of different species, and should be managed differently.

Past research, tending to concentrate on maximum exploitation of biological potential, has largely ignored such issues. Hypothetically, a short-term maize planted as early as possible would escape in years of late mid-season drought (though it would be vulnerable to cob rots if the rains persisted). Similarly, a short-term variety planted late is likely to tolerate an early mid-season drought with water requirements of the order of 60% of a crop that is tasselling at this time. Low plant densities and water conservation techniques would further increase tolerances.

More flexibility in management and yield increases from low cost husbandry improvements would enhance finger millet as an insurance starch staple. Farmers have emphasized the need to plant their traditional finger millet varieties early because they took a long period in the field. In practice much of the finger millet planting was delayed. Varieties should be screened for a short-term selection to allow January planting. The impact on yield of low-cost changes in cultural practices, such as seed rate, seedbed preparation, and planting methods should be examined. A shorter-maturing variety, which performed well when January planted, would have the advantage of moving the heavy weeding requirements for finger millet back into late January or early February, when labour is relatively available, and out of the peak demand period. This would increase farmers' flexibility during the October-December peak, and contribute to the expansion of the system in this way.

Improved maize yields are dependent on the use of chemical fertilizers; this use is itself dependent on the establishment of a distribution network. In uncertain rainfall conditions, small farmers with very low levels of cash available for input purchases, consider fertilizer a risky investment. Only low levels of fertilizer consistent with a limited cash layout and high, reliable returns to the cash spent will be acceptable to farmers. Fertilizer management techniques should aim to minimize losses from rainfall uncertainty. Short-term varieties will help in this respect, but detailed management requires consideration of the main sources of loss for each different maize planting opportunity and fertilizer management designed to avoid applications until outcomes become clear. For example, basal dressings of a type and method to maximize residual effects, all nitrogen placed relative to the individual plants, seedbed nitrogen postgermination and late nitrogen dressings delayed to minimize probabilities of wastage from mid-season drought, are some risk reducing possibilities.

As a complement to the fertilizer work, prognoses of rainfall performance from past early-season rainfall histories have given good results in the semi-arid areas of Kenya. Plant densities and the levels of top dressing are adjusted to expected seasonal conditions (Stewart and Kashasha 1982) based on the profile of the first 30-50 days of the season. This does pose formidable communication and logistical problems but could make a significant contribution to the efficient utilization of chemical fertilizer, enhancing the flexibility of the farmer to control his environment.

Consolidating Animal Draft in the System

Two research thrusts are outlined below with the common objective of retaining animal draft power in the farming system. One focuses on animal nutrition, the other on improving the ability of cows to provide draft, milk, and calves for replacement. Farmers of both groups will benefit from these thrusts. Non-owners who are prepared to develop forage enterprises may open a way for reciprocity with owners between forage and draft services, or manure.

Increasing Dry Season Feed

Historically it has proved difficult to improve community-owned grazing in Africa. More acceptable local political organization may pave the way for community initiatives on grazing areas. This could help the dry season grazing situation in these parts of south Chibi where some soils and locations make land unsuitable for arable farming. In other parts of south Chibi, where most of the land has arable potential, it will eventually be allocated and other solutions to the dry-season feed problem must be found. Further, it is unlikely in the situation where human food is scarce, that land will be allocated wholly to planted grass or pasture for the sake of the draft animals. In the longer term, when high food-crop yields have been achieved and perhaps if milk emerges as a cash opportunity, planted grass may find a place.

Several thrusts to suit the current situation are described:

Increased Fodder from High Maize Populations

It is known that maize populations, particularly of varieties with a small plant structure, can be increased to very high levels, often with increases in grain yields. However, given the drought problem in south Chibi, increases in fodder from this thrust may be limited. There will be a balance between increasing populations and efficient water use in poor years. Experiments should explore this relationship.

Fodders Planted After the Groundnut Crop

As the first crop harvested, early planted groundnut leave a period of rain and residual moisture on which fodder can be grown. A bulk fodder or a forage legume or both intercropped would provide hay or grazing for the dry season. It would be a development of the existing strategy of some owners of planting maize or bulrush millet very late for use as forage, if a grain crop does not materialize. Complementary to this the use of a shorter-term groundnut variety, if necessary with stooking after pulling, to minimize sprouting and allow the crop to dry, would prolong the period of moisture availability.

Forage Legumes Intercropped into Maize

In the same way that early harvesting of groundnut may be exploited for a late fodder crop, complementarities of water and nutrient demand between maize and annual, forage legumes may allow intercropping to increase hay stocks for the dry season. This may have other advantages. Much of the prosperity of the early commercial farmer, before the advent of chemical fertilizers, was built on a green-manuring legume. (Rattray and Ellis 1952). Forage legumes may be selected for this thrust that not only aid the dry season feed problem but also promote soil fertility and improve the water holding capacity of the Chibi sands.

Hypothetically, a forage crop, which can be cut with the maize stover, then allowed to recover on residual moisture before being winter ploughed into the land may be very beneficial to the system. Practically, with the existing shortage of human food in the system, management of the intercropped legume for the time being should ensure that maize yields are not penalized. This will probably dictate the appropriate time of planting of the legume *vis-a-vis* the maize crop, and the density of the legume. Both factors will likely restrict the output from the legume intercrop. To meet these objectives legumes should have the following characteristics:

1. Be shade tolerant.
2. Be palatable to local cattle when cut and stored as hay.
3. Be cut for hay after 2-3 month's growth.
4. Recover vigorously from cutting for hay. Nodulate vigorously in south Chibi soils without inoculum.
5. Turn in easily with a local ox plough

As a complement to the introduction of an intercropped legume, the plant arrangement of the maize crop should be examined with a view to allowing light through to the legume. Finally, the effect of the time of cutting maize stover on its nutritive value and palatability should be examined.

The Improvement of Cows as Draft Animals

Because of their values as a source of new animals and milk, cows are likely to increasingly replace oxen as draft animals. This trend has been marked in Chibi over the last 10 years. The performance of cows as mothers, as a source of draft power, and of domestic milk is clearly confounded by the competing demands of each function on the nutrition of the animal.

Experimentation, within the context of the seasonal rainfall cycle and farming in south Chibi, should seek to examine the feeding, servicing, calving, and weaning options for meeting these commitments. Such a research thrust might be supplemented by the following livestock services for south Chibi farmers: (a) standing bull or A.I. to give timely servicing according to the options identified by research, and to improve draft conformation in the local cows; and (b) sales channels to remove male calves for fattening to minimize the competition for dry season food sources.

Because of current difficulties in getting cows in calf, practical implementation of a program of better calving options by either local bulls or by a government service would be dependent on farmers becoming more proficient at detecting heat, and more inclined to control service. A pilot project with standing bulls may itself improve their ability to detect heat and would test the local demand for such a service. Desirable calving options could be superimposed on the pilot project on completion of a research program.

Improved Complementarity in Labour and Draft Requirements in the October-December Peak

One experimental thrust, i.e. the later planting of short-term finger millet varieties, has already touched on this strategy. With the heavy weeding requirement for finger millet, a late planted crop would shift the weeding burden back into late January when the main pressure for weeding is removed. Similarly, testing shorter varieties of maize to allow a better crop with late planting will also contribute. In general, shorter-term crops or varieties enhance farmers' flexibility in the Chibi environment and help them manage seasonal pressure more effectively.

Two other experimental thrusts may produce technologies to help dissipate the October-December peak, i.e. changes in tillage and planting sequences; and improved ox weeding in maize.

Changes in Tillage and Planting Sequences

At present virtually all winter-plough land is reploughed before being planted. Thus some land receives two ploughings while other land must wait until two months after the start of the rains for a single ploughing, due to the overall scarcity of draft power. Techniques for direct planting of winter ploughed land, either dry or wet, would greatly improve farmers' flexibility to react to seasonal circumstances and allow a better spread of limited draft capacity through the community.

The practicality of direct planting may depend on the timing of the winter ploughing, the incidence of very early rains in the new season, and the resulting weed burden on the lands at planting time——it will vary from season to season.

Nevertheless a technology, and guidance to help farmers to recognize when direct planting of winter ploughing was feasible, would be of great value.

Reduced Draft

Herbicide is not explicitly included here. Fertilizer is given priority for the relatively limited amount of available cash. However single tines, as reduced draft implements, are seen to have a major potential:

1. They allow fewer animals in the work team.
2. The draft requirement is lowered, perhaps allowing even weak animals to prepare wider areas before the rains start.
3. The rate of work is increased; animals move faster while in work and with breaking only the planting line, about 20% of the passes of full mould-board ploughing are needed.

A tine has thus a range of benefits. It reduces power requirements and increases the work rate effectively, increases the capacity of available animals, and by increasing the possibility of breaking dry ground, it spreads the demand for draft services over a longer period. At the same time, reduced draft would place less burden on cows and help check the strains imposed on reproduction and calf rearing.

The maintenance of soil fertility is not discussed as a separate thrust. Subsistence oriented systems, heavily dominated by starch staple enterprises, present real problems for crop rotation once fallow land is exhausted. It is a classic long-term problem. The technical answers are known but well beyond the seasonal resource capabilities of farmers to implement as a whole package. Such major management revisions have to be approached in (relatively) small steps. Each step contributes to the solution of the long-term problem, yet is within the immediate short-term interests and reach of the farmer to adopt.

Within the Chibi system, the research thrusts outlined include two such steps; (a) the use of low levels of chemical fertilizer on maize, and (b) the possible fertility effects of a legume grown primarily to improve cattle nutrition during the dry season.

Heavy Population Densities, Good Rainfall, and Dependence on the Handhoe——a Kenya Example (Lihanda 1978; Wangia 1980)

Farming Systems in Parts of Kakamega, Western Kenya

Vihiga Division of Kakamega District in Western Kenya is one of the most densely populated parts

Table 8. Rainfall data (mm) for Vihiga Division.

	Jan	Feb	Mar[a]	Jun	July	Aug	Sep	Oct	Nov	Dec
6 years out of 10	86	133	176	144	122	155	151	134	155	125
4 years out of 10	56	86	128	124	85	130	113	115	113	86
2 years out or 10	31	45	85	90	54	101	75	101	91	48
E_o [b] for Kisumu	185	179	199	150	150	166	177	187	172	183

a. April and May are omitted as rainfall is always reliable and adequate.
b. Kisumu is the nearest radiation information.

of Africa with over 500 persons/km^2 dependent on dryland farming. Over 60% of farmers hold less than 1 ha of land. Vihiga is at an altitude of 1 650 m and has an annual average rainfall of 1 850 mm in a bimodal pattern, with growing seasons from February to June and August to December. Table 8 shows probabilities of less than the specified millimetres of monthly rainfall for a station within the area.

In 6 years out of 10, rainfall is below E_0 in each of the 10 months shown, so growing conditions are rarely perfect. March-June is the best period for heavy vegetative growth. The shorter August-December period is much less reliable. January is the driest month and December-February forms the least reliable period in the year. July is a drier trough between the two seasons. With the very dense population, infrastructure in the area is well developed, access is good, and the area is dotted with small trading centres where storekeepers buy crops and sell farm requisites; regular markets are held throughout the area. Most transactions are within the local economy.

Farmers are predominantly subsistence producers and a high proportion of family males work in local centres or in the major towns of Kenya. Some sales of maize and beans, i.e. the main staples, are made because of a need for cash, but about 80% of both crops are consumed on the farm. Over 50% of cash incomes are from non-farm sources. Starch food crops, in order of importance are: maize, bananas, millet, sorghum and sweet potatoes; and for protein: beans and cowpeas. the latter being largely grown for their leaves. Foods are harvested from the two growing seasons with the long-rain harvest starting in May and completed in September. The short-rains harvest, from November to January, is less reliable. From February until June there is often a serious scarcity of foods. Many families are obliged to buy from the market.

The threat of a maize scarcity over this period is a strong incentive for farmers to attempt a short-rains maize crop, despite lower rainfall reliability exacerbated by the long-rains maize crop drying out on the fields and preventing timely short-rains plantings. Small numbers of cattle, between 1 and 4 animals are kept for domestic milk supply and for manure.

Production is based on the use of the handhoe for seedbed preparation. Methods reflect the scarcity of land and the close interaction between crops and animals. Although hybrid maize and chemical fertilizers are used by most farmers, local maize is also grown for early food in the long-rains season and because recommended hybrids are too long-maturing and therefore unreliable in the short-rains season. Most maize fields are intercropped with beans in both rainy seasons. A small area of grazing is maintained on the holding and cattle are largely tethered and stall-fed with crop by-products. Wangia (1980) has documented the importance of different by-products. Farmers are feeding maize leaves, stalks, and residues, and banana stems and 96% of farmers reported using green maize material and 84% said it was their second or third most important feed source.

The basic constraints on the development of the farm system in the area are land availability and the maintenance of fertility with the lands under continuous use. The efficiency of land use has to be improved in the context of strong farmer priorities for an adequate food supply and very limited amounts of cash for the purchase of inputs. Unlike many other systems in Eastern Africa there is no option for the extensive use of land. Diagnostic survey work amongst farmers operating the system stressed (a) an increasing dependence on by-products to feed cattle to maintain milk and manure supplies, and (b) the problem of re-using land planted in the long-rains to maize, particularily to longer-term hybrids, for a short-rains crop of maize. Maize established in the period mid-February to mid-March matures and the dries off in the field, occupying the land as late as mid-September. As Table 8 shows, this allows only 105 days through to the end of the short-rains season, which is too short for a maize crop at this altitude.

Research Indicators

Three research focii emerge from this brief outline of the characteristics of the farming system in a high density area with good rainfall and dependent on the handhoe for land preparation.

INTERCROPPING

It is a traditional practice in African agriculture and experimental work has consistently shown higher land equivalent ratio (LER) values than from monocropping. Two aspects are important for intercropping experimentation directed towards farmer recommendations, rather than the exploration and understanding of the biological potential of intercrops. They are (a) the farmers' options for use of the products and his reasons for intercropping must be understood, and (b) farmers' present practices should form the starting point for intercropping experiments that seek appropriate recommendations.

Double and Relay Cropping

The experiences with cropping systems work in South East Asia is going to be of relevance to the dense population areas of Africa, though maize, rather than rice, will be the dominant crop. In the example system, the sacrifice of biological potential in the long-rains by testing a shorter-maturing maize, pays dividend by enhancing the probability of a maize crop in the short-rain season, by increasing the reliability of both crops, and by providing earlier new food in the February-June hungry period when retail maize prices are high. Relay planting of a 130-140 day variety allows continued use of the long-term hybrid in the long rains as well as improving the potential from the short-rains crop. Both the present intercropping of beans, with relatively wide maize spacing in and between rows, and the use of maize leaves and tops from the maize for cattle feed, facilitates a relay crop and suggests that it may rapidly find a place in this situation.

Presently farmers are unwilling to risk the purchase of fertilizer on the unreliable short-rains maize crop. An earlier start to the season (although rainfall is rarely ideal over the August-December period) may stabilize its performance sufficiently to make investment in fertilizer an acceptable risk. Fertilizer experiments need evaluating for the level of return to the cash employed as well as the consistency of the return, as the criteria for choosing the level for recommendation.

By-Products for Animal Feed

The significant and increasing use of crop by-products for animal feed highlights this topic as an area for research. All farmers grow bananas, and stems and leaves show up as a minor animal-feed. Bananas are a common feature of highland farming systems in Eastern Africa and are virtually unresearched. There is wide scope here and much to learn from farmers (for example in Rwanda and in parts of Tanzania) on banana management in an intercrop, and their use as animal feed. Absolute land scarcity tells us that by-products will probably remain a major source of animal feed. However with milk a significant cash source in the local market, and if there were an assured maize supply through the market, the growing of animal feed for dairy production might become a specialized activity.

Several areas of by-product research are important. The trade-offs in the following first three practices centre around the priority for grain for human food and the need for by-products for animal feed:

1. Overplanting maize and using thinnings for animal feed.
2. Leaf strippings and toppings from maize for animal feed.
3. Inter- or relay cropping maize with a fodder crop, usually a legume, for animal feed.
4. Conservation of maize by-products and fodders.
5. Cheap enhancement of maize by-products and residues to improve their nutritional status. (Local soda is presently being examined as a means of enhancement in Kenya).

This section has looked into examples of two increasingly common farm situations among Eastern African small holders. Despite the obvious differences in the two example systems some of the indicators for research attention have been the same.

The final section of the paper takes up these similarites and identifies some research areas of wide interest and some perspectives important to effective research for small-farmer systems in Eastern Africa.

Some Important Research Areas and Perspectives for Eastern Africa's Small Farmers

Some of the same priorities were identified for the two example systems because, despite clear differences between the systems, both were under pressure from population, with little or no unused land, and both included crop and livestock subsystems with strong interactions between the two. The examples demonstrate that small holders, operating at very low levels of production, have a reliable supply of food, especially starch staples, as a first priority in organizing their farming. Both illustrated that cash availability and power availability impose severe limitations on solutions that will be useful. These features are characteristic of small-holder farming in Eastern Africa, and are very different from large-scale commercial farm operations. Use of a research perspective from advanced agriculture may misdirect research efforts for small holders.

Identified Research Areas from the Example Systems

The two examples highlighted three research areas of general importance in Eastern Africa. These are discussed again briefly in turn:

1. Stability in Starch Staple Production

The paper has re-iterated the paramount importance of a reliable food supply, day in day out, to small farmers. The examples have indicated that population pressures reduce the flexibility of farmers to manage natural, biological, and market hazards, and assure food for their families. Food insurance strategies absorb land resources; cassava that is held in the ground, millet or sorghum held in the store for the hungry period, have all taken land and labour to grow. Sweet potatoes that are often planted as a reaction to seasonal contingencies, take land and often labour at a crucial time of the season. Cattle and small stock, sold off to meet contingencies need grazing land.

Farmers commonly overcommit resources to food production aiming at sufficiency under the worst expected conditions and selling the surpluses in less than worst seasons. On the whole, good seasons mean low prices with low demand and a high supply of surpluses. These types of buffers are being squeezed. The squeeze is paralleled by a drift to the urban areas to look for cash-earning opportunites as an alternative source of insurance, and by increasingly widespread and frequent food aid programs.

Increasing stability in starch staple production will help remove the need for food insurance management using increasingly scarce land resources, and allow farmers to re-allocate these insurance food resources to meet market needs. It will also provide a base for intensification of land use by reducing the risks of loss from inputs purchased with very scarce cash for use in food production.

One route to improved stability and management flexibility is shorter-maturing varieties of maize and other crops important to small holders. Another route is the encouragement of changes in starch staples. This is often felt to be an impenetrable barrier, and that farmers are locked into their food preference patterns. However the history of Eastern African food staples shows rapid change. Traditional staples are finger millet, bulrush miller, and sorghum. Maize has swept these away in many areas. Irish potatoes, which with a potential for three crops a year in some areas, have become a main starch staple for millions in the Central Highlands of Kenya. When the incentives are there small farmers do change, and their food staples are no exception.

The home economist has a major role in helping adaptation in preservation, preparation, and cooking activities. One of the reasons for the widespread acceptance of maize is its easier preparation and, more recently, village level grinding facilities, both of which are attractive to farmers wives.

2. Double, Relay, and Intercropping

Part of the advantage with shorter-term crops and varieties is that of following these with a second crop; either double or relay cropping. At lower altitudes in the tropics this becomes practical even in a 5 month rainy season. Relaying is facilitated where the original planting is intercropped as plant arrangements are often more conducive to relay establishment. While certain forms of inter- and relay cropping are inhibited by mechanization and a high incidence of input use, they offer less problems to the hand cultivator and are low cost ways to intensification. I have noted earlier the problem of timely planting when using the handhoe as a source of power. Weed control is another similar problem where crop establishment continues over a 2 or even 3 month period. An intercrop that smothers weeds is a valuable device for prolonging establishment rather than diverting labour to weeding the earlier plantings.

Much more basic information on weed smothering, insect and disease effects in intercropping, as well as the biological relationships with the dominant crop are needed for *Phaesolus* bean, cowpea, pigeon pea, Irish and sweet potato, and cassava.

3. Forage Legumes and Legumes in General

Legumes provide the major source of human protein in most Eastern African small-farm systems. While fodder grasses have been researched and extended, relatively little work has been done on forage legumes. As a low cost supplementary feed, particularly where unenhanced crop residues form a major part of animal diet in the dry season, they have much to offer.

As a non-technical scientist I am not clear on the current state of the arts in using legumes to maintain or enhance soil fertility. If and when the art is perfected it will have massive potential as a low-cost means of fertility maintenance in small holder agriculture.

Until the early 1950s the whole of the Zimbabwe commercial maize crop was managed on a green manuring cycle and because of low costs, this has much to offer to small farmers. As a rotation device however, it runs foul of a general rule that small-farmers operating season-by-season with very limited resources to meet immediate basic needs will rarely re-allocate scarce land or labour to achieve indirect or long-term benefits. Thus animal food and soil fertility have to be produced either as by-products or by using 'off peak' resources; land at the end of the rainfall season or labour after the rush of crop establishment and when the first weeding is over. Both conditions drastically compromise optimum technical management of the crops involved but do increase production. Legumes managed by double, relay, and intercropping techniques have great potential for both animal feed and fertility enhancement.

Systems using Land Extensively

The two examples chosen represent the types of systems under heavy land pressure, where crises are currently arising. In many parts of the world, land is still used extensively rather than intensively and Eastern Africa is no exception. The major wheat growing areas of the world as in USA and Canada have relatively low yields. In such areas a key to high production is the area that can be put under cultivation in the season. Large numbers of small farmers operate under these conditions in Eastern Africa. They are in a transition stage. In most cases, land is no longer plentiful enough to maintain soil fertility by a fallow rotation, but farmers resources are quite inadequate to cultivate more than a small proportion of the cultivatable area each season. These situations are characterized by two phenomena already noted in the paper, i.e. (a) an extended planting period of 2-3 months and (b), a difficult decision on when to divert power, either hand or animal, from planting extra area for the season to weeding the original plantings.

Extended planting, even late in the season and even using hired power sources offers returns, in many of these areas, of between 5 and 10:1 to cash outlay. Fertilizer has to give very good responses to compete and it is these benefits that have to be foregone in order to apply the fertilizer on the early plantings at the right time and to weed those plantings, to ensure results form the fertilizer. Weak, top down linkages between research and the small farmer have often ignored the economics of his situation. Necessarily, once the arable/fallow ratio reaches a critical stage, intensification, i.e. earlier weeding and the use of fertilizer begins to compete. However, the levels of fertilizer recommended must be chosen on the basis of returns to cash outlay, not only to the left of the technical optimum on the response curve but also to the left of the most profitable level of application, which is often misnamed the economic optimum.

Use of this criterion will most readily draw small farmers into intensification and the use of fertilizer. It is a further example of the historical tendency to try to impose final technical solutions on small farmers, due to a failure to understand the economics of their current situations. Recommendations have to be consistent with the existing dominant, economic relationships while, where possible, establishing a trend towards long-term solutions of major technical problems.

The extended planting period and the competition between establishment of new areas of crop, and weeding the first plantings characteristic of these extensive systems indicate important research areas.

Short Maturity Periods

Again, short-maturing varieties and species allow extended planting within a given rainfall profile.

Tolerance to Late Planting

This seems to be an untouched area in variety selection. A marked time of planting effect exists in much of Eastern Africa. Its cause is not clear but it has been attributed both to soil temperature changes with the onset of the rains, and to an early nitrogen flush due to changes in the balance of soil bacteria.

If soil temperature is a cause in some areas, then varieties and species may exhibit differential tolerances to temperature ranges. Guidance on varieties or species that could be planted late with mimimal loss of yield potential would be very valuable to farmers with low power resources. Some farming situations would certainly justify this as a screening criterion in a selection program.

Management of Late Planted Crops

Researchers have assumed that farmers should plant at the 'right' time and little or no work has been done on the management of late planted crops. Clearly, where there is a marked 'time of planting' effect there will be marked interactions between time of planting, fertilizer levels, and perhaps plant density and seed rates. Information should be available on the best way to manage late planted crops for situations where it is the farmers' advantage to continue to plant late.

Reduced Tillage Techniques

Reduced and minimum tillage techniques, including the use of herbicides, are a corollary to tolerance to late planting, and management of late planted crops, that are referred to above. Such strategies increase early planting by minimizing the power demands of the tillage sequence. Herbicides also offer a way around the clash between extended area and early weeding.

It is among the extensively operated systems that the tackling of long technical problems, particularily the rundown of soil fertility, is most difficult. It is often into the transition stage of the fallow period increasingly failing to restore fertility, before returns to intensifying inputs compete with returns to putting an extra area under crop. This watershed will vary with the particular circumstances of each local situation.

Perspectives for Effective Agricultural Research for Eastern African Small Holders

The paper has repeatedly touched on differences in the orientation of classical agricultural research and research needs for small farmers. It has mentioned a communications gap between researchers and farmers. The two are closely related. All farmers operate systems which, because of farmer priorities and farmers' limited resource bases, require compromises in the way individual crop and animal enterprises are managed. The key question in technology transfer is 'how will the farmer evaluate a change offered to him'. Unless researchers are aware of farmers' criteria, they can neither effectively plan nor evaluate experiments aimed at farmer recommendations.

For small holders, reliability in performance and returns to cash outlay will always be of first importance. For extensive and transitional systems, returns to seasonal labour use will dominate an evaluation; for intensive systems the classical return to land will dominate the evaluation. The example systems and the brief discussion of extensive systems have shown us that farmers' criteria are usually multiple and vary with their particular circumstances. We need to understand local specific farming systems to get the criteria right as a prelude to planning experiments to derive farmer recommendations.

Understanding systems has other benefits. Not only do we identify criteria for planning and evaluating experiments, but we understand why the farmer has to compromise in management. By defining system constraints to more effective exploitation of biological potential, we identify research priorities. We also understand system interactions that have two attributes; we can identify the true costs and benefits of new materials and management practices. For example the benefits of herbicides on maize may be an extra acre of cotton planted, or the benefits of planting direct into winter ploughed land are the yield improvements from a month's earlier planting. We can also see alternative ways of solving identified system problems, and bring a wider range of new technology options to bear. For example, herbicide on the cotton crop may allow a release of labour to weed maize, and allow the viable application of maize fertilizer. The more relevant options which can be placed in front of farmers, the greater the chance of acceptance. Widening out researchers' perspectives from the blinkered tradition of commodity yield per unit area of land is a prerequisite to effective research for East African small farmers.

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Agriculture and Food Policy Issues in Kenya: Research Agenda

W.M. Mwangi and G. M. Ruigu*

The purpose of this paper is to present a brief socio-economic research agenda for Kenyan agriculture. In undertaking such a task it is important to note that Kenyan agriculture is extremely diverse. Ecologically it ranges from tropical on the coast to semi-temperate agriculture on the highlands, and from high rainfall to arid and semi-arid areas. There is great uncertainty in weather conditions, particularly rainfall, and this affects crop and livestock production.

The production structure is also vastly different for small holders and large farms, in terms of both technology used and the crops grown. In delineating areas of research it is important to take cognizance of the fact that the constraints that limit agricultural production in the various farming systems are also very diverse. It is thus essential that research should attempt to identify and quantify the relative importance of different constraints which face agricultural production in Kenya.

Agricultural Production

Cash Crops versus Food Crops

Agricultural production in Kenya is directed towards attaining several objectives including satisfying domestic food needs, supplying domestic commercial and industrial needs, and earning foreign exchange. Kenya's agriculture is fairly diversified and cash crops and food crops are grown by both large and small-scale farmers. Because of the importance of these crops in overall economic development, the balance between subsistence and cash-crop production should be given a high priority in research.

The expansion of cash crops at the expense of food crops and the concomitant decline in nutrition is causing concern in several areas of the country, particularly in the sugar producing areas of Western Kenya. In addition, the issues of comparative advantage should be carefully assessed in determining what crops to expand or reduce. Kenya is said to have a comparative advantage in production of coffee and tea, but there are significant variations due to fluctuation of prices.

Land Use and Development

Kenya is fairly short on good agricultural land. About 80% of the land cannot support food production without irrigation and other inputs. Current investment levels and technology in the dry low-potential areas can only support extensive livestock production and pastoral nomadism (McCarthy and Mwangi 1982). Consequently, one of the most pressing problems of the country is land-use intensification in order to meet the needs of a rapidly growing population of 3.4% per annum. In order to make the best use of the available land resources, research should address the effects and implication of land-use intensification. The economic potential of all under-utilized land should be established, with particular attention to land use in the arid and semi-arid areas where the bulk of Kenya's land resources are located.

It is also notable that land scarcity has forced people to move from the high potential areas into the arid and semi-arid areas bringing with them inappropriate technologies for these areas. The better utilization of land will have to be effected in conformity with the three principles set out in the national paper on food policy (Kenya 1981) including to: (a) ensure efficient utilization of land to meet food needs while making a growing contribution to foreign exchange earnings, (b) ensure maintenance of fertility, prevent soil erosion and silting, and protect water catchment areas, and (c) discourage land speculation.

Research pertaining to land policy needs to be undertaken. Studies on the comparative performance of small versus large-scale farming

* Senior Lecturer and Chairman, Department of Agricultural Economics, University of Nairobi; and Senior Research Fellow, Institute of Development Studies, University of Nairobi, Nairobi, Kenya, respectively.

systems are required in order to determine appropriate strategies for agricultural development. In addition, the socio-economic effects of the current land tenure system and the emergence of a land market in small-holder areas should be investigated (Institute for Development Studies 1978). This should be linked with assessment of the problem of increasing landlessness and unemployment.

The impact of recent changes in the patterns of land settlement in the country requires investigation. Particular attention should be given to the social and economic impacts of different settlement schemes. The implications of the subdivision of cooperatives and company large-scale farms into small-holder farms should be addressed in order to assess implications for productivity, employment, and income.

An overall evaluation of changes in farming systems since the adoption of the Swynnerton Plan (1954) should be undertaken. (The Swynnerton Plan contained recommendations to intensify the development of African agriculture). The historical perspective should shed light on the dynamics of agricultural development in the last two to three decades.

Livestock Production and Pastoralism

Pastoralism plays an important role in the economy of Kenya, and consequently socio-economic research on livestock should be among the priorities of our research agenda. Research should aim initially at conducting a survey of the livestock population to identify characteristics of different livestock systems and to help in understanding the characteristics of dairy and beef production, and draft power animals.

Research should also help in the analysis of the factors affecting decision-making when investing in livestock within existing socio-economic conditions as well as within the context of total farming systems, help in determining economically viable levels of livestock production, and identifying socio-economic constraints inhibiting high levels of production. The response of pastoral systems to exogenous factors such as the establishment of group ranches, land adjudication, the individualization of land rights and concomitant cultivation of dry-season grazing areas, and price policies should be examined.

An important area of needed research concerns the integration of crop and livestock enterprises. Of special interest would be the role of small ruminants that thrive well in marginal areas. Research should be directed to increasing the production of meat and milk from small ruminants (Gatere 1982). In the high rainfall areas, emphasis is more likely to be on dairy production rather than beef, and on semi-zero and zero grazing systems. The economics of this system of production need to be investigated.

Agricultural Employment

Available evidence suggests that contrary to what might be expected in a country exhibiting rapid population growth and severe land pressure in many areas, labour scarcity is not only experienced in the estate sector but also in small-holder areas (International Labour Organization 1981; Haugerud 1981). At the same time, there are some densely populated areas where the rates of underemployment are high. Research is required on rural labour markets, labour mobility, and migration.

Family and hired labour are important inputs in all the farming systems in the country. The objective of research here should be to identify the causes of low labour productivity, suggest ways of reducing or eliminating seasonal labour bottlenecks, and identify opportunities for generating more jobs in rural areas aimed at mainly reducing rural-urban migration, which is a drain on labour availability especially at peak periods. Research should also include non-agricultural work performed by rural families.

Input Supply Systems

To increase agricultural productivity, it is necessary to increase yields by greater use of purchased inputs including fertilizers, pesticides, and feeds etc. It is therefore necessary to improve the supply of inputs to farmers. Research is required to assess the economic performance of the input supply industries in terms of goods and services provided, and to identify the constraints that may be operating on the supply of inputs, and to make recommendations as to how these may be alleviated.

Input supply is currently highly concentrated in the hands of very few firms (Mwangi 1982). This input supply system has tended to be a bottleneck in increasing agricultural production. Research should be directed towards finding ways of reducing this concentration, which will certainly result in reducing domestic input prices especially if competition is increased in these industries.

Research in the past has tended to concentrate on cash crop fertilizer responses and the description of fertilizer supply systems. Research must now not only address itself to the issue of profitability of fertilizer use, but must include food crop varieties responsive to fertilizer use, uncertainty of yields, high transport cost, unavailability of fertilizer at the village level, and lack of credit. The concern about availability of inputs such as fertilizer and seeds at village level should also include the quality of these inputs, and a review of government involvement in input supply especially in its price determination and quality of service.

In the area of tools and machinery, research should focus on the financial and economic profitability of alternative types of mechanization and the social consequences of mechanization on small scale farms in various farming systems.

Agricultural Credit and Production Risks

Agricultural Credit

Agricultural credit is an important factor in enhancing agricultural production. In fact, lack of credit to purchase modern inputs, especially by small farmers, is usually used as one of the reasons why they do not adopt innovations faster.

In Kenya, agricultural credit is provided through commercial banks, cooperative societies, individual crop authorities, and several specialized government institutions, the most important of which are the Agricultural Settlement Fund and the Agricultural Finance Corporation (this is to be converted into an Agricultural Bank).

The Kenyan credit system has many shortcomings. It has failed to reach most of the small farmers, is not properly integrated into the overall financial system, and charges too low interest rates (Donaldson and Von Pischke 1973; Heyer 1976; Long 1978).

The price of credit (interest rate) is usually of great concern to the government and it is in fact kept low as a matter of policy. The issue of interest rates will call for serious consideration, and research should determine the interest elasticity of the demand for agricultural credit in the country. This would be a useful piece of information for the policy maker.

Research should also try to identify what are the specific needs of the small-farm borrower. How should these needs influence lending operations and the structure of the credit delivery system? It is research that can determine the extent to which credit is a constraint in small-farmer food production and also determine its impact on increasing food production.

The specific areas of research on credit should include formal and informal credit, consumption and production credit, and rural savings. The funds collected during Harambee Meetings, (i.e. self reliance or pulling-together meetings) in rural areas would seem to indicate that the shortage of finance in rural areas might not be as serious as has been supposed. The link between rural producers and urban migrants should be investigated to find out how much it is used or can be used to fund rural investment. Finally, research must address itself to the political economy of agricultural credit.

Production Risks and Uncertainty

The assessment of the impact of risk and uncertainty on farmers' behaviour and the adoption of new technology should be high on our research agenda. The main aim of research here should be to assess to what extent risk aversion by farmers in various farming systems leads to under-investment and to what extent it inhibits the adoption of modern technologies. Research should also identify the existing mechanisms that farmers are using to adjust to and insure themselves against risk, and how these mechanisms can be made more effective and efficient.

The importance of crop insurance in helping farmers manage risks has been recognized by the government. The government is now in the process of enacting a Crop Insurance Act. Formal crop insurance is a necessary but not a sufficient condition for risk management. Its role needs to be assessed. Research should also assist in developing risk-adapting cropping strategies such as intercropping that will contribute to yield stability and hence reduce farmers' income variability.

Marketing and Pricing Policies

Market Interventions

In Kenya, most of the important agricultural commodities, including food crops and cash crops, are under the control of statutory boards. Only a handful of products, including poultry and eggs, and the highly perishable fruits and vegetables, are left to the competitive market. The country is thus characterized by a centralized marketing system. The boards are established to undertake marketing. Trade through unauthorized channels is forbidden. Marketing policy is tied to pricing policy. There are gazetted prices for major food crops and livestock that are implemented through single channel marketing. In practice there is considerable illegal and semi-legal trade in maize and other commodities as the formal and informal channels interact.

A primary concern in this marketing situation should be one of ensuring that the costs of marketing are as low as possible. Research is urgently required to analyse factors that influence the size of the marketing margin. A comparative evaluation of the performance of statutory boards, cooperatives, and private entrepreneurs should be undertaken. It should also evaluate the supply of marketing services of each type of intermediary. Such information would be useful in determining the appropriateness of each type of intermediary.

Cooperatives

In addition to the statutory boards, cooperatives are an important instrument in marketing. There are three main strata in the Kenya cooperative movement incorporating primary cooperative societies, cooperative unions, and nationwide apex cooperatives. In 1982 there were 1 316 agricultural societies with a membership of 1 026 474 and a turnover of 2 055 million Kenyan shillings, i.e. approximately US$150 million. The cooperatives, like the statutory boards, also largely operate without competition. (The role of the private trader is largely restricted in Kenya.) Research should address the performance of the cooperative movement and evaluate its ability to meet stated government objectives. The unit costs of marketing, variation in the ratio of costs to earnings, existence or non-existence of profits and the level of payout to farmers are some of the criteria that could be used in assessing performance.

Pricing Policies

The Kenya government intervenes in the pricing of a wide range of agricultural products. Most of the pricing of important foods such as maize and maize meal, milk and milk products, beef and other meats, beans, sorghum and millet etc. have their prices rigidly fixed by the State from the farm gate, through processing and wholesaling to retailing. Only a handful of products have their prices determined in a competitive market. In addition, the prices of the main cash crops are left to be determined in international markets.

The objective of pricing as stated in the 1974-78 Plan is that in 'fixing these prices, the government will maintain a fair measure of stability of farm prices while making the absolute level of prices attractive enough to encourage production.'(Kenya 1974-78).

More studies are required in the area of pricing policies. Such studies should address the impacts of pricing policies on the farm-output mix, and the composition and quantities of food produced and consumed. The research should help determine whether government objectives are being realized. Are price levels high enough to provide adequate incentives to ensure domestic self-sufficiency for the commodities in question? What are the impacts of prices on resource allocation? Do they ensure allocation of resources to the production of commodities that the consumer desires? Ideally the prices of products and inputs must be such that collectively, farmers who individually control agricultural resources will be induced to produce sufficient food and other commodities to meet national requirements (Ruigu 1982). Research should also determine the relative profitability of food crops and cash crops since they compete with each other for land, labour, and capital (Maitha 1974). There have been too few studies in the area of enterprise competition.

Seasonal patterns of production are of great importance in crop and livestock production. Research is required to determine the impact of seasonally differentiated pricing (as for milk production) and also in relation to cost and supply of storage (as in the case of grains).

Agricultural Price Policies and Domestic Terms of Trade

Price policies have an impact on the domestic terms of trade and on income distribution. While farmers prefer high prices for their products, the processers and consumers would prefer low prices for the same products. A conflict of interest therefore exists between agricultural producers on the one hand, and consumers on the other, and it has to be resolved. Farmers often complain that all prices are rising except theirs, i.e. the terms of trade between agriculture and industries are moving continuously against agriculture.

Research is needed to analyse the terms of trade with a view to improving them. The prices that farmers pay for farm inputs such as labour, machinery, fertilizer etc. should be considered together with available technologies in assessing the agricultural terms of trade. The scope of the research should be widened to include an examination of the system of industrial protection and its impact on agriculture.

Response of Farmers to Prices and Other Incentives

To consider adequately the role of the agricultural sector in the development of the Kenyan economy, the responsiveness of that sector to various incentives must be known. Only with knowledge of this responsiveness can the effects of various policies on agricultural and on overall growth be responsibly examined (Behrman 1968). Research is therefore required to determine how Kenyan farmers respond to economic incentives and policy instruments such as prices, extension services, credit programs etc. and the basis for the specific response or non-response.

Transportation and Marketing

Transportation is one of the facilitators of marketing that creates place utility. Studies are required to address transportation costs and policy.

The system of producer pricing for some agricultural commodities and livestock products is uniform throughout the country. The transportation costs are pooled and a uniform transportation charge is made. A uniform consumer price is also charged for commodities like milk. This pricing system implies hidden subsidies for producers, who are further from the markets, and to the consumers who are located far from the production areas. The extent of these subsidies and their impacts need to be evaluated.

Restrictions on Movements of Agricultural Commodities

Kenya has a complex regulation of movement of agricultural commodities. With few exceptions, all movements of maize require a movement permit. The restrictions interfere with the free flow of commodities from one market to another and sometimes cause major price differentials. This is partly because the services of potential arbitraguers (traders) are eliminated and the statutory board is unable to operate in all areas. The impact of such restrictions should be examined, including effects on marketing costs and on inefficiency arising due to cross-hauling of commodities. Some complaints have been heard about cross-hauling of commodities such as sugar. Cross-hauling could arise because of market restrictions, administrative procedures, inadequate storage, location of processing facilities, and inadequate market information.

Food Consumption and Nutrition

As income grows, demand for food will shift in favour of more livestock products, fruits, and vegetables at the expense of grains. Demand analysis should be undertaken to provide price and income elasticities for planning. Since substitution within consumption occurs, cross elasticities should also be determined. Studies on demand for domestic consumption and expenditure have in the past been largely confined to urban areas. They should now be extended to rural areas.

Improvement of nutrition of rural people is an important contribution to agricultural and rural development. To a large extent nutritional status is determined by income, thus the problem may be considered as one of inadequate income. Research should undertake an assessment of the nutritional status of various income groups in different farming systems, especially the rural landed poor and the rural-landless poor.

Women in Agricultural Development

The role of women in agricultural and rural development is well recognized but the quantitative information at the micro level is hard to obtain (Eicher and Baker 1982). Research should be undertaken at the micro level to establish their role, especially in household decision-making. A quantification of their time allocation to various activities in the household should be undertaken for various farming systems in the country. The contention that women contribute more to food production than men should be evaluated in different farming and livestock systems.

It is also claimed that various institutions in the society influence women's access to resources and services such as land, credit, extension services, and education. Research should examine and determine the extent of this influence.

Summary

This paper has addressed socio-economic research issues in Kenyan agriculture. It has highlighted questions concerning land use, crop and livestock production, and agricultural employment. It has also addressed research issues pertaining to input supply systems including fertilizers, pesticides, and machinery. In addition, research problems relating to agricultural credit, production risks and uncertainty were identified. The possible role of insurance to cope with the latter problem was also briefly noted.

A major part of the paper dealt with research needs in the area of marketing and pricing policies. The specific areas of research that were identified concern the role of various market intermediaries, the level of prices and their impacts, domestic terms of trade, farmers responsiveness to prices and other incentives.

The final part of the paper dealt with food consumption, nutrition, and the role of women in agricultural development. Again, the pertinent research issues were identified.

The paper does not wish to imply that no research has been carried out in all the areas enumerated. Rather, the starting point for any research should begin with the assessment of the usefulness of any previous research in order to identify gaps and areas for further research.

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Summary of Discussions——Sessions 2 and 3

Research Priorities in Semi-Arid Eastern Africa from the Development Viewpoint

In spite of a large number of technical specialists manning agricultural projects in Africa it is discouraging that agricultural production continues to lag behind the demand.

In discussing priorities in agricultural research, it was noted that they are spelled out in development plans for various Eastern Africa countries. However, due to inadequate resources, some projects have to be funded from external sources. One of the problems with the latter is that their contribution is usually short term and unpredictable. Also it is difficult to implement some of these projects unless one authority has control of all the necessary resources. It was emphasized that a factor limiting agricultural production is inefficient transfer and adoption of new technology by the target farming group.

The World Bank seems to be reluctant to finance research programs and projects that have long term pay-offs, those without immediate returns and also where the latter is neither predictable nor assured, e.g. erection and equipping diagnostic animal health laboratories and/or rehabilitation programs. Such facilities should probably be funded from alternative sources.

A need was expressed to strengthen the in-country capacity for producing scientific manpower. Consequently the 'twinning' arrangement mentioned in the paper should be followed up; and similarly the development of 'centres of excellence' for various agricultural research disciplines. ACIAR may assist in formulating these proposals.

The problem of financing and investing in forestry research programs was raised. In this discipline, returns are long term and often not tangible, e.g. soil/water conservation etc. However, it was pointed out that the return to forests designed for fuelwood are quicker and funding of such projects should therefore not present any problem.

Agro-Research for Australia's Semi-Arid Tropics: Report of the Darwin Symposium, March 1983

Regarding crop interplanting it was noted that it is a new concept in the dry areas and is still at the experimental stage. Crops such as cowpeas and pigeon peas are intercropped, in strip planting.

Some concern was expressed that the central role of forestry in the development of difficult sites is not adequately reflected in the paper. A number of Australian species hold considerable potential for the development of social forestry in the Eastern Africa Region. The meeting emphasized that ACIAR should consider providing a balanced program with equal emphasis on crops, livestock, and forestry, because the region stands to benefit enormously from the Australian forestry experiences.

Climatic and Soil Constraints: Water Supply, Soil Stability and Soil Fertility

The Sudanese clays are considered the most productive soils for farming operations in the Sudan. They tend to lose their fertility when monoculture is practised but under rotational cropping, nutrient levels appear to be maintained. Also, these clay soils are difficult to work when wet, hence sowing has to be done before wetting or at low levels of soil moisture. With irrigation, sowing is done after the first light irrigation.

The benefits of keeping land bare fallow as practised in the subtropics of Australia, were discussed. Under Australian subtropical conditions, bare fallow is recommended to allow ground water re-charge because water is a limiting factor in crop production during the dry season. Soil erosion can be a major problem in bare fallow although it may depend on the degree of soil bareness and the type of soil; it is more serious in sandy soils than in clay soils.

Field Crop Production in the Australian Tropics and Subtropics

The question of providing water for livestock during the wet season when evaporation is also high was raised. This problem is not very important in Australia because of the presence of surface and subsurface water, which is readily made available to livestock.

Agricultural research resource allocation in Australia is generally based on the economic importance of a project in the nation. There is however a problem of reorienting old and ongoing projects to meet a new situation which may require a different order of priorities.

Although there are similarities between the Australian and Eastern Africa semi-arid lands, the two are not really identical. Some of the major differences are the size of farms, scale of operation, soil tillage goals, and the mixture of enterprises found on the farm.

The Eastern Africa semi-arid lands would benefit from genotypes developed in Australia. It must however be recognized that the superiority of a given genotype decreases as environmental factors become more and more limiting.

Australia is fortunate in that a good balance exists between basic and applied scientists, extension officers, and farmers as contributors to the total process of agricultural innovation. Perhaps this is explained by a historical fact that the farmers came first and were able to make many achievements before agricultural science evolved as a profession in Australia.

Research on a Minimum Tillage Tropical Legume-ley Farming Strategy

A question was raised on the high toxicity and relative safety in handling herbicides such as Roundup.® It was generally agreed that unlike Gramoxone® whose alarming mammalian toxicity was the subject of recent heated debates, Roundup is a second generation herbicide with a generally low mammalian toxicity.

It was generally agreed that Roundup is effective in weed control but it is extremely expensive and may not be accessible to farmers. The cost of production of Roundup is not known (company secret), but when the patent expires, which is expected shortly, production cost of this herbicide will be established. There are good prospects that the selling costs of Roundup will then drop in the next 10-15 years to an acceptable level. Attempts should be made now to determine its efficacies. It is likely that when its full range of herbicidal effectiveness is determined, various world agencies could make it available at an acceptable cost to needy countries.

Improving the Nutrition of Grazing Animals Using Legumes, Fertilizers, and Mineral Supplements

In a feedlot situation beef animals are fed totally and it is erroneous to refer to this practice as supplementary feeding.

In a successful oversowing program, the natural grass is burned and then the regrowth is grazed. It is important to select the right controlled grazing pressure (with reference to the legume) to ensure the successful establishment of the legume and its continued vigour.

In Australia, a controlled mating season using natural service is practised. Calves must be weaned at an appropriate time to reduce weaning stress, ensure their survival, and at the same time prevent the dam from being excessively punished.

It was noted that sometimes animals will not graze what appears otherwise to be good sward. This reduced intake may be due to the composition of the herbage. The situation may be helped by including a fodder shrub or pasture legume in the sward.

It was observed that almost all genotypes of cattle respond to better nutrition in nearly all cases. It is the magnitude of the response that may be different.

The role of pasture plants in controlling parasites (ticks and helminths) was discussed. Some plants, e.g. *Stylosanthes scabra*, may trap and/or poison the young stages of ticks and larvae of helminths thereby preventing them from reaching the grazing animal. This should be investigated in greater detail.

Unlike other fodder legumes, *Leucaena* does not compete with grass because of the height difference between the two.

Animal Health Factors in Livestock Production

In the African context every animal may be suffering from several diseases. The question was raised as to whether Australia has developed certain control models that may apply to African conditions, e.g. the control of mastitis, liver flukes, etc. It was explained that in the consideration of models one had to consider certain factors, e.g. for mastitis control in dairy cattle, control is through drug administration as well as proper hygiene and nutrition.

It was suggested that beef and dairy cattle in Sudan have a liver fluke problem. Other important diseases include rinderpest, anthrax, and brucellosis. A major constraint is vaccine production, both in quality and quantity; this is an important area for collaboration.

In Kenya there has been continuing cooperation with Australian scientists in a number of ways, viz. (a) epidemiological studies with a group in Western Australia (needs expansion with adequate training opportunities for Kenyans), (b) tick research (collaboration in tick resistance studies and in acaricide research), and (c) helminths (this work is to be continued).

An area without collaboration is vaccine production. Kenya produces its own vaccines (9 different types) but production faces a financial constraint resulting in transferring the services to commercial organizations. Some Kenyan vaccines are available to farmers free of charge, but subsidized through export sales. Collaboration in vaccine research would appear a high priority. Pleuro-pneumonia is a big problem in the movement of cattle, and this is another area for collaborative research.

It was explained that in Australia vaccination against brucellosis is not normally done. Some states, e.g. Tasmania, Victoria etc. have no incidence of this disease, which is only confined to a small area in the Northern Territory, where it is due for eradication shortly. After eradication, testing for brucellosis will be continued.

Although Australia does not have major African diseases, e.g. rinderpest, nevertheless there is interest in collaborative research on African diseases.

Research and Development Aimed at Genetic Improvement of Livestock

The question of the size and fertility of sheep was raised. It was observed that some of the flocks found in Eastern Africa have the desired levels of the two traits.

The technique of progeny testing is generally not used in sheep breeding where the traits of interest have high heritability.

The role of crossbreeding in increasing birth and mature weight of indigenous sheep was discussed. It was noted that certain indigenous types of sheep are more precocious and are able to mate all the year round.

Fuelwood and Agroforestry

The meeting noted that both papers provided subject matter important to forestry in the region. It was stressed that further organized species trials should be encouraged and should cover all ecozones. The fast growing exotic species have capabilities of meeting growing demand for wood and thereby relieving the mounting pressures on the meagre indigenous vegetation.

Regarding acquisition of tree seeds, it was observed that the lack of foreign exchange poses an important constraint. Commercial seed sources should not be totally condemned because some such seed have given satisfactory material. Bilateral exchange of seed was recommended.

The controversy on whether eucalypts tend to dry up the soil led to an extended debate. The meeting noted that nearly all Australian watersheds are covered by *Eucalyptus* communities. The fears about eucalypts in the Eastern Africa Region are based on imaginary ideas without any scientific base. Observations documented on possible water depletion in pastures taken from profiles extending to 7 m have revealed no competition between herbaceous species during the wet season. During the dry season the herbaceous plants stop growing and hence do not compete with eucalypts for moisture. However, substantial competition for nitrogen was noticeable between eucalypts and grasses. By contrast, legumes intercropped satisfactorily with eucalypts.

Although Australia has no experience with tree planting for sand dune fixation, some species growing on sand dunes in the Australian desert could be worth trying elsewhere.

Farming Systems and Socio-Economics

Further elaboration is required on the ICRISAT farming system research approach to determine the drawbacks before the introduction and adoption of this system by local farmers. The main innovation of this system was considered to be the improvement on soil and water management. This package was tried and modified at ICRISAT and on farmers' plots for about 6-7 years before eventually being presented for adoption.

It was suggested that one of the weakest links in farming systems research is the 'on-farm-trials' procedure, which is non-attractive to those researchers who are attracted to the traditional disciplinary techniques and who do not wish to cooperate with extension. Ways and means should be found to convince the two groups to work together in solving the farmers' problems through the farming systems approach.

One delegate felt that farming systems research was being pushed rather too fast and is being over-emphasized.

It was also suggested that farming systems research may increase research costs as it involves stations that cannot adequately finance the ongoing research work. The ICRISAT farming system approach may have been a success due to availability of funds. It was also suggested that researchers may be discouraged from pursuing farming systems research as it does not offer or show credit to the research disciplines. The farming systems research may not necessarily be more expensive since costs are controllable, but no clear-cut answer was forthcoming. It was, however, emphasized that farming systems research is more relevant to solving farmers' problems than the traditional disciplinary approach. It was also suggested that in some cases this approach may interfere with the researchers performances.

On monitoring and evaluation of the impact of farming systems research, it was pointed out that scientists at ICRISAT are involved in devising methods to this end.

Session 4

Working Group Discussions

Working Group Discussions

Working groups were formed to discuss the following four main topics——soil and crop management; livestock; forestry; and farming systems and socio-economics.

The aim of the working groups was to extend the discussion of the papers presented earlier in the workshop, but with more of a disciplinary/commodity focus. The papers and the summaries of the discussions that followed the papers formed the basis of each group discussion.

Working groups were asked to define areas of research that are (1) a high priority in Eastern Africa and (2) those in which Australia is felt to have sufficient research experience and capacity.

In this manner, the scope for collaboration between Eastern African agricultural research institutions and their Australian counterparts was discussed as follows:

Group 1.——Soil and Crop Management

Present: E.F. Henzell (Chairman), M. Abebe, A.N. Alio, G. Brhane, S.J. Carr, J. Coulter, B. Grof, R.K. Jones, J.K.Leslie, B.N. Majisu, M.N. Noor, J.J. Ondieki, W.A. Sakira, and F.J. Wang'ati.

This group discussed four main topics——research management and staff development; communication of scientific information; soil research; and plant research. Plant research was considered under two headings——crops and forages.

1. Research Management and Staff Development

The group recognized important problems in the Eastern African countries in the areas of research organization and management, and in staff development. The difficulties of research organization are primarily political matters to be resolved by the countries themselves, but there are aspects of research management and of the conduct of research that might be assisted by ACIAR. The countries are not short of advice on these matters. Their problem is to provide leadership to and develop the skills of the staff who conduct research at the grass roots level.

The Group recommended that ACIAR projects should be designed to:

(1) Help in developing the technical skills and leadership ability of collaborating scientists from the Eastern African countries while they are working on the projects.

(2) Provide information and advice to scientists working on similar problems at institutions and locations other than the specific ones at which ACIAR is working.

The Group drew attention to the important point in the Kenyan paper arguing that projects should last for more than 3-5 years if they are to have a major impact.

2. Communication of Scientific Information

The Group considered it very important that ACIAR not only should carry out research but also should help to meet the communication needs of scientists in the Eastern Africa Region.

Accordingly, within the disciplinary and commodity focus of ACIAR's projects, attention should be given to:

(1) Reviewing the research work already done.

(2) Disseminating such reviews to all interested scientists within the region.

(3) Publishing the results of completed research (most, but not all, delegates supported continuation of the East African Agriculture and Forestry Journal).

(4) Holding regional workshops and conferences.

3. Soil Research

The Group identified two themes or sets of problems that are of major concern to the Eastern African countries.

The first of these relates to the problems of efficient use of rainfall, soil conservation, and maintenance of soil fertility in the cropping systems of semi-arid areas. These problems are common to Kenya, which accords a high priority to research in its semi-arid and arid areas, and to Ethiopia (in areas of higher elevation than are commonly found in Australia), and the other four countries. In the Sudan, they occur on both sandy and clay soils and in both the mechanized and traditional agricultural sectors. There is a need there to restore areas of degraded soils and to prevent further degradation. The solution to these various problems is likely to require research on tillage and soil surface management, sources of nitrogen (legume or fertilizer), and other fertilizer requirements.

It was observed that the definition of semi-arid varied between countries, and had been used for much wetter areas in Uganda and Tanzania than in the others.

The second theme relates to the management of irrigated soils, which was highlighted as a problem area by the delegates from Ethiopia, Kenya, Somalia, and Sudan. The aim of research would be to improve the management of irrigation so as to measure the efficiency of water use in crop production and the efficiency of use of fertilizers (especially nitrogen), and to prevent salinization. Other relevant aspects concern problems of mechanization, insect and weed control, and reclamation of saline land. It was noted that Australia has similar problems and is engaged in research on them, but cannot offer any simple, quick solutions.

4. Plant Research

(1) Crops: There was a general recommendation that ACIAR should provide assistance to the Eastern African nations in improving the resistance of crops such as sorghum and millets to the drought and heat stresses of semi-arid regions.

(2) Forages: There was general support for the recommendation that ACIAR should assist research on forage legumes, and in some cases, research on pasture improvement generally. Forage legume research was seen as of high priority in both the semi-arid regions and the moister environments of parts of Tanzania and Uganda. The need for a close coordination with ILCA's existing activities was noted.

5. Special Requests

Kenya requested assistance in the setting up of services for plant quarantine and maintenance of plant genetic resources. It was observed that this matter may be of interest to the Australian Development Assistance Bureau.

Ethiopia asked for assistance in breeding teff. While this crop is largely unknown outside Ethiopia, Australian plant breeders who have worked with small-seeded forage grasses may be able to assist.

The Somali delegation suggested that Australian scientists might be able to advise on the agronomy and improvement of rainfed oilseed crops such as sunflower and safflower.

Other topics mentioned as of possible relevance to ACIAR were participation in a review of horticultural research in Kenya and in plant protection for cereals and grain legumes (also Kenya). It was noted that many of the areas nominated as of high priority for ACIAR-supported research would require a multidisciplinary approach.

Group 2.——Livestock

Present: J.W. Copland (Chairman), M. Abdullahi, P. Atang, S. Bekure, A.E.O. Chabeda, J.J. Doyle, A.H. El Jack, T. Gebremeskel, A.M. Macha, J.D. Wachira, and S. Waghela.

This working party discussed three aspects of livestock production research priorities, namely animal nutrition, animal breeding, and animal health.

Research Priorities

1. Animal Nutrition

There was general consensus that animal nutrition was one of the major factors affecting livestock production in Eastern Africa. The priorities discussed reflected the various management practices in the livestock systems of each country represented. However, the common agreed priorities for research are:-

(1) The introduction of pasture legumes and the development of suitable pasture management procedures are needed to overcome the marked dry season drop in the nutritional status of livestock. The

marked loss of up to 15% of body weight during the dry season often negated the weight gains made by cattle during the rainy season. Research is needed to evaluate native and exotic pasture legumes in the various climatic zones. Australian research techniques in evaluating pasture legumes were considered to be highly beneficial by all the scientists of the countries represented. This is considered to be a long-term project in need of ACIAR support.

(2) A comprehensive research program is needed to utilize the full potential of the various crop residue by-products that are readily available. In addition, investigations into improving the nutritional quality of specific crop residues are needed as well as their use in supplementing breeding livestock during periods of nutritional stress. Mineral nutrition of pasture and livestock was considered to be a high priority for collaborative research.

(3) The identification of the factors involved in low weaning weights and remedies to overcome the identified factors was felt to be a major research priority of cattle in pastoral areas of Eastern Africa. It was agreed that the solution to low weaning weights would improve the ability of young stock to develop resistance to infectious agents and to increase survival rates during the heat stresses of the semi-arid areas.

(4) Collaborative research supported by ACIAR was strongly indicated by members of the working group into the development of research techniques for measuring the dry matter intakes of cattle kept under extensive range systems. Allied to this was the use of remote sensing techniques for monitoring the availability of pasture and the introduction of more productive management systems.

(5) It was considered that identification of the optimum and economic levels of livestock carrying capacity on various pasture types during different seasons warranted a major input.

Although the sociological difficulties were recognized by the participants, the need to overcome the increasing risk of over-grazing and resulting soil degradation were of major importance to all the countries represented. Also, it was considered that a strong multidisciplinary collaborative approach was required and it was recommended that ACIAR give consideration to supporting such a research team, as a matter of high priority.

2. Animal Breeding

(1) The coordination and collection of existing animal breeding data from each country and the evaluation of the results were considered to be a high priority; it was agreed that collaborative research would be the best approach.

(2) The identification of breeds and the production characteristics that make them suitable for different ecological zones was felt to be a high research priority.

(3) The role of introduced exotic breeds and their suitability to improve the various animal production systems in the several climatic zones was considered to require a research input.

3. Animal Health

(1) Production losses caused by ticks and tick-borne diseases were unanimously agreed to be a major production constraint. The relevance of Australian research experience in this priority area was noted by the working group and a strong recommendation for ACIAR support was made for collaborative research projects in this field.

(2) The role of trypanosomiasis and East Coast fever as important constraints to increased animal production throughout East Africa was recognized.

(3) The apparent and insidious role of helminth infections of all livestock in Africa was considered to be important, particularly in young stock kept under both extensive pastoral and intensive conditions. Attention was drawn to the considerable research inputs made by Australia to prevent and control losses caused by parasitism to livestock. It was recommended that this be considered by ACIAR for collaborative research support.

(4) The value of the techniques and methodologies of epidemiological studies and their subsequent analysis was recognized. This allowed administrators to identify and cost out animal health constraints in the systems involved. It was agreed that ACIAR research support should be encouraged on infectious agents common to both East Africa and Australia, which would involve research training and appreciation of the methodologies involved. This would allow East African scientists to identify their own animal health problems, which could result in obtaining the best returns on research inputs.

Special Request

Somalia and Sudan requested research inputs into the nutrition and diseases of camels.

Group 3.——Forestry

Present: L.D. Pryor (Chairman), H.G. Dion, S. Midgley, A.N. Mphuru, H.A.R. Musnad, and J.A. Odera.

The Group made the following 11 general comments:

1. Fuelwood production has very high priority in all countries of the Region and in all arid to humid ecological zones in those countries.
2. Australian species are considered to be highly important in future fuelwood production.
3. There is a need for more trials in different ecological conditions as well as on degraded sites to determine the fuelwood potential of different species under a range of management conditions. This should extend from publicly owned larger plantations, both rainfed and irrigated, to small privately owned woodlots, plantings around villages, field boundaries, and in agroforestry systems.
4. The assessment of production potential in both quantity and value is essential.
5. There is a need to increase the within-country familiarity with Australian material from senior officer to technician levels, especially by contact with species, silvicultural methods, and utilization in Australia.
6. There will be benefits in many cases from establishing trials according to an internationally agreed standard design that would facilitate common data assembly and analysis. It is recommended that this course be adopted where appropriate.
7. There exists in the Region a considerable amount of information on species choice for different sites and appropriate silviculture. Much of this information is scattered in unpublished records and at present not readily accessible. There is a pressing need for the collation and dissemination of such information.
8. The assessment of calorific, browse, and nitrogen fixation values in species that are candidates for fuelwood production is very desirable.
9. Improvement in the use and conversion of wood as an energy source is needed.
10. There is a need to improve timber preservation methods especially for poles used in rural buildings.
11. It is noted that in association with fuelwood production there will often be merit in and the opportunity to produce small saw logs. Associated with this will be a need to improve sawing methods especially with fast growing species in the small-scale village context.

The Group made eight specific recommendations to ACIAR; in association with the appropriate research institutions it is recommended that ACIAR consider contributing to the regional fuelwood research program in the following ways:

1. By assisting in the selection of species and by the collection and distribution of seed of appropriate Australian species for research and development.
2. By providing a coordinator and/or technical assistance in the design, management, and analysis of trials as proposed above in item 3.
3. By arranging exchange visits (and study tours) designed to:
   (1) Improve identification of Australian species already in use in the Region and to assist in the authentication of potential seed producing stands already in existence in Eastern Africa.

(2) Assist African foresters to develop familiarity with Australian species, their potentialities, methods of use and handling. This should include short visits by senior professional staff and longer periods of in-service experience by technical staff.

4. To develop further appropriate research in fuelwood silviculture on other aspects as outlined in items 8 and 9 above with a view to the transfer of results to requesting countries as soon as possible. Such research should include support by research in Australia and provision on a basis according to the need of Australian scientists to work with African researchers.
5. ACIAR could provide assistance by supporting Australian foresters to locate unpublished research reports dealing with fuelwood production in Eastern Africa and assisting with the publication and dissemination of the information. As an adjunct, ACIAR might assist with the organization of a technical meeting to deal with silviculture for fuelwood production.
6. In view of opinion currently expressed from time to time, ACIAR might consider ways of making available scientific information on water relations and water use by quick growing species, especially eucalypts, in relation particularly to the lowering of water tables, site degradation, and total water use, to assist in rational land-use planning in relation to fuelwood production.
7. By organizing a study tour in Australia to examine wood preservation methods especially for round wood of small sizes.
8. By arranging consultation on sawing techniques for small-size, fast grown logs; and inspection and familiarization of methods by utilization officers by study in appropriate localities.

Group 4.——Farming Systems and Socio-Economics

Present: J.L. Dillon (Chairman), M.P. Collinson, H.H.M. Fakki; J.K. Gitau, G. Gunasekera, J.N.R. Kasembe, M. Mekuria, R.A. Odingo, and J.G. Ryan.

The first topic considered by the Group was the structure of agricultural research organizations in the Eastern Africa Region, it being agreed that an understanding of this structure was important both for the development of collaboration with Australian scientists via ACIAR and for the further development of farming systems and socio-economic research. For Kenya it was noted that research is conducted by ministries, parastatals, universities and some private firms, and that a recent report on Kenya's research organization by ISNAR is available. In Tanzania, research is coordinated by a single parastatal body. In Sudan there is a national Agricultural Research Council with a coordinating and functional role. The Institute of Agricultural Research in Ethiopia coordinates all agricultural research in that country. It was agreed that both within and between the countries of the Region there was currently very weak inter- and intra-professional contact. Now-defunct East African regional committees in such areas as seeds, soils, plant protection, and agricultural economics should be revived and a similar committee be established for farming systems research. In particular, a need was seen for the organization of regional workshops in the area of farming systems research and for the development of linkages between universities in the region and the farming systems research conducted by other agencies so that the concepts of farming systems could be better introduced to university teaching programs.

A second topic considered was the current lack of a vehicle for recording and publishing research carried out in the Region. It was agreed that a strong effort should be made to re-establish the East African Journal of Agriculture and Forestry.

The third topic discussed by the group was the question of needed research in areas for which Australian competence might be available on a collaborative basis via ACIAR. Five areas of research were seen as having a high priority, as follows:

1. Soil management and fertility in the context of farming systems and involving questions of climatic risk, labour management, and land use and conservation. Particular need was seen for investigation of the potential role of legumes and reduced tillage in crop-livestock systems in terms of improving soil fertility and soil conservation, and the provision of increased

animal feed.

2. The development of procedures and institutional arrangements for the generation and analysis of farm level data covering both the physical and financial aspects of production.
3. Market research orientated to forecasting the supply, demand, and price prospects of the more important agricultural commodities so as to assist both government policy makers and planners, and producers.
4. Whole-farm modelling so as to enable *ex ante* appraisal of possible new technology.
5. Analysis of the delivery systems that service agriculture's needs for input provision (credit, fertilizer, etc.) and output marketing so as to suggest improvements which would facilitate the transfer of technology.

Session 5

Plenary Session

Plenary Session

The Chairmen of the four Working Groups briefly summarized the discussions that were presented during their respective sessions. The topics that emerged as prospective candidates for collaborative research are listed in each of the following summaries:

Summary of Soil and Crop Management Discussion

E.F. Henzell———Chairman

1. Efficient use of rainfall, soil conservation and improvement of soil fertility in cropping systems of the semi-arid tropical areas. The solution is likely to require research on tillage and soil surface management, sources of nitrogen (legmes and/or fertilizers), and other nutrient requirements.
2. Improvement of the resistance of crops such as sorghum and millets to drought and heat stresses, which are a feature of semi-arid tropical regions.
3. Improvement of pastures with emphasis on forage legumes (pasture and tree) for both semi-arid tropical regions and the more humid environments in the region.
4. Improvement of the yield potential of teff, the staple cereal of Ethiopia, and of rainfed oilseeds such as sunflower and safflower in Somalia.
5. Control of pests, pathogens, and weeds of cereal and legume crops.

Summary of Livestock Production Discussion

J.W. Copland———Chairman

1. Improvements in animal nutrition, particularly in the dry seasons. The role of pasture legumes, crop residues, other by-products, mineral nutrition, and remote sensing of pasture conditions could be investigated in this regard.
2. Causes of low weaning rates in pastoral areas that affect disease susceptibility, and reduce the chances of survival resulting in decreased production.
3. Improvements in animal health. This could include tick and tick-borne disease control, control and prevention of parasites such as liver fluke, study of the epidemiology and economics of the control of diseases such as rinderpest and bovine pleuro-pneumonia, and the immunological aspects of trypanosomiasis.
4. Development of improved breeds of dairy cattle, sheep, and goats.

Summary of Forestry Discussion

L.D. Pryor———Chairman

1. The introduction, testing, and provision of silvicultural information on a wider range of fast growing Australian hardwood tree species such as *Acacia* and *Casuarina* primarily for the production of fuelwood but also building poles and for use in association with cropping systems to stabilize soil, increase fertility, and provide fodder for animals. These species are needed in semi-arid and more humid subtropical and tropical environments, especially in areas of high population density, to replace dwindling resources in wood either as individual farm or community woodlots.
2. The management of Australian species as components of agroforestry systems at village level including studies of their moisture and fertilizer relationships and the requirements for use of the species as browse for animals in complementing their use for fuelwood.

Summary of Farming Systems and Socio-Economics Discussion

J.L. Dillon——Chairman

1. The integration of fodder legumes and minimum tillage practices into traditional farming systems in the semi-arid tropics, the implications for draught power, and human labour availability and utilization, and crop/livestock systems.
2. The use of whole-farm models in economic appraisal of the viability of introducing new component technologies in traditional farming systems.
3. The analysis of market prospects and trends for major agricultural commodities.
4. The conduct of farm management surveys of small holders to gain more understanding of farm and village production systems and information on household incomes, wealth, and input-output relationships.

Communications Discussion

1. Reviews of research work in subjects of particular relevance to Eastern Africa where Australia has recognized competence, and the dissemination of such reviews amongst the interested scientific community.
2. Publication of the results of collaborative research between Eastern Africa and Australia. There was strong support for ACIAR to assist with the continuation of the East African Agriculture and Forestry Journal and to sponsor regional workshops and conferences.

It was agreed that projects supported by ACIAR should aid to develop the skills and leadership capabilities of collaborating scientists in Eastern Africa so that there will be an enhanced capacity for them to conduct similar research beyond the life and specific projects. Information and advice should be provided to scientists working on similar problems in countries other than those with which ACIAR may have formal relationships. If research projects are to have a significant impact it was felt desirable that they continue for a period of at least five years.

The Proceedings of the Consultation will be published by ACIAR.

Appendix 1

Participants and Observers

Delegates who attended the Nairobi Consultation.

Participants

Australia

J.W. Copland
Research Co-ordinator
ACIAR
P.O. Box 1571
Canberra City, A.C.T. 2601
Telephone: (062) 474828
Telex: AA62419
Field of specialization: Animal Science and Fisheries

J.L. Dillon
Head
Department of Agricultural Economics & Business Management
University of New England
Armidale, N.S.W. 2351
Telephone: (067) 732373
Telex: AA66050
Field of specialization: Farming Systems, Agricultural Economics

B. Filshie
Officer-in-Charge
Centre for International Research Co-operation
CSIRO
P.O. Box 260 Civic Square
Canberra, A.C.T. 2608
Telephone: (062) 484495
Telex: AA62446
Field of specialization: International Relations

E.F. Henzell
Chief
Division of Tropical Crops and Pastures
CSIRO
Cunningham Laboratory
306 Carmody Road
St. Lucia, Qld. 4067
Telephone: (07) 3770209
Telex: AA42159
Field of specialization: Administration of Agricultural Research

R.R. Howe
Director
Animal Breeding & Research Institute
W.A. Department of Agriculture
P.O. Box 757
Katanning, W.A. 6317
Telephone: (098) 21175
Field of specialization: Animal Genetics

A.J.V. Janes
Australian Team Leader
Magarini Settlement Project
(McGowan International Pty. Ltd.)
P.O. Box 700
Malindi, Kenya
Telephone: (Malindi) 20956 (B), 20337 (H)
Telex: SXSMYD21181
Field of specialization: Agronomy/Project Management

R.J. Jones
Assistant Chief – CSIRO Division of Tropical Crops and Pastures
& Officer-in-Charge – CSIRO Davies Laboratory (Townsville)
CSIRO
Davies Laboratory
PMB P.O. Aitkenvale
Townsville, Qld. 4814
Telephone: (077) 794855
Telex: AA47181
Field of specialization: Pasture Agronomy

R.K. Jones
Principal Research Scientist
Division of Tropical Crops and Pastures
CSIRO
306 Carmody Road
St. Lucia, Qld. 4067
Telephone: (07) 3770209
Telex: AA42159
Field of specialization: Plant Nutrition/Soil Fertility

J.K. Leslie
Deputy Director
Division of Plant Industry
Department of Primary Industries
G.P.O. Box 46
Brisbane, Qld. 4000
Telephone: (07) 2776380
Telex: AA41620
Field of specialization: Agronomy

R.L. McCown
Agronomist
CSIRO
PMB P.O. Aitkenvale,
Townsville, Qld. 4814
Telephone: (077) 794855
Telex: AA47181
Field of specialization: Farming Systems Ecology

P. McGowan
Project Supervisor/Director
McGowan International Pty. Ltd.
P.O. Box 912
Albury, N.S.W. 2640
Telephone: (062) 213566
Telex: AA56038
Field of specialization: Project Supervision

J.R. McWilliam
Director
ACIAR
P.O. Box 1571
Canberra City, A.C.T. 2601
Telephone: (062) 474828
Telex: AA62419
Field of specialization: Plant/Crop Improvement, Agricultural-Research Aid

J.V. Mertin
Director
Mertin & Associates
6 Watson St
Fullarton, S.A. 5063
Telephone: (08) 795333
Telex: AA88765 AD131
Field of specialization: Scientific Editing

S.J. Midgley
Experimental Officer
Division of Forest Research
CSIRO
P.O. Box 4008
Canberra, A.C.T. 2600
Telephone: (062) 818258
Telex: AA62751
Field of specialization: Forestry—Australian Species, Village-Level Forestry

A. Neylan
Consultant
ACIAR
P.O. Box 1571
Canberra, A.C.T. 2600
Telephone: (062) 474828
Telex: AA62419
Field of specialization: Management

L.D.Pryor
Forestry Advisor
ACIAR
Department of Forestry, Australian National University
P.O. Box 4
Canberra, A.C.T. 2600
Telephone: (062) 951574
Telex: NATUNIV (Cable)
Field of specialization: Forestry

J.G. Ryan
Deputy Director
ACIAR
P.O. Box 1571
Canberra City, A.C.T. 2601
Telephone (062) 488588
Telex: AA62419
Field of specialization: Agricultural Economics

Ethiopia

M. Abebe
Research and Extension Co-ordinator
Institute of Agricultural Research
P.O. Box 2003
Addis Ababa
Telephone: 160301
Telex: MIRIMURY
Field of specialization: Soil Science

T. Gebremeskel
Head
Animal Breeding & Improvement Division
Ministry of Agriculture
P.O. Box 62347
Addis Ababa
Telephone: 448040
Field of specialization: Animal Breeding

M. Mekuria
Head
Department of Socio-Economics & Farm Management Studies
Institute of Agricultural Research
P.O. Box 2003
Addis Ababa
Telephone: 161055-59
Field of specialization: Agricultural Economics

International

P. Atang
Director OAU/IBAR
OAU
P.O. Box 30786
Nairobi, Kenya
Telephone: 338544
Telex: 22893
Field of specialization: Animal Production & Health in Africa

S. Bekure
Team Leader
ILCA
P.O. Box 46847
Nairobi, Kenya
Telephone: 592122
Field of specialization: Agricultural Economics

G. Brhane
Co-ordinator for Sorghum & Millets, Eastern & Southern Africa
ICRISAT/SAFGRAD
OAU
P.O. Box 30786
Nairobi, Kenya
Telephone: 338544
Telex: 22893 OAU/IBAR/NAIROBI
Field of specialization: Sorghum Breeding

P. Brumby
Director-General
ILCA
P.O. Box 5689
Addis Ababa, Ethiopia
Telex: 21207
Field of specialization: Livestock

S.J. Carr
Senior Agriculturalist
World Bank
P.O. Box 30577
Nairobi, Kenya
Telephone: 24391
Field of specialization: (Crops) Small Holder Agriculture in Eastern Africa

M.P. Collinson
Economist
CIMMYT
P.O. Box 25171
Nairobi, Kenya
Telephone: 592206
Telex: 22040 ILRAD
Field of specialization: Farming Systems Research

J.K. Coulter
Agricultural Research Adviser
World Bank
1818H St.
Washington, D.C.
USA
Telephone: (202) 6761764
Field of specialization: Research Management (Soil Science)

J.J. De Castro
Veterinarian
ICIPE
P.O. Box 30772
Nairobi, Kenya
Telephone: 43235
Field of specialization: Ticks

P.N. Deleeuw
Ecologist
ILCA
P.O. Box 48647
Nairobi, Kenya
Field of specialization: Ecology, Animal Production, Pastoralism

H.G. Dion
Consultant
CIDA
c/- Willis Resources Branch
200 Promenade du Portage
Hull, Quebec
Canada
Telephone: 819-994-6060
Telex: 053-4140
Field of specialization: Agronomy

J.J. Doyle
Director of Research
ILRAD
P.O. Box 30709
Nairobi, Kenya
Telephone: 592311
Telex: 22040, ILRAD
Field of specialization: Veterinary Medicine

R. Goldman
Chief of Party
Harvard Technical Assistance Pool Project
Ministry of Agriculture
P.O. Box 47098
Nairobi, Kenya
Telephone: 43261
Field of specialization: Economics

A.R. Gray
Director-General
ILRAD
P.O. Box 30709
Nairobi, Kenya
Telephone: 592311
Telex: 22040 ILRAD
Field of specialization: Parasitology

B. Grof
Senior Scientist
CIAT
AA 67-13 Cali
Columbia, South America
Telephone: 680111
Telex: 05769 CIATCO
Field of specialization: Tropical Pastures

G. Gunasekera
Principal Soil & Water Scientist
ICRISAT
Patancheru P.O.
Andhra Pradesh 502 324 India
Telephone: 224016
Telex: 0152-203
Field of specialization: Soils & Irrigation

J.A. Kategile
Program Officer
IDRC
P.O. Box 62084
Nairobi, Kenya
Telephone: 330850
Field of specialization: Animal Sciences

L.J. Lambourne
Director of Research
ILCA
P.O. Box 5689
Addis Ababa, Ethiopia
Telephone: 183215
Telex: 21207 ADDIS
Field of specialization: Animal Nutrition

J. Lenahan
Training and Outreach Officer
ILRAD
P.O. Box 30709
Nairobi, Kenya
Telephone: 592311
Telex: 22040 ILRAD
Field of specialization: Education

R.M. Newson
Senior Research Scientist
ICIPE
P.O. Box 30772
Nairobi, Kenya
Telephone: 43235
Field of specialization: Livestock Ticks

R.A. Odingo
Principal Planning Officer
ICIPE
P.O. Box 30772
Nairobi, Kenya
Telephone: 43445
Field of specialization: Management

J.M. Ojal
Manager for Communication Systems
ICIPE
P.O. Box 30772
Nairobi, Kenya
Field of specialization: Administration & Training

T.A. Taylor
Senior Research Officer
ISNAR
P.O. Box 93375
2509AJ The Hague, Netherlands
Telephone: (070) 472991
Telex: 33746
Field of specialization: International Agricultural Research

S. Tessema
Animal Production Officer
FAO Dryland Farming Research Project—Katumani
P.O. Box 340
Machakos, Kenya
Telephone: (Machakos) 21506
Field of specialization: Animal Nutrition

D.M. Thairu
National Project Co-ordinator
FAO
P.O. Box 340
Machakos, Kenya
Telephone: 21506/7/8 (Machakos)
Field of specialization: Agronomy

D.A. Trotman
Natural Resources Adviser
Overseas Development Administration (ODA)
British High Commission
P.O. Box 304654
Nairobi, Kenya
Telephone: 335944
Field of specialization: Natural Resources-Aid Program

S.C. White
Soil & Conservation Engineer
ODA
P.O. Box 137
Embu, Kenya
Telephone: 20196
Field of specialization: Soil Conservation/Land Use Planning

Kenya

A.E.O. Chabeba
Assistant Director
Ministry of Livestock Development
P.O. Kabete
Telephone: 592231
Field of specialization: Animal Production

S. Chema
Director of Research
Ministry of Livestock Development
P.O. Kabete
Telephone: 592231
Field of specialization: Virology

J.K. Gitau
Director of Research
Ministry of Agriculture
P.O. Box 30028
Nairobi
Telephone: 720609
Telex: 2276
Field of specialization: Research Management & Planning

B.N. Majisu
Director
Kenya Agricultural Research Institute
P.O. Box 57811
Nairobi
Telephone: Kikuyu 2121
Telex: KARI Nairobi
Field of specialization: Plant Breeding

W.M. Mwangi
Senior Lecturer & Chairman
Department of Agricultural Economics
University of Nairobi
P.O. Box 30197
Nairobi
Telephone: 592211
Field of specialization: Agricultural Economics

D.N. Ngugi
Dean
Faculty of Agriculture
University of Nairobi
P.O. Box 30197
Nairobi
Telephone: 592121
Telex: VARSITY
Field of specialization: Agronomy

J.A. Odera
Director
Forestry Research Department
Kenya Agricultural Research Institute
P.O. Box 74
Kikuyu
Telephone: (Kikuyu) 2220/2173
Field of specialization: Silvicultural Research

R.N. Oduwo
Assistant Science Secretary
National Council for Science & Technology
P.O. Box 30623
Nairobi
Telephone: 336173/4/5/6
Field of specialization: Veterinary Science

J. Ondieki
Chief Research Officer
Ministry of Agriculture
P.O. Box 30028
Nairobi
Telephone: 720030
Field of specialization: Research Administration

G.M. Ruigu
Senior Research Fellow
Institute for Development Studies
University of Nairobi
P.O. Box 30197
Nairobi
Telephone: 334244
Telex: VARSITY
Field of specialization: Agricultural Economics

J.D. Wachira
Chief Research Officer/Deputy Director
Kenya Agricultural Research Institute (KARI)
P.O. Box 30148
Nairobi
Telephone: Kikuyu 2121
Field of specialization: Animal Production (Nutrition)

S. Waghela
Assistant Director—Livestock Development (Veterinary Research)
Veterinary Research Laboratory
Ministry of Livestock Development
P.O. Kabete
Telephone: 592231
Field of specialization: Veterinary Pathology & Microbiology

F.J. Wang'ati
Acting Deputy Secretary
National Council for Science and Technology (NCST)
P.O. Box 30623
Nairobi
Telephone: 336173
Field of specialization: Agricultural Meterology

Somalia

M. Abdullahi
General Manager
Ministry of Livestock
National Tsetse & Trypanosomiasis Control
P.O. Box 8659
Mogadishu
Telephone: 80541/3
Field of specialization: Veterinary Entomology

A.N. Alio
Director
Agricultural Research Institute
Ministry of Agriculture
Mogadishu
Telephone: 80717/14
Field of specialization: Crop Management

M.N. Noor
Vice Minister of Agriculture
Ministry of Agriculture
P.O. Box 801
Mogadishu
Telephone: 80504
Field of specialization: Plant Breeding

Sudan

A.H. El Jack
Associate Professor & Chairman
Department of Animal Science
University of Gezira
P.O. Box 20
Wad Medani
Telephone: 67825
Field of specialization: Reproductive Physiology-Farm Animals

H.H.M. Faki
Agricultural Economist
Department of Statistics & Agricultural Economics
Agricultural Research Corporation
Medani
Field of specialization: Agricultural Economics

H.A.R. Musnad
Head
Arid Zone Research in Forestry, Agricultural Research Corporation
Ministry of Agriculture
P.O. Box 658, Forestry Research Centre ARC
Khartoum
Telephone: 76700-75802
Field of specialization: Silviculture

Tanzania

J.N.R. Kasembe
Director-General
Tanzania Agricultural Research Organisation (TARO)
P.O. Box 9761
Dar es Salaam
Telephone: (B) 27231, (H) 50559
Telex: TARO DSM (CABLE)
Field of specialization: Genetics & Plant Breeding

A.M. Macha
Director-General
Tanzania Livestock Research Organisation (TALIRO)
P.O. Box 6910
Dar es Salaam
Telephone: 31091
Field of specialization: Genetics

A.N. Mphuru
Head
Division of Agriculture
Faculty of Agriculture, Forestry & Veterinary Science
University of Dar es Salaam
Telephone: 2511
Telex: 55308 UNIVMOG
Field of specialization: Crop Protection

Uganda

W.A. Sakira
Senior Agronomist
Kawanda Research Station
P.O. Box 7065
Kampala
Telephone: 62272
Telex: Ministry of Agriculture & Forestry (Entebbe)
Field of specialization: Weed Science (Farming Systems & Weed Control)

H.S.K. Nsubuga
Associate Professor & Head
Department of Animal Science
Makerere University
P.O. Box 7062
Kampala
Telephone: 56931
Telex: MAKUNIKA (Cable)
Field of specialization: Animal Health & Production

Appendix 2
Acronyms and Abbreviations

Acronyms and Abbreviations

ABRI	Animal Breeding and Research Institute, Western Australia
ACIAR	Australian Centre for International Agricultural Research
CBPP	Contagious Bovine Pleuro-Pneumonia
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical
CIDA	Canadian International Development Agency
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo
CIP	Centro Internacional de la Papa
CSIRO	Commonwealth Scientific and Industrial Research Organization
EAAFRO	East African Agriculture and Forestry Research Organizations
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria
E_o	Evaporative Demand
FAO	Food and Agriculture Organization of the United Nations
FSR	Farming Systems Research
GDP	Gross Domestic Product
GTZ	Deutsche Gesellschaft fur Technische Zusammenarbeit
ICARDA	International Center for Agricultural Research in the Dry Areas
ICIPE	International Centre for Insect Physiology and Ecology
ICRAF	International Council for Research in Agroforestry
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IDRC	International Development Research Centre
IFDC	International Fertilizer Development Center
IITA	International Institute of Tropical Agriculture
ILCA	International Livestock Center for Africa
ILRAD	International Laboratory for Research on Animal Diseases
ISNAR	International Service for National Agricultural Research
IUFRO	International Union of Forestry Research Organizations
KARI	Kenya Agricultural Research Institute
KATRIN	Kilombero Agricultural and Research Training Institute, Tanzania
LER	Land Equivalent Ratio
NCST	National Council for Science and Technology, Kenya
NORAD	Norwegian Agency for International Development
OAU	Organization of African Unity
ODA	Overseas Development Administration, U.K.
SAFGRAD	Semi-Arid Food Grain Research and Development
SAT	Semi-Arid Tropics
SIDA	Swedish International Development Authority
TALIRO	Tanzania Livestock Research Organisation
TARO	Tanzania Agricultural Research Organisation
UNDP	United Nations Development Program
USAID	United States Agency for International Development
VADA	Valley Agricultural Development Authority, Ethiopia