Biological control of grass weeds in Australia : an appraisal

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Summary

Two biological control methods are considered for the more than 250 grasses regarded as weeds in Australia, 170 of which, including the most important, are of exotic origin.

1. Inundative or bioherbicidal control where agents already present in Australia, probably fungi, would be used like herbicides. Mostly it is grass weeds important in crops which would repay such an approach but only a few of these have a range of fungi already infesting them in Australia.

2. Classical or inoculative control, where agents from the home range of the grass would be introduced into Australia. Only a few types of agents, notably gall makers and smut fungi, have sufficient specificity to be considered for introduction and then only if the grass weeds are not related generically to crop or pasture/lawn grasses.

The taxonomic relations of the grass weeds to crop and pasture/lawn grasses are detailed. Conflicts of interest that arise because many grasses either are both crop weeds and valuable pasture or lawn grasses or are generically related to them, are listed.

Examples are given of the possible use of the two methods as follows:

***Avena* spp., *Hordeum* spp and *Echinochloa* spp. because of their close relation to crop grasses, *Stipa* spp. because they are native pasture grasses and *Cynodon dactylon* because both a lawn grass but also a crop weed, could only be controlled using agents already present in Australia inundatively. *Bromus* spp. which could also be the subject of bioherbicidal control, *Holcus* spp. and, in particular, *Phragmites* spp. which has a large number of apparently specific agents in its Old World home range, could possibly be controlled by the classical introduction of exotic agents. *Sorghum halepense* could have rhizome-feeding agents introduced to control it but not agents attacking aerial parts of the plant which would infest crop sorghum. *Eleusine indica* could possibly be controlled using both methods. *Nassella trichotoma* is probably too closely related to native *Stipa* spp. to allow the introduction of agents.**

It is concluded that each genus of weedy grasses and in some cases each weedy grass species has to be considered individually and the type of biological control selected according to the following features:-

i) whether the weedy grass is related to crop and/or pasture grasses,

ii) whether a pool of potential agents occurs in Australia already,

iii) if not and potential agents occur in the grass weed's native range, whether they have sufficient host restriction to be introduced into Australia.

Introduction

The possibility of biologically controlling grasses which have become weeds in Australia has been discounted by commentators on the subject for some considerable time. This has been due mainly to the close relation of these weeds to cereal crops and pasture grasses. This paper discusses the biological control of grass weeds in Australia in the light of recent developments in the subject and indicates which grass weeds would be most susceptible to the different methods of biological control.

The Australian Grass Weeds

More than 250 members of the grass family Poaceae (= Gramineae) are regarded as weeds either in standard Australian weed texts and lists (Auld and Medd 1987, Kleinschmidt and Johnson 1977, Lamp and Collet 1979, Parsons 1973, Swarbrick 1983, Whittet 1968, Wilding *et al.* 1986) or are aquatic weeds (Mitchell 1978, Sainty and Jacobs 1981) or have herbicide recommendations for their control (Swarbrick 1984). Of these, 170 species, including most of the important weeds, are of exotic origin.

The taxonomic relations of Australian grass weeds and crop grasses are based on Watson and Dallwitz (1985) and Clayton and Renvoize (1986) (Table 1). There are only two major differences between their classifications. One, the separation of the centothecoid group as a separate sub-family in Clayton and Renvoize (1986) and its inclusion as a tribe of the Oryzaneae within the sub-family Bambusoideae by Watson and Dallwitz (1985), is not relevant here as there are no Australian weeds, crops or pasture grasses in that centothecoid group. The other is the placement of the tribe Stipeae in the sub-family Arundinoideae by Watson and Dallwitz (1985) instead of in the sub-family Pooideae by Clayton and Renvoize (1986).

Recent discussions on the taxonomic position of the Stipeae either concur with Watson and Dallwitz (1985) (Watson *et al.* 1985, Barkworth and Everett 1986) or suggest that this tribe is basal to the Pooideae rather than belonging to it (Kellogg and Campbell 1986). The evolutionary position of both the rust fungi and smut fungi infesting Stipeae suggests that this tribe is intermediate between the Arundinoideae and the Pooideae (Watson 1972, Savile 1979, 1987). For these reasons the tribe Stipeae is placed as belonging to both Pooideae and Arundinoideae in Table 1 and this combined relation would have to be taken into account when considering biological control of grasses in this tribe.

The weeds *Hordeum* spp. and *Agropyron* spp. are the only ones related tribally or more closely to the important crop grasses, *Hordeum* spp. (barley), *Triticum* spp. (wheat) and *Secale cereale* L. (rye) (Table 1). A group of andropogonid weeds are related tribally to *Zea mays* L. (maize), *Sorghum bicolor* (L.) Moench (sorghum) and *Saccharum officinarum* L. (sugar cane). Weeds in the genera *Aira, Avena, Arrhenatherum, Holcus, Lophochloa, Molineriella* are subtribally or more closely related to the important crop grass *Avena sativa* L. (oats) and many other weedy grass genera are tribally related to that crop (Table 1). Weeds in the genera *Avena, Echinochloa, Hordeum, Oryza, Sorghum, Pennisetum, Panicum* and *Setaria* are closely related generically to the important crop grasses *Avena sativa* (oats), *Echinochloa* spp. (Siberian and Japanese millets), *Hordeum vulgare* L. (barley), *Oryza sativa* L. (rice), *Sorghum bicolor* (sorghum), *Pennisetum glaucum* (L.) R. Br. (pearl millet), *Panicum miliaceum* L. (proso) and *Setaria italica* (L.) Beauv. (foxtail millet) respectively.

Table 2 lists the weedy grasses which are closely related ("G" = same genus) to crop or pasture/lawn grasses and those cases where the same grass ("S" = same species) is both a weed in some situations (i.e. crops) and an important component of native or improved pastures are also indicated based on comments on the pasture importance of grasses in Whittet (1969), Reid (1981), Burbidge (1966, 1968, 1970, 1984), Lazarides (1970), Wheeler *et al* (1982), and Tothill and Hacker (1983). The biological control of these grasses could be compromised by conflicts of interest between land users wishing to maintain these grasses in pasture or lawns or wishing to grow related crops and others seeking to control the same or closely related grasses biologically. Indeed, many grasses would be considered valuable fodder for stock but weeds when that same land was ploughed for crops by the same farmer. Table 3 lists the grass weeds for which there would not be economic conflicts of interest in Australia although some are regarded as minor lawn or decorative garden plants and others such as *Ammophila arenaria* (L.) Link are used for sand dune stabilization.

Biological Control Methods

Two types of biological control will be considered here.

1. Inundative or bioherbicidal control, where an agent is artificially increased, bulked up, and applied by the land user in the same manner as a chemical herbicide. Disease organisms such as fungi and nematodes

Table 1. Taxonomic position of Australian grass weed genera

Position of grass crop genera indicated where different from weed genera. Based on Clayton and Renvoize (1986) (C. & R.), relevant differences between them and Watson and Dallwitz (1985) (W. & D.) as indicated.

- FAMILY POACEAE (= GRAMINEAE)
  - SUB-FAMILY BAMBUSOIDEAE
    - TRIBE BAMBUSEAE
      - SUB-TRIBE ARUNDINARIINAE
        - *Arundinaria*
      - SUB-TRIBE BAMBUSINAE
        - *Bambusa*, *Phyllostachys*
    - TRIBE ORYZEAE
      - *Oryza*, *Leersia*
    - TRIBE EHRHARTEAE
      - *Ehrharta*
  - SUB-FAMILY ARUNDINOIDEAE
    - TRIBE ARUNDINEAE
      - *Danthonia* (= *Rytidosperma*), *Cortaderia*, (both in Danthonieae, (W. & D.)), *Arundo*, *Phragmites*
    - TRIBE ARISTIDEAE
      - *Aristida*
  - SUB-FAMILIES ARUNDINOIDEAE/POOIDEAE
    - TRIBE STIPEAE
      - *Stipa*, *Nassella*, *Oryzopsis* (= *Piptatherum*) (all 3 in Stipeae, Arundinoideae (W. & D.) but all 3 in Stipeae, Pooideae (C. & R.))
  - SUB-FAMILY POOIDEAE
    - TRIBE POEAE
      - *Festuca*, *Lolium*, *Vulpia*, *Psilurus*, *Cynosurus*, *Lamarckia*, *Poa*, *Desmazeria*, (= *Catapodium*), *Dactylis*, *Briza*
    - TRIBE HAINARDIEAE
      - *Pholiurus*, *Parapholis*, *Hainardia* (= *Monerma*) (all 3 in Poeae (W. & D.))
    - TRIBE MELICEAE
      - *Glyceria*
    - TRIBE AVENEAE
      - SUB- TRIBE AVENINAE
        - *Avena*, *Arrhenatherum*, *Holcus*, *Periballia* (= *Molineriella*), *Aira*, *Rostraria* (=*Lophochloa*)
      - SUB-TRIBE PHALARIDINAE
        - *Anthoxanthum*, *Phalaris*
      - SUB-TRIBE ALOPECURINAE
        - *Agrostis*, *Ammophila*, *Lagurus*, *Polypogon*, *Alopecurus*, *Gastridium*, *Echinopogon*
    - (all 4 tribes in Poanae (W & D))
    - TRIBE BROMEAE
      - *Bromus*
    - TRIBE TRITICEAE
      - *Hordeum*, *Agropyron*, CROPS; *Triticum*, *Secale*
    - (2 tribes in Triticanae (W. & D.))
  - SUB-FAMILY CHLORIDOIDEAE
    - TRIBE ERAGROSTIDEAE
      - SUB-TRIBE ELEUSININAE
        - *Leptochloa*, *Dinebra*, *Eragrostis*, *Triraphis*, *Eleusine*, *Dactyloctenium*, *Diplachne*
      - SUB-TRIBE SPOROBOLINAE
        - *Sporobolus*
    - TRIBE CYNODONTEAE
      - SUB-TRIBE CHLORIDINAE
        - *Chloris*, *Brachyachne*, *Spartina*, *Cynodon*
      - SUB-TRIBE ZOYSIINAE
        - *Tragus*, *Perotis*
      - (all above chloridoid sub-tribes combined (W. & D.))
  - SUB-FAMILY PANICOIDEAE
    - TRIBE PANICEAE
      - SUB-TRIBE SETARIINAE
        - *Panicum*, *Echinochloa*, *Brachiaria*, *Urochloa*, *Paspalum*, *Axonopus*, *Setaria*, *Paspalidium*, *Eriochloa*, *Stenotaphrum*
      - SUB-TRIBE MELINIDINAE
        - *Rhynchelytrum*, *Melinis*
      - SUB-TRIBE DIGITARIINAE
        - *Digitaria*
      - SUB-TRIBE CENCHRINAE
        - *Cenchrus*, *Pennisetum*
    - TRIBE ANDROPOGONEAE
      - SUB-TRIBE SACCHARINAE
        - *Imperata*, CROP; *Saccharum*
      - SUB-TRIBE SORGHINAE
        - *Sorghum*, *Dichanthium*, *Chrysopogon*, *Bothriochloa*
      - SUB-TRIBE ANDROPOGONINAE
        - *Andropogon*
      - SUB-TRIBE ISCHAEMINAE
        - *Ischaemum*
      - (all above sub-tribes in "awned" Andropogoneae (W. & D.))
      - SUB-TRIBE ANTHISTIRIINAE
        - *Hyparrhenia*, *Themeda*, *Iseilema*, *Heteropogon*
      - SUB-TRIBE ROTTBOELLIINAE
        - *Hemarthria*, *Rottboellia*
      - (above 2 sub-tribes in "awnless" Andropogoneae (W. & D.))
      - SUB-TRIBE CHIONACHININAE
        - *Chionachne*
      - SUB-TRIBE TRIPSACINAE
        - CROP: *Zea*
      - (above 2 sub-tribes in Maydeae (W. & D.))

are particularly able to be developed as bioherbicides (Wapshere 1982). Bioherbicides could be developed from diseases already present in Australia on the weed grass concerned or, if sufficiently specific, disease organisms on the grass could be imported and then developed as bioherbicides (Wapshere 1987).

2. Classical or inoculative control, where the agent is simply introduced, released, then disperses and self-propagates achieving control without further human intervention (Wapshere 1982). Given adequate specificity either to the grass weed alone or to it and a few unimportant close relatives, almost all types of phytophagous organisms could be introduced as classical agents. They would then pose no risk to any crop or pasture/lawn grass whether native or imported.

Bioherbicidal Control of Grass Weeds

For all those grass weeds listed in Table 2 with importance as crop, pasture and lawn grasses it would not be possible to introduce biological control agents from overseas. Only agents present in Australia would normally be considered and they would have to be developed as bioherbicides for these grass weeds.

As it is costly both to develop and to apply a bioherbicide this method of biological control could be used mainly for grass weeds which are major crop weeds, where the cost of development and of application would be repayable. Table 4 lists the grass weeds which are important in crops (Auld and Medd 1987, Wilding *et al.* 1986) and/or have the most herbicide recommendations (Wapsh-

Table 2 . Australian grass weeds closely related to crop, pasture and lawn grasses

Weed	Crop or pasture or lawn grass	Relation S = Same species G = Same genus
Agropyron repens	*Agropyron* spp. (wheat grasses)	G
Agrostis spp.	*A. avenacea* (blown) and *Agrostis* spp. (bents)	S & G
Aristida spp.	*Aristida* spp. (three-awn)	S & G
Avena spp.	*A. sativa* (oats)	G
Bothriochloa macra	*B. erianthoides* (satin top) and *Bothriochloa* spp. (blues)	G
Brachiaria spp.	*B. mutica* (para) and *Brachiaria* spp.	S & G
Bromus spp.	*B. catharticus* (prairie)	S & G
Cenchrus spp.	*C. ciliaris* (buffel) and *C.setiger* (birdwood)	S & G
Chloris spp.	*C. gayana* (rhodes) and *Chloris* spp.	S & G
Chrysopogon aciculatus	*Chrysopogon* spp. (golden-beards)	G
Cynodon spp.	*C. dactylon* (couch)	S & G
Dactylis glomerata	*D. glomerata* (cocksfoot)	S
Dactyloctenium spp.	*D. radulans* (button)	S & G
Danthonia spp.	*Danthonia* spp. (wallaby)	S & G
Dichanthium spp.	*D. sericeum* (Queensland blue) and *Dichanthium* spp. (blues)	S & G
Digitaria spp.	*Digitaria* spp. (summer grass)	G
Echinochloa spp.	*E. frumentacea* and *E. utilis* (Siberian and Japanese millets)	S & G
Echinopogon spp.	*Echinopogon* spp. (hedgehogs)	S & G
Eragrostis spp.	*E. curvula* (African love) and *Eragrostis* spp. (loves)	S & G
Eriochloa spp.	*Eriochloa* spp. (early spring)	S & G
Festuca spp.	*Festuca* spp. (fescues)	S & G
Glyceria maxima	*G. maxima* (water meadow)	S
Hordeum spp.	*H. vulgare* (barley)	G
Iseilema spp.	*Iseilema* spp. (flinders)	S & G
Lolium spp.	*L. perenne* (perennial rye grass), *L. multiflorum* (Italian rye) and *L. rigidum* (Wimmera rye)	S & G
Melinis minutiflora	*M. minutiflora* (molasses)	S
Oryza spp.	*O. sativa* (rice)	G
Panicum spp.	*P. miliaceum* (proso) and *Panicum* spp. (panics)	S & G
Paspalidium spp.	*P. globoideum* (shot), *P. jubiflorum* (Warrego summer) and *Paspalidium* spp. (panics)	S & G
Paspalum spp.	*P. dilatatum* (paspalum), *P. scrobiculatum* (scrobic) and *Paspalum* spp.	S & G
Pennisetum spp.	*P. glaucum* (pearl millet), *P. clandestinum* (kikyu) and *Pennisetum* spp.	S & G
Phalaris spp.	*P. aquatica* (phalaris) and *Phalaris* spp. (canaries)	S & G
Poa spp.	*P. pratensis* (Kentucky blue) and *Poa* spp. (tussocks)	S & G
Setaria spp.	*S. sphacelata* (setaria) and *S. italica* (foxtail millet)	S & G
Sorghum spp.	*S. bicolor* (sorghum), *S. sudanese* (Sudan) and *S.* x *almum* (Columbus)	G
Stenotaphrum secundatum	*S. secundatum* (buffalo)	S
Stipa spp.	*Stipa* spp. (spears)	S
Themeda spp.	*T. australis* (kangaroo) and *T. avenacea* (native oats)	S & G
Tragus australianus	*T. australianus* (small burr)	S
Urochloa spp.	*U. panicoides* (liverseed)	S & G

Table 3. Grass weeds with no or little conflict of interest for control

Aira spp.
Alopecurus spp.
Ammophila arenaria
Andropogon virginicus
Anthoxanthum odoratum
Aristida spp.
Arrhenatherum elatius
Arundinaria spp.
Arundo donax
Axonopus spp.
Bambusa spp.
Brachyachne spp.
Briza spp.
Chionachne hubbardiana
Cortaderia spp.
Cynosurus spp.
Desmazeria rigida
Dinebra retroflexa
Diplachne spp.
Ehrharta spp.
Eleusine spp.
Gastridium phleoides
Hainardia cylindrica
Hemarthria uncinata
Heteropogon contortus
Holcus spp.
Hyparrhenia hirta
Imperata cylindrica
Ishaemum rugosum
Lagurus ovatus
Lamarckia aurea
Leersia spp.
Leptochloa spp.
Lophochloa cristata
Molineriella minuta
Nassella trichotoma
Parapholis incurva
Perotis rara
Pholiurus pannonicus
Phragmites spp.
Phyllostachys spp.
Piptatherum (= *Oryzopsis*) *miliaceum*
Polypogon spp.
Psilurus incurvus
Rhynchelytrum repens
Rottboellia exaltata
Spartina Townsendii
Sporobolus spp.
Triraphis mollis
Vulpia spp.

ere 1987). Of these, those with a conflict of interest and for which agents that could possibly be developed as bioherbicides are already present in Australia, are *Agrostis tenuis* Sibth., *Avena* spp., *Bromus* spp., *Cenchrus* spp., *Chloris* spp., *Cynodon dactylon* (L.) Pers., *Digitaria* spp., *Echinochloa* spp., *Eragrostis* spp., *Hordeum* spp., *Lolium* spp., *Panicum* spp., *Paspalum* spp., *Pennisetum clandestinum* Chiov., *Phalaris* spp., *Poa annua* L., *Setaria* spp., *Sorghum halepense* (L.) Pers. and *Urochloa panicoides* Beauv. The few remaining grass weeds in Table 4 which involve less conflict of interest and for which

Table 4. Principal grass weeds suitable for bioherbicidal control

Based on those listed as crop weeds in Auld and Medd (1987) and Wilding *et al.* (1986) and on those with most herbicide recommendations (Wapshere 1987)

Agrostis tenuis
Arrhenatherum elatius
Avena spp.
Briza minor
Bromus spp.
Cenchrus spp.
Chloris spp.
Cynodon dactylon
Digitaria spp.
Echinochloa spp.
Eleusine indica
Eragrostis spp.
Holcus lanatus
Hordeum spp.
Lolium spp.
Panicum spp.
Paspalum spp.
Pennisetum clandestinum
Phalaris spp.
Poa annua
Setaria spp.
Sorghum halepense
Urochloa panicoides
Vulpia spp.

it might be possible to consider introducing agents from overseas for subsequent development as bioherbicides, are *Arrhenatherum elatius* (L.) Presl., *Briza* spp., *Eleusine indica* (L.) Gaertn., *Holcus lanatus* L. and *Vulpia* spp. As none of these are native to Australia, additional agents could be found for introduction from their home ranges. However, of these grasses only *E. indica* does not have tribal relations with an important crop or pasture grass.

Any attempt to control a particular grass weed within a cereal crop or amongst other grasses in a pasture sward would require a certain level of specificity. It has been shown that a larger guild of specific agents occurs where a given weed occurs together with a large group of species in the same genus, as at evolutionary centres of genera or subgenera (Wapshere 1974a). Table 5 shows the relation of Australian grass weed genera in terms of their species distribution between Australia and elsewhere. Large groups of specific or near specific agents on Australian grasses would be expected in those genera which occur only in Australia and close regions or have large groups of species in Australia (in A1, A2 and B1, Table 5). Fewer specific or near specific agents would be likely to be present here on grasses in those genera with few or no Australian representatives (in A3, B2, C1 and C2 in Table 5), and nearly specific agents would probably only be found if they had been inadvertently introduced. A few exotic grass weeds, e.g. species of *Avena*, *Hordeum* and *Lolium* have a large group of inadvertently introduced agents on them here (Simmonds 1966, Sampson and Walker 1982, Woodcock and Clarke 1983, Shivas 1989, Cook and Dubé 1989, Queensland Department of Primary Industry, unpubl.) but most of the grasses in the exotic genera listed in C2 have very few fungi recorded on them in Australia.

Table 5. Relation of weedy grass genera in Australia to native and overseas grasses

Based on figures for world and Australian species in each grass genus in Baines (1981).

A) GRASS GENERA IN WHICH WEEDS ARE ALL AUSTRALIAN NATIVES.
  1) GENERA WHICH ARE SOLELY AUSTRALASIAN.
    Danthonia (=Rytidosperma), Echinopogon.
  2) GENERA WITH EXOTIC REPRESENTATIVES BUT WITH LARGE NUMBERS OF SPECIES NATIVE TO AUSTRALIA.
    Aristida, Dichanthium, Iseilema, Paspalidium, Stipa.
  3) GENERA WITH MOST REPRESENTATIVES EXOTIC BUT WITH A FEW AUSTRALIAN SPECIES.
    *Bothriochloa, Brachyachne, Chionachne, Chrysopogon, Diplachne, Eriochloa, Hemarthria, Heteropogon, Imperata, Leptochloa, Perotis, *Phragmites, Themeda, Tragus, Triraphis.*

B) GRASS GENERA IN WHICH ONE OR MORE WEEDS ARE EXOTIC AND OTHERS AUSTRALIAN NATIVES.
  1) GENERA WITH EXOTIC REPRESENTATIVES BUT WITH LARGE NUMBERS OF SPECIES NATIVE TO AUSTRALIA.
    Agrostis, Brachiaria, Chloris, Digitaria, Eragrostis, Panicum, Poa, Sorghum, Sporobolus.
  2) GENERA WITH MOST REPRESENTATIVES EXOTIC BUT WITH A FEW AUSTRALIAN SPECIES.
    Agropyron, Cenchrus, Cynodon, Dactyloctenium, Echinochloa, Festuca, Glyceria, Leersia, Oryza, Paspalum, Pennisetum, Setaria.

C) GRASS GENERA IN WHICH WEEDS ARE EXOTIC TO AUSTRALIA.
  1) GENERA WITH ONE OR VERY FEW AUSTRALIAN SPECIES
    Alopecurus, Arundinaria, Bambusa, Bromus, Hyparrhenia, Ischaemum, Rottboellia.
  2) GENERA EXOTIC TO AUSTRALIA
    *Aira, Ammophila, Andropogon, Anthoxanthum, Arrhenatherum, Arundo, Avena, Axonopus, Briza, Cortaderia, Cynosurus, Dactylis, Desmazeria, Dinebra, Ehrharta, *Eleusine, Gastridium, Hainardia, Holcus, Hordeum, Lagurus, Lamarckia, Lolium, Lophochloa, Melinis, Molineriella, Nassella, Parapholis, Phalaris, Pholiurus, Phyllostachys, Piptatherum, Polypogon,Psilurus, Rhynchelytrum, Spartina, Stenotaphrum, Urochloa, Vulpia.*

* See later discussion for these 2 genera.

Classical Control of Grass Weeds

This method does not have the economic constraints of bioherbicidal control, but it is severely constrained as far as grasses are concerned by the impossibility of introducing any agent that would infest any crop or pasture/lawn grass once released. Thus none of the weeds listed in Table 2 as the same species as crop or pasture/lawn grasses could be controlled in this way, and the others could only be considered if any agents overseas were restricted to the weedy species of that grass genus. The discussion below indicates that species specificity is rare amongst grass organisms compared with generic specificity. The risk posed to the large number of native grass species has also to be considered, particularly those related to the weedy grasses.

As already noted, it has been established that the greatest number of agents specific to a weed or its close relatives occur at its centre of origin and/or where the groups of related species occur (Wapshere 1974a). The classical method depends on finding suitable agents for the weed concerned elsewhere in the world. Thus weeds of exotic origin and those native to Australia but with greater species representation in the same genera elsewhere (in A3, B2, C1 and C2, Table 5) should initially be considered. Weeds of genera limited to Australia or belonging to genera of wider distribution but with large species groups here (in A1, A2 and B1, Table 5) are less likely to have suitably specific agents available outside Australia. Except for *Sporobolus* spp. all genera in Table 3 belong to groups A3, B2 and C in Table 5, indicating that suitable agents could be found to control many of them in their regions of origin and perhaps elsewhere overseas for the more widespread grasses.

As specificity or near specificity is of prime importance for any agent introduced to control a grass weed, the distribution of recorded

Table 6 Recorded host range of various types of organisms
(a) Attacking Australian grass weeds of European origin in Europe

	Type of Organism	Recorded on:	No and % of Species in Each Host Range Level: One Species Only	One Genus Only*	2 - 3 Genera	4+ Genera	Total Species of Type	Reference
INSECTS	NOCTUIDAE	No	10	10	14	90	114	Forster &
	(Cutworms)	%	8.8	8.8	12.3	78.9		Wohlfahrt (1971)
	MICROLEPIDOPTERA	No	7	16	28	12	56	Schutze (1931)
	(Small Moths)	%	12.5	28.6	50.0	21.4		
	DIPTERA,	No	15	15	13	22	50	Seguy (1934)
	BRACHYCERA (Flies)	%	30.0	30.0	26.0	44.0		
	CECIDOMYIIDAE	No	17	39	7	5	51	Barnes (1946)
	(Gall-midges)	%	33.3	76.5	13.7	9.8		
	APHIDAE	No	N/A	15	10	20	45	Borner (1952)
	(Non-host-alternating Aphids)	%		33.3	22.2	44.5		
FUNGI	USTILAGINALES	No	16	37	16	6	59	Zundel (1953)
	(Smuts)	%	27.1	62.7	27.1	10.2		
	UREDINALES	No	4	7	7	10	24	Cummins (1971)
	(Rusts asexual phase only)	%	16.7	29.1	29.1	41.7		
HABIT TYPES	LEAF-MINERS	No	10	38	28	55	121	Hering (1957)
	(Insects)	%	8.3	31.4	23.1	45.5		
	GALL-MAKERS	No	29	42	9	16	67	Buhr (1964, 1965)
	(Arthropods, Nematodes & Fungi)	%	43.0	62.6	13.5	24.9		

b) Attacking grasses world wide

	Type of Organism	Recorded on:	One Species Only	One Genus Only*	2 - 3 Genera	4+ Genera	Total Species of Type	Reference
FUNGI	ASCOMYCETES							
	PHYLLACHORA spp.	No	N/A	85	25	13	123	Parberry (1966,1971)
	DEUTEROMYCETES	%		69.1	20.3	10.6		
	CERCOSPORA spp.	No	N/A	22	4	3	29	Chupp (1953)
		%		75.9	13.8	10.3		
	STAGONOSPORA spp.	No	N/A	54	11	9	74	Castellani
		%		73.0	14.9	12.1		& Germano (1975)

* Note that figure for one species only is included in figure for one genus only so that total species of given type of organism is sum of last 3 columns.

host range of organisms on a group of grasses requires examination.

The only group of grasses for which adequate data are readily available are those from Europe. A group of Australian grass weeds were selected because of their occurrence in Europe (Tutin *et al.* 1980). For all organisms listed in Table 6 European or world wide host lists were used.

Cummin's (1971) world list of rust fungi on grasses was used rather than Gaumann's (1959) European list of rust hosts because the latter has narrower specific distinctions between rust species. Cummin's (1971) list therefore gives a conservative result for the host range of grass rusts.

As well as considering grass organisms in taxonomic groupings it is also possible to use the European data to investigate their specificity when in a particular habit. Leaf miners (Hering 1957) and gall makers (Buhr 1964-65) were used for this part of the analysis.

The distribution of recorded host ranges (Table 6a) of the principal organisms attacking grasses in Europe vary, for the insects, from only 9% of noctuids limited to both one species and one genus of grass, to as high as 33% and 77% of cecidomyiids limited to one species and one genus respectively. Of the fungi the smuts which have 27% and 63% of their species limited to one species and one genus respectively are the most specific to their grass hosts.

Some other fungal genera appear to have restricted host ranges. Based on world lists, about 69% of graminicolous species in the ascomycetous genus *Phyllachora* are only recorded from one grass genus (Table 6b) and the deuteromycetous genera *Cercospora* (Hyphomycetes) and *Stagonospora* (Coelomycetes), have more than 70% of their members recorded only from a single grass genus. However, the host restrictions have not been confirmed by cross-inoculation and the taxonomy of *Cercospora* and *Stagonospora* are in a state of flux at the moment (Walker, New South Wales Department of Agriculture, pers. comm.). Despite this, the data for these fungi are comparable with those for the arthropods and habit types (Table 6).

In the case of habit types, 31% of leaf-miners from all insect groups are restricted to one grass genus. However, gall-makers are far more specific, 43% of gall-makers of all types (arthropods, nematodes and fungi), being restricted to one grass species and 63% to one grass genus (Table 6). Thus, of those organisms considered, except for the noctuids, there are several types with different habits which have sufficient specificity to serve as classical biological control agents, particularly if the grass weed belongs to a genus distinct from those of crop and pasture/lawn grasses.

In Europe, the organisms which are particularly restricted in recorded host range to one grass species or genus are:- amongst the insects; elachistid moths (Lepidoptera); chloropid flies (Diptera, Brachycera); cecidomyiid gall midges; and chalcid gall wasps in the genus *Tetramesa* (= *Harmolita*): amongst the fungi; the smuts (Ustilaginales). Furthermore, in the USA each *Tetramesa* species tested has been shown to be restricted to a single grass genus (Phillips 1920).

The rust fungi (Uredinales) on grasses are not particularly specific according to Cummin's (1971) data but would be considered to be so if Gaumann's (1959) specific distinctions had been followed. However, nearly all grass rusts have alternate hosts in the other plant families. Although persistence in Australia may not be a problem, as many exotic rusts of grasses which have found their way here can persist without their alternate hosts being present (McAlpine 1906), introduction could only occur if possible alternate hosts of agricultural or conservational importance were not infested. The same problem of infesting alternate hosts amongst the dicotyledons applies also to many grass aphids, 37% of European grass aphids having alternate hosts (Borner 1952). For this reason, only the host range of non-alternating grass aphids is given in Table 6a and these aphids are specific at the genus rather than species level.

Some species of chloropid flies, cecidomyiid gall midges, chalcid wasps and aphids infesting cereals are all major pests of these crop grasses (Balachowsky and Mesnil 1935). Similarly, some of the rust fungi, smuts, *Septoria, Cercospora, Drechslera* and *Bipolaris* (both previously *Helminthosporium*) spp. (Fischer and Holton 1957, Sprague 1950) cause major diseases of their cereal hosts. Species from these groups of insects and fungi could have the same damaging effect on grass weeds to which they were specific or near specific. Indeed the rusts and smuts of cereals have caused major disease outbreaks when they have inadvertently been introduced into Australia (McAlpine 1906, 1910).

All genera of grass weeds are not infested equally by organisms restricted to one species or genus. *Avena* spp. and *Hordeum* spp. have only a few restricted organisms infesting them whereas *Phragmites australis* (Cav.) Steud. has many specific or near specific organisms infesting it (see below). The host range distribution of organisms on the group of European grasses can be considered representative of the situation likely to exist for grass weeds from other parts of the world but for which there are no adequate data on host range distributions.

It is accepted by workers in classical biological control that plants related to the weed are more at risk from biological agents infesting that weed than unrelated plants. Thus, close taxonomic relation is a major criterion for selecting plants to demonstrate the safety of agents for introduction (Wapshere 1974b). Table 3 lists the weeds that are generically separate from important crop and pasture/lawn grasses. However to be on the conservative side it would be appropriate to consider, initially, only those genera of grass weeds which are well separated from the grass genera of agricultural importance in Australia. The genera which are little differentiated from their respective agriculturally important relatives (Clayton and Renvoize 1986) are as follows: *Ammophila, Gastridium* and *Polypogon* from *Agrostis*; *Arrhenatherum* from *Avena*; *Brachyachne* from *Cynodon*; *Briza* from *Poa*; *Imperata* from *Saccharum*; *Leerzia* from *Oryza*; *Nassella* and *Piptatherum* (= *Oryzopsis*) from *Stipa*; and *Vulpia* from *Festuca*. There still remains a large number of grass species that could be considered for classical biological control (Table 3).

However, there is no certainty that the agents specific at the generic level would be the ones able to control a given weed. If it was necessary to consider agents with a host range extending to tribal level this would delete from consideration the weeds in the Panicoid family and the weeds in the Pooid tribes, Poeae, Aveneae and Triticeae (Table 1). This would seriously reduce the number of grass weeds that could be considered for classical biological control to species of *Arundinaria, Bambusa, Dactyloctenium, Dinebra, Diplachne, Ehrharta, Eleusine, Hainardia, Leptochloa, Parapholis, Pholiurus, Phyllostachys* and *Triraphis*. Consideration could also be given to species of *Arundo*, *Cortaderia* and *Phragmites*, which are related only to a few native grass genera including *Danthonia*. Species of *Hainardia, Parapholis* and *Pholiurus* could also not be considered if Macfarlane and Watson's (1982) and Macfarlane's (1987) classifications were used.

Comments on Particular Grass Weeds

The grass weeds selected for comment are important in Australia and illustrate the problems of biological control of these weeds.

Avena spp.

Wild oats, *Avena fatua* L., and other *Avena* spp. are major annual weeds of cereal cropping and other cultivations in Australia (Wilding *et al.* 1986, Auld and Medd 1987). *A. fatua* is probably of Central Asian origin and the other weedy *Avena* spp. are of Mediterranean, Middle Eastern and European origin (Holm *et al.* 1977). *A. fatua* and the other *Avena* spp. are all closely related to each other and to the crop grass, cultivated oats, *Avena sativa*, and hybridization occurs between them. There are no *Avena* spp. native to Australia. Studies on the possibilities of the biological control of *Avena* spp. have been carried out in Europe, within the weeds native range, and in Canada where they are also unwelcome introductions, as well as in Australia. Thurston and Cussans (1976) surveyed the organisms infesting *Avena* spp. in Europe and concluded that only seed infesting fungi were worth further study. Kiewnick (1963, 1964) had previously studied the fungi infesting seeds of *A. fatua* in Germany and of the six most damaging species only one *Phoma hibernica* Grimes *et al.* was considered suitable for further study by Thurston and Cussans (1976). The other five damaging fungi were all known pathogens of cultivated cereals. *P. hibernica* is now included in *Phoma herbarum* Westend, a saprophytic fungus with a broad host range (Boerema 1964) which occurs in Australia (Woodcock and Clarke 1983). In England, the seed-borne fungus *Pyrenophora avenae* Ito and Kuribay has been investigated as a potential control agent (Wilson and Hall 1987). This fungus infests both *Avena sterilis* L. and *A. sativa* but could not maintain itself on wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare*), producing only hypersensitive necrotic spots on these two cereals. Thus it could be used to control weedy *Avena* spp. in wheat or barley crops (Wilson and Hall 1987). *P. avenae* has been recorded in Australia in its conidial stage *Drechslera avenae* (Eidam) Scherif (= *Helminthosporium avenae*) (Simmonds 1966).

In Canada, both *Helminthosporium* spp. (Watson and Harris 1975) and *Colletotrichum graminicola* (Ces.) Wilson (Mortensen 1983) have been recommended for detailed study as agents to control *Avena* spp. More recently, Mortensen and Hsaio (1987) studied the fungi infesting seeds of *Avena* spp. there and found, of the five commonest, only *Drechslera avenacea* (Curtis ex Cooke) Shoem. was restricted to *Avena* spp., the others were equally or more pathogenic to wheat, barley and rye (Mortensen and Hsaio 1987). This fungus occurs in Australia (Woodcock and Clarke 1983).

In Australia, a simulation model of the population dynamics of *Avena* spp. suggests that controlling seed production or survival would be the most efficient way of controlling these annual grass weeds (Medd and Ridings 1989). Strains of an aerially transmitted fungus disease which has a broad host range amongst pasture grasses and cereals are being investigated as regards pathogenicity and specificity to weedy *Avena* spp. The eventual aim is to develop suitable strains as mycoherbicides (Medd and Ridings 1989).

A number of fungi have been recorded on the weedy species of *Avena* in Australia and a much larger number have been recorded on the crop *A. sativa* (Simmonds 1966, Sampson and Walker 1982, Woodcock and Clarke 1983, Walkden Brown 1987, Shivas 1989, Cook and Dubé 1989, Walker NSW Department of Agriculture pers comm.).

Hordeum spp.

The barley grasses are serious pasture weeds causing stock damage because of their sharp awns and some are weeds of winter-grown crops (Auld and Medd 1987, Wilding *et al.* 1986). However, two species, *Hordeum leporinum* Link and *H. marinum* Huds. are self-seeding pasture grasses producing useful forage before heading (Reid 1981). They are closely related to cultivated barley *Hordeum vulgare* L. and are tribally related to both wheat, *Triticum* spp., and rye, *Secale cereale* (Table 1). The weedy species of *Hordeum* in Australia are natives of Eurasia.

Hordeum spp. have not been considered for biological control in other parts of the world and there are no biological control studies of agents in their home ranges but they have been recommended as one of the annual grass weeds for mycoherbicidal control in Australia (Medd and Ridings 1989). In Australia, there is a large number of fungi recorded on the crop barley, some of which have also been recorded on the weedy barley grasses (Simmonds 1966, Sampson and Walker 1982, Woodcock and Clarke 1983, Sparrow and Doolette 1987, Shivas 1989, Cook and Dubé 1989, Qld DPI unpubl.). Many of them also infest wheat and rye as well as barley (loc. cit. and Lovett 1987).

Stipa spp.

Most spear grasses are natives to Australia and are important elements of native pastures (Burbidge 1984). However, the seeds with their spiral awns contaminate wool and penetrate the skins, mouths and eyes of sheep (Auld and Medd 1987). Although species occur in Eurasia and the Americas, the Australian species form a distinct, probably basal, group of the genus and of the tribe Stipeae (Barkworth and Everett 1986). It can be expected that organisms adapted to the Australian spear grasses would already occur in Australia and that there would be little point in searching other parts of the world for suitable agents.

Approximately 17 fungi are recorded on *Stipa* spp. in Australia, including 6 smuts (McAlpine 1910, Simmonds 1966, Sampson and Walker 1982, Woodcock and Clarke 1983, Cook and Dubé 1989). Although little is known about the insects which infest them, it can be assumed that many of the native insects in Australia that have switched to exotic crop and pasture grasses (Whittet 1969, Hassan 1977, Lazenby and Matheson 1987) are derived from the fauna on native grasses. Since the agents adapted to the native spear grasses are already in Australia and some of these grasses are important in native pastures, the spear grass problem could only be tackled by inundative or bioherbicidal methods. However, little is known about the organisms infesting them and more detailed studies of the fungal flora and nematode fauna of spear grasses in Australia would be required to determine whether a sufficient pool of suitable agents on these grasses is available for development as bioherbicides.

Bromus spp.

Brome grasses are major pasture weeds in temperate Australia and can be important in crops (Wilding *et al.* 1986, Auld and Medd 1987). Despite a close relation to members of the tribe Triticeae, the large genus *Bromus* and two other small grass genera are placed in the separate tribe Bromeae (Clayton and Renvoize 1986, Watson and Dallwitz 1985) and this separation is reinforced by the latest classification of the Pooideae (Macfarlane 1987).

There is one native species of the genus, *Bromus arenarius* Labill. (Burbidge 1984) and there are no other native genera in the tribe Bromeae (Watson and Dallwitz 1985). *Bromus catharticus* Vahl. (= *B. unioloides* Kunth), prairie grass, regarded as a useful pasture grass, is a native of South America. However, the major weedy species originate in Europe, the Mediterranean region and Middle East. One of these *Bromus mollis* L. is also of some value as a pasture grass (Reid 1981).

The only weedy brome that has received attention as far as biological control is concerned is *Bromus tectorum* L., a native of Europe, which is now an important weed of western USA. This work has not, however, progressed beyond a list of fungi and nematodes occurring on the weed in North America (Peeper 1984).

A survey of the arthropods and fungi of *Bromus* spp. in Europe indicates a few organisms sufficiently specific to them to be considered as biological control agents in Australia (Table 7). At first, the most interesting insects would be the lepidopterous leaf miners *Elachista* spp. and the gall-forming insects, the aphid *Diuraphis* (*Holcaphis*) *bromicola* (H.R.L.) and the encyrtid wasps *Tetramesa* (= *Harmolita*) spp. However, the records come mainly from northern Europe and most Australian weedy bromes are of Mediterranean origin. Very little is known concerning the insects and fungi of bromes in

Table 7 (a) Arthropods specific or near specific to *Bromus* spp. in Europe

Order/Family	Species	Comments/habitat	References
Lepidoptera			
Pyralidae	*Agriphila latistria* (Haw.)		L'Homme (1923-49)
Elachistidae	*Elachista lastrella* Chret.	Leaf miner	Emmett (1979)
	E. bromella Chret.	Leaf miner	Hering (1957)
Diptera			
Cecidomyiidae	*Contarinia* sp.	Flowers	Barnes (1946)
	Mayetiola sp.	Stem-gall	Buhr (1964)
Agromyzidae	*Agromyza bromi* Spencer	Leaf-miner	Spencer (1972)
Hemiptera		Also on	
Miridae	*Amblytylus albidus* (Hahn)	*Corynophorus canescens*	Wagner & Weber (1964)
	Acetropis gimmerthali (Flor.)		Stichel (1955-1962)
Aphidae	*Diuraphis* (*Holcaphis*) *bromicola* (H.R.L.)	Shoot-gall	Borner (1952) Buhr (1964)
Cicadellidae	*Mogangina bromi* EM.		Bey-Bienko (1967)
Coccidae	*Lecanopsis taurica* Borchs		Bey-Bienko (1967)
Hymenoptera			
Eurytomidae	*Tetramesa* (= *Harmolita*) *maculata* (Howard)	Stem-gall	Claridge (1961)
	Tetramesa (= *Harmolita*) sp.	Stem-gall	Buhr (1964)

Table 7(b) Fungi specific or near specific to *Bromus* spp. in Europe

Order/Family	Species	Comments/habitat	References
Basidiomycetes			
Ustilaginales	*Ustilago bromivora* (Tulasne) Fisch	Possibly part of *U. bullata* Berk.	Zundel (1953)
	Tilletia bromina Maire	Flower head smuts	
	T. guyotiana Hariot		
Ascomycetae	*Pyrenophora bromi* (Died) Drechsler		Oudemans (1919)
Deuteromycetae	*Drechslera* (=*Helminthosporium*) *bromi* (Died) Shoem.	Leaves. Teleomorph *Pyrenophora bromi*	Oudemans (1919)
	Septoria bromi Sacc.	Leaf spot	Sprague (1950)
	Stagonospora bromi A.L. Smith & Ramsb.	Leaf blotch	
	Pseudoseptoria (= *Selenophoma*) *bromigena* Sprague & Johnson	Leaf spot	

that region of Europe. None of the insect species listed in Table 7a is known to occur in Australia. However, of the specific fungi listed in Table 7b on *Bromus* spp. in Europe, *Ustilago bromivora* (Tul.) Walsh. (as *U. bullata* Berk.), *Septoria bromi* Sacc. and *Drechslera bromi* (Died.) Shoem. are all recorded in Australia. Forms of the rust *Puccinia recondita* Rob. ex Desm. infesting *Bromus* spp. also occur here. Only two of the *Bromus* specific fungi of certain identity, *Stagonospora bromi* Smith and Ramsb. and *Pseudoseptoria bromigena* B. Sutton are not already found in Australia (Sampson and Walker 1982, Woodcock and Clarke 1983, Shivas 1989, Cook and Dubé 1989, Walker, NSW Dept of Agriculture, pers. comm.).

Holcus spp.

The two fog grasses *H. lanatus* L. and *H. mollis* L., are pasture weeds in cool higher rainfall regions of New South Wales and Victoria (Auld and Medd 1987). *Holcus lanatus* has been selected as a pasture grass but the improved varieties are not used in Australia (Reid 1981, Wheeler *et al.* 1982). Both species are of European origin and there are no native Australian species of the genus. The genus is however related to 12 native grass genera (Watson and Dallwitz 1985).

There have been no reported studies of the biological control of *Holcus* species. The placing of the genus *Holcus* in the sub-tribe Aveninae (Clayton and Renvoize 1986) indicates a sub-tribal relation with oats, *Avena sativa* (Table 1). However, a search of the literature in Europe reveals a range of organisms that have only been recorded from *Holcus* spp. (Table 8).

Of these, the gall making insects, the cecidomyiids, the encyrtid wasp *Tetramesa* sp. and the aphid *Diuraphis* (*Holcaphis*) *holci* (H.R.L.) are the most likely to be sufficiently specific. Preliminary studies on *D. holci* indicate that this aphid is dependent on stimulating gall-like stunting of the grass host to build up populations and this only occurs on *Holcus* spp. (Packham 1982). None of the insects listed in Table 8a appear to occur in Australia.

Although a few fungi are recorded on *Holcus* spp. here, none of the apparently specific ones listed in Table 8b occur in Australia (Sampson and Walker 1982, Woodcock and Clarke 1983, Cook and Dubé 1989). However, of the two smuts *Entyloma holci* (Liro) Fisch. is now regarded as a synonym of *E. dactylidis* (Pass.) Ciferri, which does occur in Australia. *Tilletia holci* (Westerdorp) De Toni is not certainly a synonym of another grass smut. Thus all insects and one of the smut fungi listed could be considered as potential classical agents.

Table 8(a) Arthropods specific or near specific to *Holcus* spp. in Europe

Order/Family	Species	Comments/Habitat	References
Lepidoptera			
Psychidae	*Reisseronia tarnierella* (Bruand)		Traugott-Olsen & Schmidt-Nielsen (1977) L'Homme (1923-49)
Elachistidae	*Elachista rufocinerea* (Haw.) *E. pulchella* (Haw.)	Also *Arrhenatherum elatius?* Leaf miners	Emmet (1979) Hering (1957)
Diptera			
Cecidomyiidae	*Mayetiola holci* Kieff.	Stem-gall	Barnes (1946)
	Contarinia sp.	Flower	Buhr (1964)
	Dasyneura sp.	Flower	
	Sitodiplosis sp.	Flower	
	Lestodiplosis sp.	Flower	
Agromyzidae	*Cerodontha flavocingulata* (Strobl.)	Leaf miner	Hering (1957)
	Metopomyza flavonotata (Hal.)	Leaf miner	
Opomyzidae	*Geomyza balachowskyi* Mesnil	Stem miner	Balachowsky & Mesnil (1935)
Hemiptera			
Aphidae	*Diuraphis (Holcaphis) holci* (H.R.L.)	Shoot-gall	Borner (1952)
	Schizaphis holci (H.R.L.)		Buhr (1964)
Delphacidae	*Muellerianella fairmairei* (Perris)		Ossianilsson (1978)
Hymenoptera			
Eurytomidae	*Tetramesa* (= *Harmolita*)sp.	Stem-gall	Buhr (1964)

Table 8(b) Fungi specific or near specific to *Holcus* spp. in Europe

Order/Family	Species	Comments/Habitat	References
Basidiomycetes			
Ustilaginales	*Entyloma holci* (Liro) Fisch.	Leaf smut	Zundel (1953)
	Tilletia holci (Westerdorp) De Toni	Flower head smut	
Deuteromycetae	*Septoria tritici* f. sp. *holci* Sprague	Leaves, f. sp. *holci* specific to *Holcus*	Sprague (1950)

Sorghum halepense (L.) Pers.

Johnson grass is a major weed of crops and roadsides in all mainland States of Australia and is also poisonous to stock. It is particularly important as a weed in subtropical cropping regions of the country (Auld and Medd 1987, Burbidge 1984, Kleinschmidt and Johnson 1977, Tothill and Hacker 1983).

The plant is a native of Mediterranean regions of Eurasia. The related *S. verticilliflorum* (Steud.) Stapf., an African species, is a widespread weed in tropical Australia (Kleinschmidt and Johnson 1977, Tothill and Hacker 1983). Both are closely related to grain sorghum, *Sorghum bicolor* with which *S. halepense* hybridizes to form Columbus grass *Sorghum* x *almum* Parodi and also to the pasture sorghums, *Sorghum sudanese* (Piper) Stapf. and hybrids (Auld and Medd 1987, Burbidge 1984). At the tribal level, both are related to sugar cane *Saccharum officinarum* being included in the group of "awned" Andropogoneae (Table 1).

Programs to find and develop bioherbicides against *S. halepense* are underway in several States of the USA. In North Carolina the fungus *Bipolaris sorghicola* (Lefebvre and Sherwin) Alcorn (= *Helminthosporium sorghicola*) causes lesions on the leaves of *S. halepense*. After confirming efficacy in the greenhouse, field testing with mass produced spores was undertaken. Results varied from 73% kill of seedlings of the grass to as low as 1% between 2 years in North Carolina and 44% and zero kill with heavy leaf damage in Mississippi (Van Dyke and Winder 1985, Winder 1989). *B. sorghicola* occurs on the crop *S. bicolor* in Australia (Alcorn and Mayers 1975).

Phytotoxins have been isolated from the leaf spot fungi of *S. halepense, Drechslera sorghicola* (Lefebvre and Sherwin) (= *B. sor-*

ghicola) and *Bipolaris* sp. (Sugawara *et al.* 1987, Pena-Rodriguez *et al.* 1988) as a prelude to their consideration as natural herbicides. Except for maize which was affected, these toxins have yet to be tested against a series of crop grasses.

The smut *Spacelotheca holci* Jack. which is considered by some to be a form of *Spacelotheca cruenta* (Kuhn.) Potter did not infest cultivars of *S. bicolor* or *S. sudanense* but readily infested *S. halepense*. Despite its specific name it does not infest *Holcus* spp.. The smut is systemic and plants remain infected from year to year and as the growth of *S. halepense* is adversely affected it loses its competitive advantage in crops. Smut infested plants do not set seed. Smut spores from California and Louisiana readily infested plants under glasshouse and field conditions (Milhollon 1985, Massien and Lindow 1986). *S. holci* does not appear to occur in Australia (Simmonds 1966, Shivas 1989, Qld DPI unpubl.) and if its specificity is confirmed it could be considered for introduction here to control *S. halepense*.

As well as studying a form of *S. cruenta*, which has the same specificity and host damaging effects as *S. holci*, from *S. halepense* in Louisiana, El-Wakil *et al.* (1985), also collected and demonstrated the pathogenicity of a *Colletotrichum* and a *Phyllosticta* species of fungi from the same grass weed. Strains of the anthracnose fungus *Colletotrichum graminicola* (Ces.) Wilson and the zonate leaf spot *Gloeocercospora sorghi* Bain and Edg. have been isolated from *S. halepense* in Arkansas and tested for virulence on the weed and against other *Sorghum* spp. for specificity. *G. sorghi* was more virulent but slightly less specific than the selected strain of *C. graminicola* which did not attack all cultivars of the crops, *S. bicolor*. A mathematical model of the biomass loss caused by these two fungi when infesting *S. halepense* can be used to forecast the effect of inundative inoculation of these 2 fungi onto weed infestations (Mitchell 1989). *C. graminicola* occurs in Australia on *S. halepense* and other *Sorghum* spp. and *G. sorghi* occurs on the crop *S. bicolor* (Simmonds 1966, Shivas 1989).

In Hungary, a strain of the bacterium *Pseudomonas syringae* van Hall causes leaf spot disease of *S. halepense.* Despite the broad host plant spectrum of this bacterium, this strain was considered to be specific to the grass weed although only maize was tested and remained uninfested by it (Mikulas and Sule 1979). *P. syringae* is recorded from other *Sorghum* spp. in Australia (Simmonds 1966, Shivas 1989).

S. halepense has been surveyed for potential arthropod agents in Israel and Pakistan. Unlike annual grain sorghum, *S. bicolor* and other *Sorghum* species occurring in Israel, *S. halepense* is a rhizomatous perennial. For this reason biological studies in Israel, within the original home range of *S. halepense,* have been concentrated on the crambid moth, *Metacrambus caractellus* Zell. whose larvae feed on and damage the rhizome of the plant (Gerling and Kugler 1973). However, there was no examination of the specificity of this moth.

In Pakistan, an elachistid *Cosmiotes* sp. nr. *illectella* was found mining the leaves and four borers were found in the stems of *S. halepense*, but only two of these, the chloropid flies *Scoliopthalmus micans* Lamb and *Polyodaspis* sp., were not known as crop pests. Preliminary examination of the specificity of first instar larvae of *C.* sp. nr. *illectella* showed they would not feed on wheat, *T. aestivum* and sugar cane, *S. officinarum* but developed to adults on *S. halepense*. Larvae of the phycitine moth, *Patna rhizolineata* Bradley were found boring in the rhizome and its specificity to *S. halepense* also received a preliminary examination. Larvae of the moth did not survive on maize, *Zea mays*, grain sorghum *S. bicolor* or oats *A. sativa*. However, survival on *S. halepense* itself was only 10% (Baloch *et al.* 1978, Khan *et al.* 1978, 1980, 1981). As *S. halepense* is not native to Pakistan, the low survival of larvae on this grass weed suggests that it is not its normal host but that the moth normally maintains itself on a native Pakistan grass. A rhizome-infesting insect specific to *Sorghum* spp. would not pose a threat in Australia to the annual grain and fodder sorghums *S. bicolor* and *S. sudanese.* However, some of the native *Sorghum* spp. are perennial, forming tussocks (Tothill and Hacker 1983, Burbidge 1968, Lazarides 1970).

Echinochloa spp.

Of the barnyard grasses, *Echinochloa crus-galli* (L.) Beauv. is a major weed of rice and other irrigated crops in Australia and is a native of Europe and India. *Echinochloa colonum* (L.) Link is also a crop weed particularly in subtropical and tropical Australia. It is of Asian origin. Five other introduced *Echinochloa* spp. are regarded as occasional weeds as are a few of the several native *Echinochloa* spp. These weeds are closely related to the fodder crops *Echinochloa frumentacea* Link (Siberian millet) and *E. utilis* Ohwi and Yabuno (Japanese millet), both of which are grown in Australia as fodder crops and some of the native species of the genus have agronomic value (Burbidge 1984, Tothill and Hacker 1983). *Echinochloa* spp. are tribally related to the important pasture genera *Digitaria, Panicum, Paspalum, Pennisetum, Setaria* but the genus is only distantly related to rice, *Oryza sativa* (Table 1), the crop within which they are such important weeds.

In Europe, *Cochliobolus lunatus* (imperfect stage *Curvularia lunata* (Wakker) Boedijn which causes shoot and leaf necrosis of *E. crus-galli* was found to be only weakly pathogenic. However, treating the weed using a suspension of spores of the fungus together with the herbicide atrazine synergistically increased the frequency and level of necrosis. The strain of *C. lunatus* from *E. crus-galli* did not cause necrosis symptoms on the dicotyledonous crops tomato and bean, *Lycopersicon esculentum* Miller and *Phaseolus vulgaris*, L. and only produced minor necrosis on older leaves of the grass crops, barley, maize, rye and wheat even when combined with atrazine in the case of maize (Scheepens 1987).

C. lunatus as its imperfect stage *Curvularia lunata* occurs on *Echinochloa* spp. in Australia but it also occurs here on a large number of other grasses including the crop grasses, rice, *O. sativa,* grain sorghum, *S. bicolor,* wheat, *T. aestivum* and maize, *Z. mays* (Qld. DPI unpubl.).

Eleusine indica (L.) Gaertn.

Crowsfoot grass is a weed of crops and pastures in tropical and subtropical Australia and is also a stock poisoner (Auld and Medd 1987, Burbidge 1984, Kleinschmidt and Johnson 1977, Tothill and Hacker 1983). It is probably of Asian origin (Holm *et al.* 1977). A closely related species *Eleusine tristachya*, (Lam.) Lam., a minor weed in Australia, is probably also a naturalized exotic (Auld and Medd 1987, Burbidge 1984). If this is so, there is no *Eleusine* species native to Australia. *E. indica* is closely related to finger millet *Eleusine coracana* (L.) Gaertn., a staple food in Africa and India (Purseglove 1972), but this crop is not grown in Australia. *E. indica* is only distantly related to the principal crop and pasture grasses here being placed in the subfamily Chloridoideae (Table 1). However, it is tribally related to the native pasture grasses *Eragrostis* spp. (love grasses) and *Dactyloctenium radulans* (R. Br.) Beauv. (button grass) and to 5 other native grass genera. It is also related to pasture and native *Chloris* spp. and lawn *Cynodon* spp. and several other native grass genera in Watson and Dallwitz's (1985) broader classification of the subfamily.

Despite the importance of *E. indica* as a weed in the tropics (Holm *et al.* 1977) attempts at biological control are very recent. Figliola *et al.* (1988) investigated two fungi *Bipolaris setariae* (Saw.) Shoem. and *Pyricularia grisea* (Cke.) Sacc. as possible bioherbicides in South Carolina. Both fungi have broad host ranges in the Poaceae and *P. grisea* occurs in Australia on *E. indica* (Qld DPI unpubl.). The only knowledge of other possible agents are those recorded on the weed as an alternate host for grass crop diseases and as pests or diseases of *E. coracana* (Ramakrishnan 1963, Holm *et al.* 1977, Purseglove 1972). All have broad host ranges amongst the Poaceae and several of the disease fungi are present on the weed in Australia (Qld DPI, unpubl.). *Melanopsichium eleusinis* (Kulk.) Mundk. and Thirum. (= *Ustilago eleusinis* Kulk.) is a smut fungus which is only recorded from *Eleusine* and *Dactyloctenium* spp. (Zundel 1953). This smut is not recorded from *E. indica* in Australia (Simmonds 1966, Qld DPI unpubl.) despite comment to the contrary by Ramakrishnan (1963). However, it has tentatively been recorded on the native grass *D. radulans* in Queensland (Simmonds 1966).

Cynodon dactylon (L.) Pers

Couch grass is a major weed in gardens, vineyards and cultivations and an occasional stock poisoner (Auld and Medd 1987). However, it is also a major lawn grass in Australia (Burbidge 1984). Amongst the crop and pasture grasses, it is tribally related only to *Chloris* (Table 1).

In Florida, where *C. dactylon* is regarded as a major weed of lawns, the eriophyid gall mite *Aceria cynodoniensis* Sayed has been suggested as an agent because it causes stunting of the grass (Cromroy 1983). This mite occurs in Australia (Gibson 1967). Although *C. dactylon* is regarded by many authors as native to Australia, as is the eriophyid mite (Jeppson *et al.* 1975), the mite was first described from Egypt (Sayed 1946). Other highly specific gall makers on *C. dactylon*, the cecidomyiid, *Orseolia cynodontis* Kffr. and Massal. and the lonchaeid, *Dasiops latifrons* (Mg.) (= *Lonchaea lasiopthalmus* Macqu.) are recorded only from Europe and Africa (Houard 1908, 1922, Buhr 1964). Neither of these highly specific gall-making flies occur in Australia (Colless, Australian National Insect Collection pers. comm.). This taken together with the occurrence of several species of the grass genus including *C. dactylon* in Africa would support the contention that *C. dactylon* is of African origin (Holm *et al.* 1977, Tothill and Hacker 1983), perhaps introduced to Australia before European settlement (Burbidge 1984).

The smut *Ustilago cynodontis* (Pass.) Hern. which is specific to *Cynodon* spp. (Zundel 1953) already occurs in Australia (Simmonds 1966, Woodcock and Clarke 1983, Shivas 1989, Cook and Dubé 1989) but the African *Ustilago hitchkockiana* Zundel similarly restricted in host range (Zundel 1953) does not occur here. *Puccinia cynodontis*, Lacroix ex Desm., a rust restricted to *Cynodon* spp. as regards its grass host, is also found here (loc. cit.). It has *Plantago* spp. as its aecidial hosts (Cummins 1971). There is a small group of other fungi occurring on the grass in Australia (loc. cit.), one *Phyllachora cynodontis* (Sacc.) Niessl. is apparently restricted to *Cynodon* spp. (Parberry 1967). From another, *Bipolaris cynodontis* (Marign.) Shoem., a selective phytotoxin has been isolated in the USA (Sugawara *et al.* 1985).

Nassella trichotoma (Nees) Arech.

Serrated tussock, a native of South America, is a weed of pastures in the tablelands of south-eastern Australia and it has been the subject of studies on the economic impact of a weed and of its control (Campbell 1982, Auld and Coote 1981, Auld *et al.* 1982, Vere and Campbell 1978a,b, 1979, Vere *et al.* 1981).

The genus *Nassella* is closely related to the genus *Stipa* (Clayton and Renvoize 1986), numerous native Australian species of which are important components of unimproved pastures (Burbidge 1984). The rusts *Puccinia* and *Uromyces* spp. and the smut *Tilletia hypsophila* Speg. infests grasses of both genera in their South American home range (Cummins 1971, Zundel 1953). There is no record of any rust or smut on *N. trichotoma* itself, nor is there any readily available knowledge concerning the arthropods infesting *N. trichotoma* in its home range. No fungi or arthropods are recorded from serrated tussock in Australia.

Phragmites australis (Cav.) Steud.

Common reed is a widespread major weed of irrigation channels, drainage ditches and poorly drained land and may occasionally be a weed in sugar cane crops in Australia (Mitchell 1978, Sainty and Jacob 1981, Holm *et al.* 1977, Auld and Medd 1987). The related tropical reed, *Phragmites karka* (Retz.) Steud. occurs in similar situations and is a weed only in tropical Australia (Mitchell 1978, Burbidge 1984, Auld and Medd 1987, Kleinschmidt and Johnson 1977).

P. australis is probably now the most widely distributed of all monocotyledonous plants. It is considered by some to be native to the Old World tropics (Holm *et al.* 1977) but most Australian botanists regard it as native to Australia as well (Burbidge 1984). The genus *Phragmites* is not tribally related to any native grass genera (Watson and Dallwitz 1985).

A survey of literature in Europe for the specific or near specific arthropods and fungi occurring on the weed in that part of its native range revealed a very large number of them (Wapshere unpubl.).

Approximately 80 arthropods, mostly insects, have only been recorded on *Phragmites* spp. or on them and another grass or aquatic monocotyledonous plant. These include:- in the Lepidoptera, a series of noctuid stem-borers and 4 leaf-mining *Cosmopterix* spp.; a large group of sap-sucking Hemiptera; amongst the Diptera, 4 stem-galling cecidomyiids, 7 stem-galling or stem-boring chloropids, 5 leaf mining agromyzids, and even an aquatic stem-mining chironomid; in the Hymenoptera, 2 stem-galling eurytomid *Tetramesa* spp. and finally a tarsonemid mite. Approximately 70 fungi have only been recorded on *Phragmites* spp. or on it and another host including:- in the Ascomycetes, species of *Leptosphaeria, Lophiostoma, Metasphaeria* and *Mycosphaerella*; amongst the Coelomycetes, species of *Ascochyta, Hendersonia, Phoma, Septoria* and *Stagonospora*; amongst the Hyphomycetes, species of *Clasterosporium* and *Deightoniella* and for the Basidiomycetes, 4 rusts , *Puccinia* spp. all, except one species, with known alternate dicotyledonous aecidial hosts and a stem smut *Ustilago* spp.

The above large number of apparently specific fungi is based mainly on Oudemans (1919) and although synonymy and more recent knowledge of other hosts of many of the fungi would reduce this number considerably there would still be a larger number of specific fungal species in the Northern Hemisphere on this grass than in Australia.

None of the specific insects have been recorded from this grass in Australia and only 4 of the many specific or near specific fungi on this grass weed in the Northern Hemisphere Old World are recorded in Australia. These are:- *Deightoniella arundinacea* (Corda) Hughes, *Heterosporium phragmitis* Sacc., *Hadratrichum phragmitis* Fuckel and the rust, *Puccinia magnusiana* Korn (Simmonds 1966 Sampson and Walker 1982, Woodcock and Clarke 1983, Cook and Dubé 1989, Walker, NSW Dept of Agriculture, pers. comm.). Only one other rust fungus, *Puccinia tepperi* Ludwig is recorded from this grass only in Australia (McAlpine 1906) but its taxonomic status is uncertain (Cummins 1971). The smut, *Tilletia nigrifaciens* Langdon and Boughton has recently been recorded only on *P. australis* here in Australia (Langdon and Boughton 1978). The widespread European smut *Ustilago grandis* Fries on *P. australis* and *Typha* spp. (Zundel 1953) does not occur in Australia.

Thus the occurrence of specific *Phragmites* arthropods and fungi suggests strongly that *P. australis* is not native to Australia but has been introduced some time before European settlement and only a few of the highly specific organisms associated with it arrived with it or afterwards.

There are therefore a very large number of possible agents that could be introduced for the biological control of *P. australis* in Australia.

Discussion

Broad surveys of the host range of insects have indicated that grass feeding species are less specific than those on non-grass hosts and this has lead to a recommendation that classical biological control should not be used for grass weeds (Bernays 1985).

However, many of the insects studied as regards host range and host selection have belonged to the oligophagous groups, Orthoptera, Noctuidae and Chrysomelidae (Bernay and Barbehenn 1987). Except for *Tetramesa* (= *Harmolita* spp.) in the USA (Phillips 1920), there has been no or very little work on host range or host selection of monophagous (limited to 1 genus) grass insects in the other groups Elachistidae, Aphidae, Cecidomyiidae, and gall-makers in general, all of which could provide host-restricted classical agents for a given grass weed. The smut fungi, Ustilaginales, have always been considered to be highly specific and there is probably sufficient generic specificity within some other groups of fungi for them also to be considered as classical agents for grass weeds.

Thus, based on the grass weeds considered in this review it appears that several suitable classical arthropodal and fungal agents could be found for grass weeds generically separated from a crop or pasture/lawn grass. There is an unusually large number of agents available in the Northern Hemisphere Old World to control *Phragmites australis* in Australia, more usual would be the number of specific agents on *Holcus* spp. and *Bromus* spp. in their European home range for possible introduction here and there is even the possibility of using classical agents for the control of *Eleusine indica*.

Given the doubts held concerning the use of agents in a classical inoculative manner for the biological control of grass weeds, it would be reasonable to use the first attempts as models for future work. Both, *Holcus lanatus* and *Eleusine indica* could make good target weeds because there are no native species in these genera. Programs against these two weeds could commence with more detailed literature surveys and a search for suitable agents in their respective home ranges, Europe for *H. lanatus* and India to China for *E. indica*, followed by the selection and preliminary testing there of apparently specific agents. Serious consideration should also be given to the classical control of *Phragmites australis*. The program against this weed could commence with a survey of the arthropod fauna and fungal flora on it in Australia. Once the absence here of a guild of specific agents was established a major program could be set underway to select and test the most effective agents known to occur on *P. australis* in the Northern Hemisphere Old World.

Unfortunately, all indications are that the potential biological control agents in the South American range of *Nassella trichotoma* infest *Stipa* spp. there as well and the importance of Australian *Stipa* spp. as native pasture grasses could preclude their introduction.

For the major grass weeds closely related to or the same as crop and pasture/lawn grasses e.g. species of *Avena*, *Hordeum*, *Cynodon*, and for grasses in genera like *Stipa* with a large number of native species here, the only option is to develop as bioherbicides those organisms, particularly fungi, already present in Australia on them or on close relatives. Because, even if the work presently underway overseas on developing bioherbicides from fungi infesting grasses such as *Avena* spp., *Sorghum halepense*, *Echinochloa* spp. etc. produced commercially usable bioherbicides, these, under present quarantine regulations, could not be used in Australia if the fungi concerned were not already present here. However, such restrictions would not apply to the introduction of a selective phytotoxin like that isolated from *Bipolaris cynodontis* on *Cynodon dactylon* and from *Drechslera sorghicola* and *Bipolaris* sp. on *Sorghum halepense* (Sugawara *et al.* 1985, 1987, Pena-Rodriguez *et. al.* 1988).

Given the cost of development and production of a bioherbicide a concerted effort to develop them from fungi present in Australia would only be worthwhile for a small proportion of grass weeds (Table 5). Fortunately, a high degree of specificity would not be essential. Hence fungi on grass weeds here with broad host ranges could be considered, as could *formae speciales* of fungi with extensive host ranges. The combination of characteristics of a fungus which enable it to be effectively developed as a usable bioherbicide are demanding (Templeton *et al.* 1986) and therefore only a small percentage of the fungal species infesting a grass weed will be suitable. However, the possibility of combining synergistically the effects of herbicides and bioherbicides as in the case of *Echinochloa crus-galli* (Scheepens 1987) could allow them to be used effectively particularly if only less virulent fungi were available. There are a large number of fungi recorded on crop and pasture representatives of the genera *Avena*, *Hordeum*, etc. as well as on *Sorghum bicolor*, and these could serve as sources for suitable fungi to control weeds in the same genera. However, fungi infesting the same grass or close relatives could not be used as bioherbicides in crops or pastures composed of that same grass. Thus *Pyrenophora avenae* could be used to control wild oats, *Avena* spp., in crops of wheat and barley (*Triticum* spp. and *Hordeum* spp.) but not in oat (*A. sativa*) crops. Unfortunately, there are only a few fungi found on weedy *Bromus* spp., *Echinochloa* spp. and many other non-native weedy grasses of crops here in Australia and for these weedy grasses the development here of suitable bioherbicides is more doubtful.

Because some of the major annual grass weeds in crops and pasture are *Avena*, *Hordeum* and *Lolium* species, attention is at present focussed on developing bioherbicides from seed-destroying fungi occurring on them in Australia (Medd and Ridings 1989). However, this approach is not suitable for any major perennial grass weeds of crops which maintain themselves from year to year by rhizomatous or tussock growth because they do not depend on seeds to regenerate.

A combined classical and bioherbicidal approach could be mounted for those grass weeds which are generically separated from crop and pasture grasses and are major crop weeds. Only two grass weeds clearly fall into this category, *Holcus lanatus* and *Eleusine indica* and it should be possible to introduce specific fungi from overseas and then develop them as bioherbicides (Wapshere 1987). This approach could also apply to *Bromus* spp. of Mediterranean origin if they and the South American *B. catharticus* could be discounted as pasture grasses.

A combined approach could also be possible for the control of *Sorghum halepense*. Rhizome feeders restricted to *Sorghum* spp. could be considered for introduction to Australia, since crop and pasture *Sorghum* spp. do not possess this organ, but specific *Sorghum* organisms attacking aerial parts of that grass weed could not be introduced. However, fungi already here on *Sorghum* spp. could be developed as bioherbicides for *S. halepense*.

In conclusion, the grass weeds in Australia selected here for discussion exemplify the problems of attempting their biological control. It can be seen that each genus of weedy grasses and in some cases each weedy grass species has to be considered individually and the type of biological control selected according to the following features:-

i) whether the weedy grass is related to crop and/or pasture grasses,
ii) whether a pool of potential agents occurs in Australia already,
iii) if not and potential agents occur in the grass weed's native range, whether they have sufficient host restriction to be introduced into Australia.

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