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ECOLOGICAL IMPLICATIONS OF GRAZING SYSTEMS:

LITTER AS A FACTOR AFFECTING THE BALANCE BETWEEN GRASS, CLOVER AND WEEDS

John Leigh and Dorothy Halsall

CSIRO Division of Plant Industry
Canberra, ACT 2601

Abstract. This review deals mainly with factors affecting the growth of legumes, especially subterranean clover, in perennial-based (principally phalaris) pastures. It also touches briefly on the effects of annual grasses (mainly species of *Vulpia* and *Bromus*) on the other sown grasses and legumes. Research over the past 6 years has shown that allelochemicals released from litter, especially from phalaris litter, have an adverse effect on legumes and are a significant contribution to legume decline in older pastures. Litter can also adversely affect the growth of weeds such as *Vulpia* and even thistles such as *Onopordon acanthium* L. (Scotch thistle).

There is widespread concern at the decline in the legume content of older perennial pastures. This decline is considered to be a major constraint to animal productivity in both the cereal/sheep zones and the permanent grazing areas (Reuter, 1989). A number of researchers both in Australia and New Zealand have shown that the higher the proportion of clover in a pasture, the faster will be the growth of livestock grazing that pasture (Ulyatt *et al.*, 1977; Kenny and Reed, 1984; Freer and Jones, 1984; Askin *et al.*, 1987). Thus, declining legume content is a serious problem affecting overall productivity.

Reasons for clover decline

Several reasons for low or declining clover content have been advanced, including:

- Grazing pressure/stocking rate;
- Selective grazing;
- Set stocking *versus* rotation management;
- Amount of bare ground, providing 'windows' for colonisation;
- Competition from sown grasses and volunteer weeds, especially annual grasses;
- Amount of carry-over seed;
- Amount of hardseededness;
- Diseases;
- Pests, especially red-legged earth mite; and,
- Allelochemicals from litter.

Inevitably, there is a great deal of overlap between two or more of the factors listed above and research is continuing around Australia to elucidate their importance and, where possible, to provide solutions and remedies. Some examples follow.

Effects of grazing.

Data were obtained at the CSIRO Ginninderra Experiment Station near Canberra by Morley *et al.* (1969) who examined animal production and changes in botanical composition under a wide range of stocking rates (2, 10, 25 and 30 breeding ewes/ha) and alternative intensities of rotational grazing regimes (set stocked *versus* 3-paddock and 9-paddock). Pastures sown in 1963 established well and the content of subterranean clover measured in December 1964 was satisfactory at around 34-38%. Four years after sowing, the clover content had declined on all treatments to a low of 7-11%. The phalaris content varied between 42 and 70%, with the balance consisting of weedy cool-season annual grass (species of *Bromus, Vulpia* and *Hordeum*).

Competition.

Two studies illustrate the problems of competition and volunteer weeds. The first was a large factorial trial carried out on a mature (25 years) phalaris/subterranean clover pasture where different treatments imposed various levels of damage on the phalaris plants root system. Amounts of disturbance were nil (control), slight (raking the surface with a tyne harrow), moderate (tyne cultivation broke up the root system to a depth of 20 cm) and severe (disc cultivation severed the roots and turned the surface over). In addition, the plots were split with parts receiving additional nutrients, trace elements, supplementary subclover seed and supplementary irrigation. The above treatments were imposed in February/March 1988 and the plots left to recover. Yield measurements coupled with botanical composition determinations made in October and November showed no improvement in clover yield in any of the treatments relative to control.

The second trial examined the effects of winter cleaning on two contrasting pastures, namely a phalaris/subclover pasture and an *Eragrostis curvula*/subclover pasture. Two sprayings of Simazine® were applied in September 1992 and September 1993, the chief objective being to reduce the prolific growth of *Vulpia* spp. (silver grass), and to increase the contribution from the sown components. The improvements were dramatic (Table 1). The sown grasses thickened up, new seedlings established, flowerhead production and seed production increased, as did the dry matter yield of the sown grasses. Clover production was not affected. The results clearly illustrate the effect that one group of species (in this case *Vulpia* spp.) can have on another (*viz.* phalaris or eragrostis).

Amount of carry-over seed and hardseededness.

The amount of carry-over seed has been identified as an important factor affecting the regeneration of subterranean clover (Carter, 1987). de Koning and Carter (1987) examined the effects of treading and grazing by sheep on the dry matter production and seed production when areas at the Waite Institute in South Australia were subjected to high, medium and low levels of stocking density. Their research showed that the grazing pressure in late winter greatly influenced growth and seed production of all cultivars, and thereby the longer-term composition of their pastures. In a subsequent paper (de Koning and Carter, 1989) they reported that the amount of seed passing through the alimentary tract of sheep was about 1.5% (soft = 0.5% and hard = 1.0%) of their intake, and that the soft seed voided under the hot, dry summer-autumn conditions experienced in southern Australia would be unlikely to survive.

Table 1. Effects of winter cleaning on *Phalaris aquatica* and *Eragrostis curvula* (Source: Leigh, Johnston, Holgate and Shoemark, unpublished data).

	Plant numbers /m^2			
	January 1993		October 1993	
	Unsprayed	Sprayed	Unsprayed	Sprayed
Phalaris	12	16	12	20
Eragrostis	11	20	12	15
	Yield (kg/ha) December 1993			
	Sown Grass		Weeds	
	Unsprayed	Sprayed	Unsprayed	Sprayed
Phalaris	2312	3976	680	464
Eragrostis	656	1752	1880	672
	Flowerheads/m^2			
	January 1993		December 1993	
	Unsprayed	Sprayed	Unsprayed	Sprayed
Phalaris	108	168	85	152
Eragrostis	7	40	43	141

On the southern tablelands (Cooma, Braidwood and Goulburn areas) 26 pasture sites were examined in January 1983 (Dear and Loveland, 1985). At each site three strips of soil were removed and their seed load recovered. In addition, on an adjacent area the numbers of subterranean clover seedlings were counted in the following autumn. The seed sampling technique was shown to be a reliable estimate of seedlings germinating in the autumn. The data suggested that seed reserves and plant density in autumn could be improved by sowing cultivars with a higher hard seed content.

In order to examine the extent to which the amount of carry-over seed affects the clover production of mature pastures, additional quantities (up to 100 kg/ha) of inoculated seed of subterranean clover (cv. Karridale) were broadcast onto a mature *Phalaris aquatica* cv. Australian and subterranean clover (cv. Mount Barker) pasture in Autumn 1988 at the CSIRO Ginninderra Experiment Station. Only 6-17% of the seed produced seedlings and only 6-12% of these survived until the spring (Figure 1). Even with the massive oversowing rate of 100 kg/ha, the number of subterranean clover seedlings only rose from about 100 (control) to 310. Clover dry matter production measured in October and again in November was not significantly increased with oversowing and remained around 100 kg/ha in a pasture where phalaris yielded about 2000 kg/ha and annual grass weeds 2500 kg/ha.

Allelochemicals from litter.

Allelochemicals are substances produced by plant material which affect growth of other plants. This can even extend to effects on plants of the same species. Allelochemicals from litter have been shown to influence legume production. The presence of barley straw has been shown to affect the germination, emergence, establishment and productivity of annual medic pas-

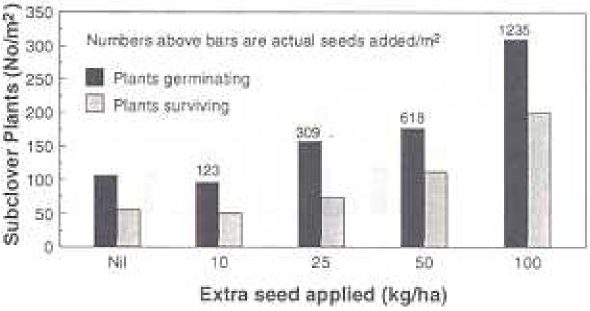

Figure 1. Effects of the addition of subterranean clover seed on germination and survival of seedlings.

tures (Quigley, 1985; Quigley and Carter, 1985). Allelochemicals from pastures and weed residues can also be damaging (Craig, 1990; Leigh *et al.*, 1994; Halsall *et al.*, 1994).

There are relatively few reports on the inhibition of pasture legumes by residues of pasture plants. However, several document the deleterious effects of retained crop residues, in particular residues retained on the soil surface as a result of minimum tillage practices, on the growth and yield of subsequent crops (Kimber, 1967; Lovett and Jessop, 1982; Purvis, 1990; Purvis and Jones, 1990). These effects have been attributed to allelopathic chemicals (Lovett and Jessop, 1982; Purvis and Jones, 1982), to phytotoxins produced during straw breakdown under wet conditions (Harper and Lynch, 1982), and to root pathogens present in the soil which are favoured by the humid conditions often associated with residue retention (Cook and Hoagland, 1991).

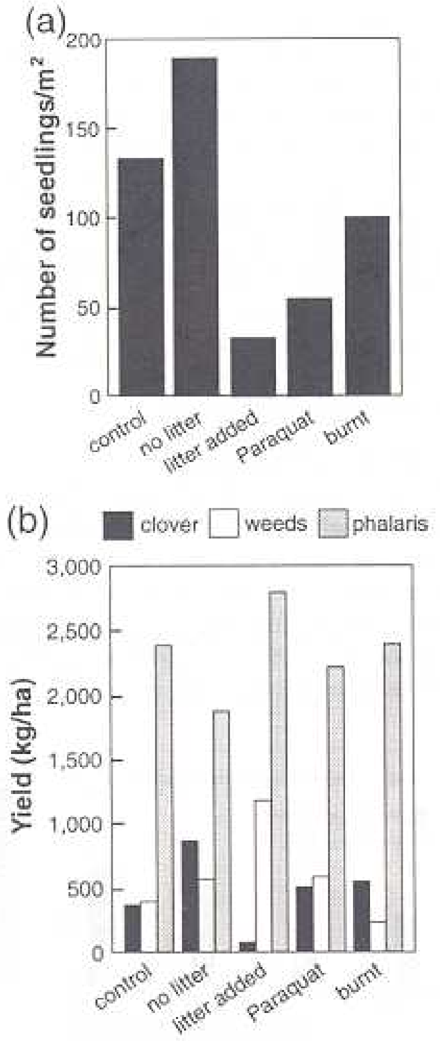

Figure 2. Effects of the removal or addition of phalaris litter on the numbers of subterranean clover seedlings (a), and clover dry matter production in spring (b).

In a series of 5 trials, three conducted in the field at Ginninderra Experiment Station and two in the CSIRO Black Mountain nursery, it was shown that mulched residues from phalaris and from wheat reduced the germination, survival and production of subterranean clover (Leigh *et al.*, 1994). Two of these field trials were imposed on a mature 25 year old pasture based on the 'Australian' cultivar of *Phalaris aquatica* and Mount Barker subterranean clover in 1988 and 1989. Treatments in which the amount of litter from phalaris was reduced by lightly raking and removing litter from between the tussocks, showed increased numbers of subclover seedlings establishing and surviving, and clover dry matter production almost doubled (Figure 2).

Addition of either phalaris or wheat litter, reduced the number of subclover seedlings which germinated and persisted, and consequently reduced the yield of subclover by up to 81%. Addition of litter in smaller amounts (equivalent to a 10 mm layer), stimulated the growth of weeds, whereas larger amounts of litter (equivalent to a 30 mm layer) reduced the yield of

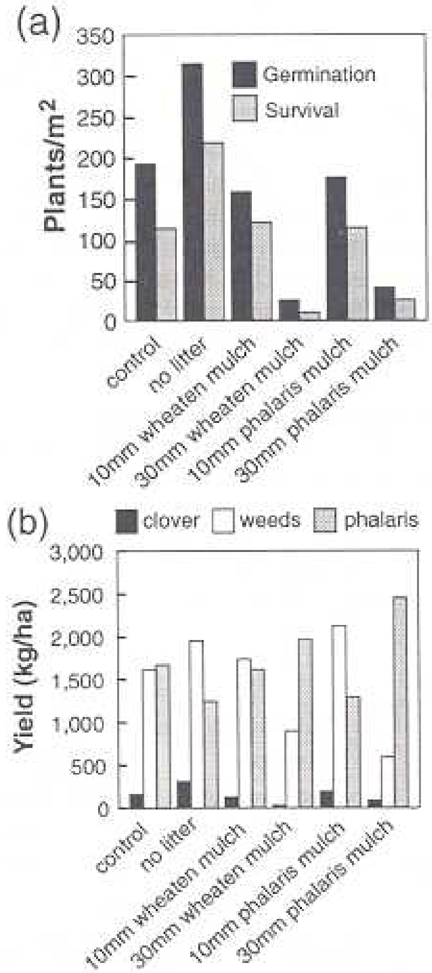

Figure 3. Effects of removal removal or addition of wheat or phalaris litter on the germination and survival of subterranean clover seedlings (a), and on dry matter production (b).

weed species (31% for wheat and 19% for phalaris) (Figure 3).

In the third field trial, it was shown that wheat litter (and wheat stubble) could have a large effect on legumes previously undersown with the last crop. By manipulating the amount of litter left on the soil surface after harvest, it was possible to significantly increase the clover content of the first year pasture phase. Where the walker straw was left on the ground, clover yield was only 58% of the control. Where the natural litter was removed clover yield increased to 170% that of control, and where the stubble was also cut low and all litter removed, clover yield increased to 197% that of control (Figure 4).

The two nursery trials were conducted under conditions where potential and actual competition from the sown phalaris and volunteer weeds were absent. Different depths of either phalaris or wheat litter were applied either as a mulch or incorporated into the top 5 cm of soil. Germination in the no-mulch treatments and where either the phalaris or wheat litter had been incorporated into the soil was high (appox 90% of sown seed). In contrast, where the litter was applied as a mulch, germination was significantly reduced, the reduction increasing as the thickness of the mulch increased. Similar effects were found for subclover yield, demonstrating the importance of incorporation of crop residues on the performance of a subsequent pasture.

There are several reports of inhibition of legumes by weed species present in pastures. One of the earliest of these concerns the inhibition of the annual medics, *M. truncatula*, *M. littoralis* and *M. polymorpha*, by the common wireweed, *Polygonum aviculare*. This inhibition was shown to be due to a water soluble compound which could be leached from the wireweed (Lovett, 1986). Nodding thistle (*Cardus nutans* L.) seeds reduced the germination and radicle elongation of five pasture species including white clover and subterranean clover (Wardle *et al.*, 1991), while two *Vulpia* species have been shown to contain allelochemicals which are activated by ultraviolet light (Pratley and Ingrey, 1990) and inhibit the germination and growth of canola (*Brassica napus* L.), wheat (*Triticum aestivum* L.), lucerne (*Medicago sativa* L.) and phalaris (*Phalaris aquatica* L.) seedlings.

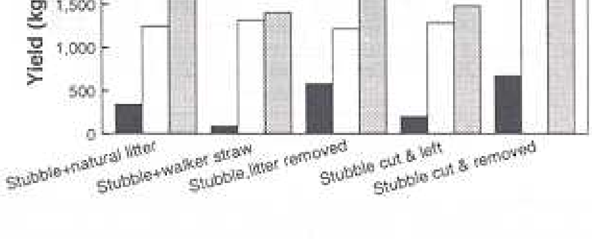

Figure 4. Effect of wheat stubble and wheat litter treatment post-harvest on subsequent growth of subterranean clover.

One of the few reports on the inhibition of legumes by residues of pasture species is the effect of endophyte-infected ryegrass (*Lolium perenne* L.) on the germination and root growth of Trikkala subterranean clover seedlings (Quigley *et al.*, 1990). Leachates of green leaves and roots of the forage grasses Kleberg blue stem (*Dichanthium annulatum* (Forsk.) Stapf. and buffel grass (*Cenchrus ciliaris* L.), were reported to inhibit germination and reduce root growth of two legumes, partridge pea (*Cassia fasciculata* Michx.) and Illinois bundleflower (*Desmanthus illinoensis* (Michx.) MacM. (Nurdin and Fullbright, 1990).

In order to understand more fully the possible effects that compounds which leach out of litter can have on legumes, a series of laboratory tests were conducted under carefully controlled conditions (Halsall *et al.*, 1994). In these tests, factors such as plant competition from both sown pasture companions and from undesirable volunteer weeds were eliminated. Cold water extracts from a wide range of crop (10 species), pasture (9 species) and weed plants (6 species) were prepared and tested on a number of commonly grown legumes (11 species) under sterile conditions. Sterile conditions were maintained so that effects due to compounds leached from the residues could be distinguished from effects due to products of decomposition or to infection by plant pathogens which are favoured by the microenvironment provided by the residues. While these latter processes undoubtedly contribute to the problem in the field, it was necessary to distinguish the contributory factors.

Some of the main findings from these extensive laboratory studies were:

1. Both wheat and phalaris extracts significantly reduced germination of all 11 lines of legume, with phalaris extract causing the greatest reduction. At the highest concentration of phalaris extract, germination was less than 40% of control in all legumes except red clover and Namoi woolly-pod vetch. Medics were particularly susceptible to phalaris extracts.
2. Radicle elongation (early root growth) was significantly reduced by extracts of either phalaris or wheat residues. For example, in Karridale subterranean clover, it was reduced to 20.5% that of control when treated with the most concentrated extract. In the other legumes examined, radicle elongation was reduced to 0-30% that of control. Also, in the presence of the extract, root tips were swollen and thickened and

the root hairs were not properly formed. The root hairs were slow to develop and were distributed over a smaller region of the radicle with many being distorted in shape.

3. Root growth over four weeks showed a significant reduction in the presence of both phalaris and wheat extracts, the roots being shortened, deformed and discoloured brown, especially at the highest extract concentration. Similar root disorders have been previously observed by Purvis (1990) who reported a reduction in root number and length and the distortion of the coleoptile in wheat seedlings germinating in the presence of decomposing sorghum (*Sorgum bicolor* (L.) Moench) stubble.

4. Neither phalaris nor wheat extracts had any detrimental effect on the growth or population levels of two commonly used rhizobia strains. However, both phalaris and wheat extracts had a deleterious effect on the nodulation of all the legumes examined. With the exception of Namoi vetch (90% of control), nodulation was reduced to less than 60% of the untreated control when exposed to the highest level of phalaris extract. As one of the major effects of residue extracts on root growth was to retard the development of root hairs, it is possible that the inhibition of nodulation was a reflection of this effect. Infection of the root by *Rhizobium* species has been shown to occur through the root hairs (Dart, 1974).

In another series of trials, Karridale subterranean clover, Grasslands Huia white clover and Jemalong barrel medic were used to test the allelopathic properties of a range of residues from pasture plants. Some interesting results obtained were as follows:

1. Germination of subterranean clover was strongly inhibited by the three phalaris cultivars and by an accession of *Eragrostis curvula*, and by its own residues. The other pasture residues (including cocksfoot) produced only slight inhibition of subclover germination (Figure 5). In contrast, germination of white clover was strongly inhibited by most pasture species at the highest extract concentration. Germination in barrel medic was strongly inhibited by all phalaris and *Eragrostis* varieties and by perennial ryegrass and subclover but not by cocksfoot or secale.

2. Root growth and nodulation were severely inhibited in nearly all species by residue extracts at the highest and intermediate concentrations.

3. Crop and weed residue responses were often severe, but differed according to the species and cultivars from which extracts were made and the species on which the extracts were tested.

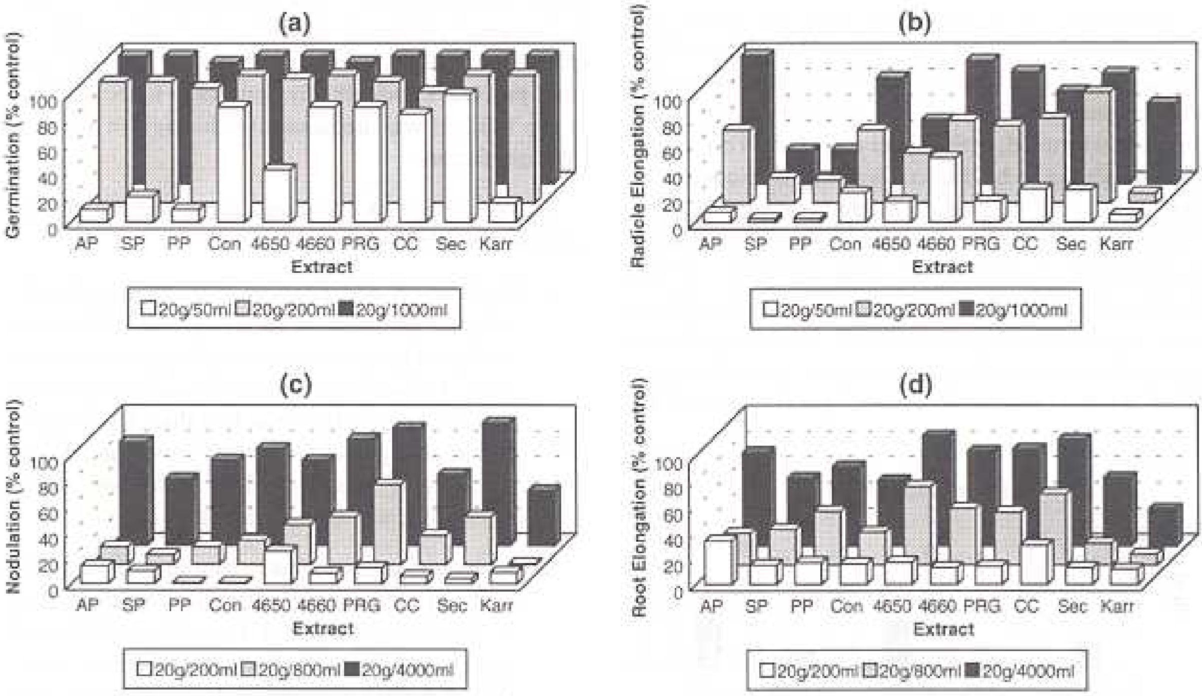

Figure 5. Effects of pasture residues on germination (a), radicle growth (b), nodulation (c) and root growth (d) of Karridale subclover. The residues tested were: Australian phalaris (AP), Sirosa phalaris (SP), Perla X phalaris (PP), Consol eragrostis (Con), Eragrostis 4650, Eragrostis 4660, Perennial ryegrass (PRG), Currie cocksfoot (CC), Black Mountain secale (Sec) and Karridale subterranean clover (Karr).

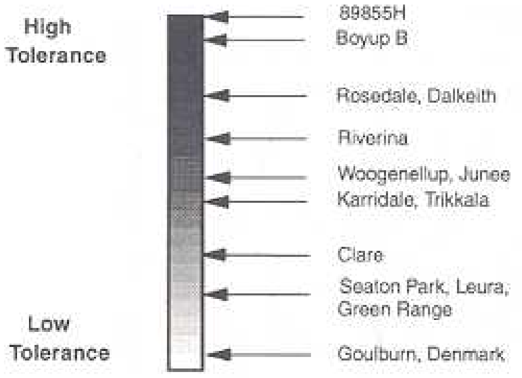

Figure 6. Rankings for tolerance to phalaris residues for subclover lines.

As mentioned previously, we emphasise that these tests were carried out under sterile conditions, and the results were not confounded by effects due to plant pathogens which, in the field, could be favoured by the increased humidity associated with retained residues. The three concentrations of extract used in the laboratory related directly to conditions likely to be encountered in the field. For phalaris residue (and assuming a litter depth of only 10 mm), a rainfall event of 2 mm would produce an extract equivalent to the most concentrated extract tested if all the water were to run off. In practice, the residues can retain up to three times their weight of water and so rainfall events up to 6 mm are still likely to produce the most concentrated extract. To obtain the intermediate extract concentration, the equivalent rainfall required would be 8 mm if all the rainfall were to run off, and up to 24 mm with water retention.

In the course of the between-species and within-species performance comparisons made in the laboratory, the finding that comparatively large differences existed between two cultivars of subclover (cvv. Karridale and Trikkala) served as a catalyst for a large screening trial involving 126 subclover lines (Leigh *et al.*, unpublished). This work showed that a wide range of tolerance/susceptibility exists within the subclover lines presently available. Many of the well known cultivars rank at the intermediate or lower tolerance levels of the scale (Figure 6).

Concurrent with these studies has been a breeding program to produce/select individuals resistant to the allelochemicals present in phalaris residues. Using irradiation techniques, with the aim of producing resistant individuals through induced mutations, combined with a very comprehensive screening program involving thousands of seeds from 5 parent lines (cvv. Karridale, Trikkala, Junee, Goulburn and Denmark), selected 'tolerant' individuals have been identified. These rare individual seedlings (only 1 from every 800-1200 seeds) were grown on for seed increase. The seed produced has now been sown out in the nursery with and without a mulch of phalaris in order to compare the performance of the selected lines over their original parents. Should any of these selected lines prove superior to their parents, then they will constitute new cultivars specifically recommended for sowing with phalaris-based pastures. These new cultivars should be similar in all respects to their parents, but have the added attribute of tolerance to litter leachates.

In the field, it has been shown that the allelopathic compounds present in sorghum stubble can be leached out of the standing stubble rendering it less toxic (Purvis, 1990). It is possible that compounds leached from the residues can be detoxified by interaction with the soil (Rice, 1984), but it is also possible that the response in soil will be more intense (Wardle *et al.*, 1991). These aspects are being investigated. Regrettably, nothing substantial is known about the chemistry of the compounds produced in phalaris which result in the deleterious allochemical reaction noted earlier. At this stage we are, as it were, attempting to fit the pieces of the jig-saw into a coherent picture.

The concentration of allelopathic compounds produced in green and dry phalaris residues varies considerably from month to month and from year to year. Dry phalaris material which had been collected approximately every 6 weeks between October 1989 and June 1992 was tested for its effect on the four standard parameters in the laboratory (Figure 7). It appeared that toxicity was worse in mid-summer, especially after dry spells and this tentative observation bears out the observation that clover levels are poorest in phalaris pastures after a dry summer when residues are plentiful and undecomposed. In wetter years clover levels are higher and the problem of clover decline is less serious.

In order to understand the relationship between weather, especially rainfall and high levels of ultraviolet light (UV), a series of trials was conducted in the field and laboratory. In the first and simplest example, straw was taken from three parts of a standard wrapped large round bale of phalaris/cocksfoot mixed hay which had been cut and baled in December 1992 and sampled in October 1993. The large differences between the unweathered straw from the centre of the bale where all parameters measured were low, contrast with values obtained from extracts prepared from the moderately weathered mostly dry outer upper sides and, lastly, with the lower section which remained damp and was partly decomposed and rotted (Table 2).

The second trial with phalaris litter was conducted under controlled conditions. Straw was contained in

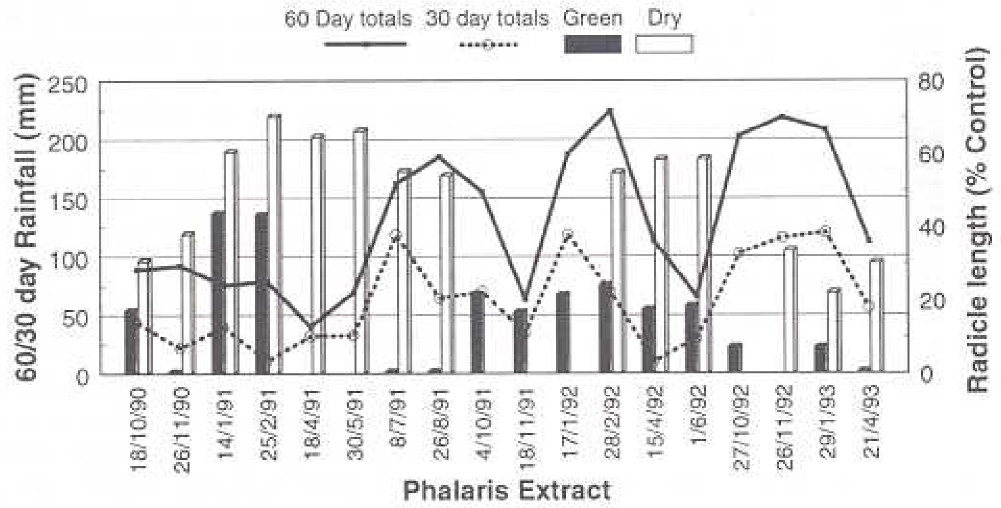

Figure 7. Seasonal effects on inhibition of radicle elongation in Karridale subclover by extracts from green phalaris leaf and dry phalaris litter.

Table 2. Effects of weathering of phalaris hay on allelochemical toxicity to subclover seedlings.

Position in bale	Percent germination	% radicle length	Percent nodulation	% root length
Unweathered centre	19	11	7	15
Weathered edge	92	23	15	32
Rotted base	97	24	18	29

covered dishes wrapped in 'glad wrap' and placed in a phytotron cabinet where day/night temperatures and light/UV light levels equivalent to those experienced in January in Canberra were simulated. Seven durations of exposure up to 60 days of the straw either dry or wet, with or without UV light were examined. At the conclusion of the period, extracts were made from the straw and the usual parameters examined. No effects of UV light were detected. Straw kept dry retained the allelopathic compounds over the period of the experiment When the straw was kept wet, the initial period of 7 days showed an increase in the phytotoxic effect of the straw. This effect disappeared after 7-14 days and the straw gradually lost its phytotoxic effect over the subsequent 46 days (Figure 8).

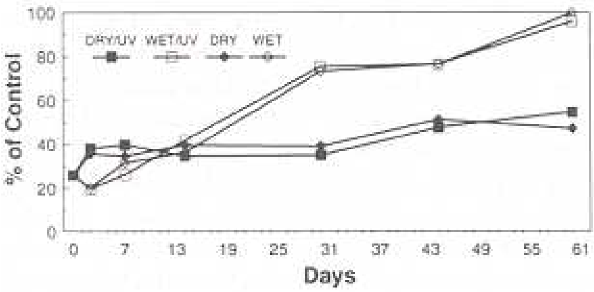

Figure 8. Effects of the exposure of phalaris litter to moisture and/or UV light for different durations on the radicle growth of subclover seedlings.

The germination results obtained in the laboratory from the straw placed in the phytotron were erratic and inconclusive, probably because of the small sample size. However additional straw treated in a similar way in the phytotron cabinets was placed on top of 15 cm round pots into which inoculated Karridale subclover had been sown. Measurements were made of the numbers of seedlings germinating and when they emerged. The number of seeds which germinated beneath straw kept wet and exposed to UV light decreased with increasing length of exposure (Figure 9). In addition, the time for emergence was appreciably extended under the wet treatments. This reduction and delay in germination was again confirmed in a later trial using another litter collection known to be less toxic. The overall effect of phalaris litter on delaying subclover germination is shown in Figure 10.

Additional examination showed that there were only minor/negligible differences between extracts prepared from the dry leaves as compared to the dry stems of phalaris. Ground material was shown to release more of the compounds than chopped material, although extracts prepared from chopped material

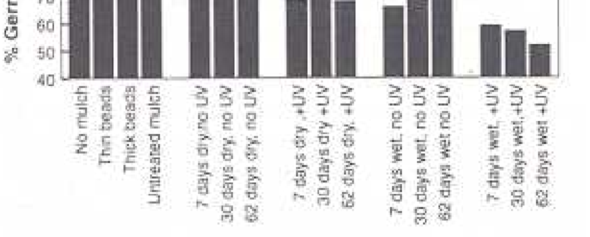

Figure 9. Effects of the exposure of phalaris litter to moisture and/or UV light for different durations on the germination of subclover seedlings.

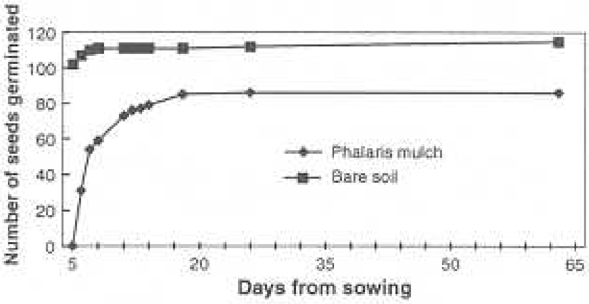

Figure 10. Comparison between the rate of germination of subclover seed without and with a mulch of phalaris.

were still damaging to seeds and seedlings.

The inhibitory effects on germination, root growth and nodulation have been examined separately, but these effects would be additive, as seedlings would be exposed to the continuing presence of the inhibitory compound(s). In the field, it could be expected that these deleterious effects on seedling establishment and growth would contribute to the problem known as clover decline and, in conjunction with the effects of *Pythium* spp and other plant pathogens, and the possible immobilization of nitrogen during residue breakdown, would preclude the successful establishment of legumes in a mulch of plant residues.

Future research will be aimed at identifying the compounds involved and determining their stability in the soil. Despite the extensive nature of these tests, we do not wish to extrapolate their possible consequences too far, although we believe they may prove to be important to the following farm related practices:

- Undersowing of legumes in the last year of a crop rotation.
- Hay making and forage harvesting of pastures which grow rank in summer in order to minimize litter in autumn.
- Heavy grazing of pastures in late summer in order to minimize litter in autumn.
- Weed control in pastures.
- Selection of suitable pasture grass species with a view to their compatibility to particular species and cultivars of legume.
- Specifically selecting legumes for their tolerance to allelochemicals and/or breeding cultivars of phalaris which produce low levels of these allochemicals.
- The desirability of including grasses between legume breeders rows or spaced plant selections and, conversely, legumes between grass breeders spaced plant or row selections.
- Manipulating the dead herbage produced following the use of knockdown herbicides, which may well prevent the successful establishment of legumes in pastures sown under minimum tillage regimes or sown broadcast from the air.

Conclusions

Research in CSIRO is continuing to examine some of these implications under field conditions, including determining management practices which would avoid these problems and selecting strains of legumes which are more tolerant of these compounds. We trust that by using an integrated approach taking into account the many factors involved, clover yields in annual and perennial pastures in both the wheat/sheep zone and the higher rainfall areas can be increased. This may help avoid the economic losses being sustained and loosely encompassed in the syndrome called 'Legume Decline'.

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References

Askin, D., D.B. Powan and R.J. Lucas (1987). The effects of clover content and herbage mass of lamb growth rate in the autumn. In "Herbivores Nutrition Research". Eds. J.B. Hacker and J.M. Ternmouth.) Australian Society of Animal Production, Sydney. pp. 233-234.

Carter, E.D. (1987). Establishment and natural regeneration of annual pastures. In "Temperate Pastures, their Production, Use and Management". Eds. J.L. Wheeler, C.J. Pearson and G.E. Robards. CSIRO, Australia. pp. 35-57.

Cook, R.J. and W.H. Hoagland (1991). Wheat yield depression associated with conservation tillage caused by root pathogens in the soil not phytotoxins from the straw. *Soil Biology and Biochemistry*, **23**: 1125-1132.

Craig, A. (1990). Development of annual clovers for the high rainfall zone. Proceedings 31st Annual Conference, Grassland Society of Victoria. pp. 83-85.

Dart, P.J. (1974). The Infection Process. In "The Biology of Nitrogen Fixation". Ed. A. Quispel. North Holland/Elsevier Amsterdam. pp. 381-429.

Dear, B.S. and B. Loveland (1985). A survey of seed reserves of subterranean cover pastures on the Southern Tablelands of New South Wales. Proceedings 3rd Australian Agronomy Conference, Hobart. p 214.

de Koning, C.T. and E.D. Carter (1987). Impact of grazing by sheep on subterranean clover cultivars. Proceedings Australian Agronomy Conference, Melbourne. pp. 61-69.

de Koning, C.T. and E.D. Carter (1989). The survival of seed of subterranean clover following ingestion by sheep. Proceedings of the XVI International Congress, Nice, France. pp. 1031-1032.

Freer, M. and D.B. Jones (1984). Feeding value of subterranean clover, lucerne, phalaris and Wimmera ryegrass for lambs. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **24**: 156-164.

Halsall, D.M., J.H. Leigh, S.E. Gollasch and M.D. Holgate(1994). The role of allelopathy in legume decline in pastures. 2. Comparative effects of pasture, crop and weed residues on germination, nodulation and root growth. *Australian Journal of Agricultural Research* (In press).

Harper, S.H.T. and J.M. Lynch (1982). The role of water-soluble components in phytotoxicity from decomposing straw. *Plant and Soil*, **65**: 11-17.

Kenny, P.T. and K.F.M. Reed (1984). Effects of pasture type on the growth and wool production of weaner sheep during summer and autumn. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **24**: 322-332.

Kimber, R.W.L. (1967). Phytotoxicity from plant residues. 1. The influence of rotten wheat straw on seedling growth. *Australian Journal of Agricultural Research*, **18**: 361-374.

Leigh, J.H., D.M. Halsall and M.D. Holgate (1994). The role of allelopathy in legume decline in pastures. 1. The effects of pasture and crop residues on the germination, survival and production of subterranean clover in the field and nursery. *Australian Journal of Agricultural Research* (In press).

Lovett, J.V. (1986). Allelopathy: the Australian experience. In "The Science of Allelopathy". Eds. A. Putnam and C.S Tang. John Wiley & Sons, pp 75-99.

Lovett, J.V. and R.S. Jessop (1982). Effects of residues of crop plants on germination and early growth of wheat. *Australian Journal of Agricultural Research*, **33**: 909-916.

Morley, F.H.W., D. Bennett and G.T. McKinney (1969). The effect of intensity of rotational grazing with breeding ewes on phalaris-subterranean clover pastures. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **9**: 74-84.

Nurdin, and Fulbright, T.E. (1990). Germination of 2 legumes in leachate from introduced grasses. *Journal of Range Management*, **43**: 466-467.

Pratley, J.E. and J.D. Ingrey (1990). Silvergrass allelopathy on crop and pasture species. Proceedings of 9th Australian Weeds Conference. Adelaide.

Purvis, C.E. (1990). Differential response of wheat to retained crop stubbles. 1. Effect of stubble type and degree of decomposition. *Australian Journal of Agricultural Research*, **41**: 225-242.

Purvis, C.E. and G.P.D. Jones (1990). Differential response of wheat to retained crop stubbles. II. Other factors influencing allelopathic potential; intraspecific variation, soil type and stubble quantity. *Australian Journal of Agricultural Research*, **41**: 243-251.

Quigley, P.E. (1985). Inhibition of medic pastures by cereal stubble. Proceedings Workshop on Tillage Systems, Rotations, Nitrogen and Cereal Root Diseases. Waite Agricultural Research Institute, Adelaide. pp. N4-N6.

Quigley, P.E. and E.D. Carter (1985). The effects of cereal straw on productivity of annual medic pastures. Proceedings 3rd Australian Agronomy Conference, Hobart. pp. 2-4.

Quigley, P.E., F.J. Snell, P.J. Cunningham and W. Frost (1990). The effects of endophyte infected ryegrass on the establishment, persistence and production of mixed pastures in Australia. Proceedings of First International Symposium on *Acremonium*/Grass Interactions. Eds. R.E. Joost and S.E. Quisenberry. Louisiana State University Agricultural Centre. pp. 49-52.

Reuter, D.J. (1989). An overview of pasture nutrition research and extension in the sheep grazing areas of Australia. SA Department of Agriculture, Adelaide.

Rice, E.L. (1984). "Allelopathy", 2nd Edition. Academic Press, New York.

Ulyatt, M.J., J.A. Lancashire and W.T. Jones (1977). The nutritive value of legumes. *Proceedings New Zealand Grassland Association*, **38**: 107-118.

Vincent, J.M. (1970). "A Manual for the Practical Study of the Root-Nodule Bacteria". IBP Handbook, No 15. Blackwell Scientific Publications, Oxford.

Wardle, D.A., M. Ahmed, and K.S. Nicholson (1991). Allelopathic influence of nodding thistle (*Carduus nutans* L.) seeds on germination and radicle growth of pasture plants. *New Zealand Journal of Agricultural Research*, **31**: 185-191.