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Review

Grazing Animals as Weed Control Agents[1]

IAN POPAY and ROGER FIELD[2]

Abstract. Literature on the effectiveness of grazing animals (especially cattle, goats, and sheep) in controlling weeds is reviewed. Availability of animals and the ability to fence them onto or off weed infestations are essential. Weeds of pastures are the most suitable subjects for control, although weeds of arable crops, forestry, and waste places are sometimes amenable to control by grazing animals. Although grazing animals themselves often cause weed problems in pasture, adjusting grazing timing or intensity or both can sometimes redress the balance. Increasing sheep or cattle stocking rates prevents animals from grazing selectively and can help control some weeds. Adjusting grazing pressure can also improve the growth of desirable pasture species so that these are more competitive and able to resist invasion of annual or biennial weeds. Introducing a different class of stock, like sheep into a cattle system or goats into a sheep system can control many weeds. Goats are capable of browsing on and controlling spiny or poisonous brush weeds, including gorse and poison ivy, without suffering adverse effects. Examples are given of the use of grazing animals for weed control in crops and forestry. **Nomenclature:** Gorse, *Ulex europaeus* L. #[3] ULEEU, poison ivy, *Toxicodendron radicans* ssp. *pubescens* (Tourn.) Mill. #[3] TOXRA, cattle, *Bos taurus*, goats, *Capra hircus*, sheep, *Ovis aries*.

Additional index words: Non-chemical weed control, integrated weed management, low input sustainable agriculture, *Agropyron cristatum, Allium sativum, Alnus rubra, Carduus nutans, C. pycnocephalus, C. tenuiflorus, Carthamus lanatus, Centaurea solstitialis, Cirsium arvense, C. palustre, C. vulgare, Cortaderia fulvida, Cucumis sativus, Cynara cardunculus, Cyperus rotundus, Delphinium spp., Discaria toumatou, Echium plantagineum, Elaeis guineensis, Euphorbia esula, Festuca arundinacea, Fragaria* × *ananassa, Gossypium hirsutum, Holcus lanatus, Hordeum glaucum, H. leporinum, H. murinum, Juncus* spp., *Lolium perenne, Lolium rigidum, Lycopersicon esculentum, Marrubium vulgare, Medicago sativa, Mentha* × *piperita, Nassella trichotoma, Onopordum acanthium, O. illyricum, Phalaris aquatica, Pinus caribaea, P. ponderosa, P. radiata, Pseudotsuga menziesii, Pteridium spp., Ranunculus spp., Rosa micrantha, R. rubiginosa, Rubus fruticosus, Sclerolaena birchii, Senecio jacobaea, Silybum marianum, Solanum tuberosum,* thistles, *Toxicodendron diversilobum, T. vermix, Trifolium repens, T. subterraneum, Zea mays,* CARLA, CENSO, CIRAR, CIRPA, CIRVU, CRUNU, CRUPY, CYPRO, ECHPL, EPHES, HORLE, HORMC, HORMU, LOLRI, STDTR, SENJA, SILMA, TOXDI, TOXVX.

INTRODUCTION

Integrated Weed Management (IWM) has not been adopted as widely or as readily as Integrated Pest Management (IPM), now widely accepted as a way of dealing with insect pests of plants (46) in some situations. IPM is often a combination of biological, cultural, and insecticide control, coordinated so that beneficial insects are not adversely affected by pesticides. In the case of weeds, chemical control, cultural control, and biocontrol tend to be studied and often applied independently.

Especially when grazing animals are being used for weed control, there is a significant opportunity for using a careful combination of grazing animals, conventional biocontrol agents, herbicides, and cultural control. Studies into the effect of herbicides on pasture weeds are often confounded with uncontrolled animal grazing, or the lack of it. Only a handful of published papers deal with the combination of grazing control and herbicide or even with the combination of conventional biological control and herbicides.

Grazing animals. Dictionary definitions of 'graze' specify

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[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 1508 West University Ave., Champaign, IL 61821-3133.

eating growing grass. For the purpose of this review, grazing animals are sheep, cattle, and goats which normally eat grass or pasture, but which will sometimes browse, or feed on, twigs and shoots of other plant species. Pigs (*Sus scrofa*) sometimes graze grass, but their weed control activities, mentioned briefly, are probably more associated with their rooting behavior. Domestic birds, too, will sometimes eat grass, and have been known to graze weeds selectively. Fish, notably grass carp (*Ctenopharyngodon idella* Val.), marine mammals and aquatic birds (53, 120) have been used, or their use discussed, for control of aquatic weeds, but they are not, for the purposes of this review, regarded as grazing animals.

Weed control decisions. When a farmer makes a decision to attempt weed control, the aim may be to eradicate a weed from the farm, to minimize the loss of revenue each year, sometimes by a blanket application of herbicide, or simply to keep weed populations at or below a predetermined level, above which a weed population is deemed unacceptable (17). Weed control decisions are often based only on visual thresholds and intuition. Such an approach relies heavily on experience and perceptions of the desirable outcome of weed control. There is rarely reliable biological information or cost-benefit analysis to support decisions based on visual threshold assessments. Particularly in pastoral situations the undesirable visual impact of sparse populations of tall weeds may prompt the use of control measures for cosmetic reasons rather than because of short or long-term effects on pasture productivity. The long-standing reputation of weeds as 'noxious' in the legal, as well as in the popular, view can also prejudice such decisions. Farmers often also base their decision on their perception of likely seed returns to the soil and future spread if nothing is done immediately.

The application of threshold models to aid decision-making on weed control is conceptually excellent but has yet to receive practical acceptance for the use of grazing animals as a means of weed control. There are potential benefits in making weed control decisions based on simple weed population assessments in the field and the application of an appropriate computer software package. The greatest need is for assistance with decision-making in low input, extensive pastoral production using grazing animals. Weed control decisions based solely on subjective assessments have a greater margin for error in this area than in more intensive production systems.

BASIC PRINCIPLES OF USING GRAZING ANIMALS FOR WEED CONTROL

For grazing animals to be useful for weed control, such animals must be available for use, and they must be able to be fenced onto or off an area in order to adjust grazing pressure.

Grazing animals must be available if they are to be used as weed control tools in any agricultural system. In Europe and North America, extensive use of fertilizers and pesticides has allowed development of highly advanced, yet simple, agricultural systems. Many modern farms have no animals; for example, 62% of the 1982 USA beef market was controlled by large feed-lot production (75). However, in some agricultural systems, like the 70 million ha Australian wheat (*Triticum aestivum* L.) and sheep zone, farmers can vary the area allotted to wheat and to pastoral systems from year to year (96). This ability of many Australian and New Zealand farmers to use grazing animals for weed control explains why much of the research on this topic has been conducted in those countries.

Proper use of grazing animals to control weeds could help enhance the value and productive capacity of the world's 3213 million ha of permanent pasture (97). In smallholder farming systems in Africa and Asia, animals are routinely fed on harvested weeds, on weed and crop residues remaining after crop harvest (69, 76), and on weeds growing among tree crops, and in this way contribute to weed control. Auld et al. (3) have raised the interesting question of whether weeds being utilized by animals can still be considered as 'weeds,' but they would still need to be removed from the crop if the animals were not there to eat them.

Grazing animals themselves may cause weed problems, either by stimulating a 'natural' shift from grassland to woody species (121), as a result of overgrazing, or by selective grazing when some pasture species are ignored. Rabbits (*Oryctolagus cuniculus*), which can be regarded as unfarmed grazing animals, can damage pasture communities and make them more liable to invasion by weeds, but can also keep woody and other weeds under control until the rabbits themselves are controlled (16).

Grazing animals are used primarily for food or fiber, and their use for weed control is of secondary concern. However, when weed control becomes the main objective, some sacrifice of animal production may be necessary. Thus old sheep, or otherwise worthless goats, in 'sacrifice flocks' may be used only for weed control. This is particularly so when the animals have to be pushed hard to give complete

control of the offending weeds and may lose condition, or their fleeces or skins may be devalued by physical damage or vegetable matter contamination.

Stock control. Controlled grazing—the ability to concentrate stock on to weed infestations at some stages of growth or times of the year, and the ability to keep them off pasture or weeds at other times—is often the key to weed control. Carter (13) emphasized the value of fencing in his review of weed control by grazing animals in the Australian integrated crop-pasture-livestock system.

Direct weed control and pasture conditioning. Animals grazing pasture can influence weeds either directly, by eating or damaging the weeds, or indirectly, by 'conditioning' the pasture and making it more competitive and resistant to subsequent weed invasion. The second effect is strongly influenced by stock class, and interactions between pasture species and stock class could also be expected. Within this category is included 'pasture improvement,' often suggested as a control method for weeds such as serrated tussock [*Nassella trichotoma* (Nees) Hack. #[3] STDTR] (3). Controlled animal grazing of such improved pastures is essential to maintain them in the improved condition. Horses (*Equus caballus*) and cattle have large hooves which create gaps in turf, and are selective grazers, avoiding some weeds and also avoiding dung-soiled pasture. Sheep graze more evenly, but can still be selective, avoiding prickly vegetation. Goats graze evenly, from the top of the sward downwards, seem to have a preference for fibrous vegetation, and are not deterred by spiny material. With almost any species of brushweeds, e.g., gorse (99), goats can also do considerable damage by climbing and breaking branches and pushing bushes over.

Stock classes. Often grazing restricted to only one class of stock, such as cattle, leads to particular weed problems because some weedy plants are less palatable to some classes of stock. Introducing a different class of stock can help to control weeds which have become predominant. Thus, sheep can control buttercups (*Ranunculus* spp.), Paterson's Curse (*Echium plantagineum* L.) or tansy ragwort (*Senecio jacobea* L. #[3] SENJA), left by cattle or horse grazing. Cattle can be used to control bracken (*Pteridium* spp.) untouched by sheep, and goats can control thistles and brushweeds that are ignored by other stock (91, 99). In some circumstances, different stock classes can be grazed together to give improved weed control. Thus, sheep can control ragwort without seriously affecting cattle production (7), and goats grazed with beef cattle can control thistles without affecting cattle productivity (116). Under some circumstances, cattle production may actually be enhanced, partly because of weed control and partly because of the goats' preference for grass over clover.

Sustainability. More widespread adoption of grazing animals for control of weeds could lead to a reduction in herbicide use, itself seen by some as a healthy trend, which may lead to pastures with a greater diversity of useful species. Having more animal species on a farm could allow a more balanced approach to weed control, and under some circumstances may be more profitable for the farmer.

Costs and benefits. The benefits of using animals for weed control can include:

- more effective weed control than with herbicides
- improved pasture quality
- less effect on non-target species
- some natural fertility return
- reduced pesticide residues
- 'environmentally friendly' production systems
- more sustainable control
- lower direct costs
- the weeds controlled may be converted to animal protein and thus acquire value
- gains in animal liveweight.

There are also costs associated with using grazing animals. These can include:

- capital cost of animals
- cost of fencing, water provision, and animal care
- loss of animal condition or liveweight
- reduction in value of animal products such as wool or skin
- damage to non-target species
- uneven fertility return promoting more localized weed growth
- damage to soil structure
- damage to forests, native plant reserves and neighboring properties by 'escapees'
- spread of weed seeds in feces or on wool, hair, or hooves
- treading damage to pasture by pugging, which allows more weed invasion

Integrated weed control. Control of weeds by grazing animals is usually thought of in isolation from other weed control methods. In fact, integration of grazing management with other methods may pay large dividends. Grazing management is often ignored in texts on weed control, especially those dealing with 'biological control' (85).

Combining grazing management with herbicides has been used in the Australian spray-graze technique (13, 21) in which weeds are sprayed with low rates of phenoxy herbicide to make them more palatable, and then grazed heavily. However, there is a danger that poisonous weeds, like tansy ragwort, become more palatable when sprayed.

Very little research has been carried out, or at least reported, on the effects of combining grazing management with either classical or inundative biological control, and even less on combinations of grazing management, cultural treatment (e.g., cultivation practices, pasture species, fertilizer applications), biological control, and herbicide use.

PASTURE AND RANGELAND WEED CONTROL

Although grazing animals can be used for weed control in many situations, control in pastures is particularly amenable to controlled animal grazing. The management of weed populations at levels close to an economic threshold requires control strategies that are predictable and relate closely to the biology of the weeds and their competitive relationship with the crop or pasture. There must be emphasis on the long-term containment of weed populations, which implies a knowledge of seed dormancy, longevity, and germination. The periodicity of weed plant establishment and the timing of the onset of flowering have major implications for the introduction of management decisions affecting control. Knowledge of vegetative ramet production and seasonality of subsequent new plant establishment in perennial species is critical if population expansion is to be contained.

Within a given pasture management regime and climatic range the biology of the target weed is relatively constant. The descriptions below of specific weeds that may be controlled by grazing animals include, in some cases, reference to their most important biological characters that ensure survival and promote undesirable interference with crop or pasture species.

Use of sheep for controlling weeds. Amor (2) pointed out that grazing by sheep is the main method of biological control on dryland farms in Victoria, Australia and that sheep are used extensively to suppress weeds on fallows and, to some extent, to reduce seed production of weeds in pastures before cropping. In Australian crop/pasture rotations there is no clear distinction between weed species (in the cropping phase) and pasture species, one of the reasons for the rapid development of herbicide resistance in species such as wall barley (*Hordeum glaucum* Steud. #[3] HORMC and *H. murinum* L. #[3] HORMU), hare barley (*H. leporinum* Link. #[3] HORLE,) and rigid ryegrass (*Lolium rigidum* Gaudin #[3] LOLRI) (90). Johnstone and Peake (51) demonstrated that it was possible to manipulate rangeland vegetation by using sheep grazing to convert an area badly infested with leafy spurge (*Euphorbia esula* L. #[3] EPHES) into good crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.] pasture containing a very limited amount of leafy spurge.

Judicious timing and intensity of grazing with sheep can also be used to improve the control of weeds that have appeared in sheep-grazed pastures. This can be because the sheep will actually eat the weeds at certain times of the year, or at higher stocking rates (gorse seedlings can be controlled by intensive grazing with sheep) or because the grazing regime 'conditions' the pasture to be more competitive and therefore resistant to weed invasion [as can occur with hare barley, wall barley and bull thistle, *Cirsium vulgare* (Savi) Tenore #[3] CIRVU, in ryegrass pastures (38, 40)]. These different effects are often inseparable.

Use of cattle for controlling weeds. For some weeds, cattle can give better control than sheep, partly because they have different grazing patterns and partly because their larger hooves can do more damage to young, tender, emerging shoots. However, they are also more selective grazers than sheep, especially of dung-soiled pasture. Hooves and large dung patches can create bare patches in pastures, which allow invasion of new weed seedlings (77).

Use of goats for controlling weeds. Woody weed proliferation has been defined as one of three major types of land degradation, and the possibility of using goats for rangeland restoration in New South Wales has been discussed (30). Goats are capable of controlling a large number of spiny and prickly weed species totally untouched by sheep and cattle (4, 99). They have also been used to control unpalatable pasture weeds like serrated tussock (10), galvanized burr [*Sclerolaena birchii* (F. Muell.) Domin] (10), white horehound (*Marrubium vulgare* L. #[3] MAQVU) (47) and rushes (*Juncus* spp.) (98). However, feral goats offer a serious threat to indigenous forests, and to young exotic forestry plantations. Their value would be enhanced considerably if their movements could be controlled by methods other than fencing. The feasibility of using electric shock collars to restrict the range of grazing goats has been evaluated (26). Shock collars effectively contained goats within the designated test area, and this non-visual 'fence'

may make development of commercial weed-grazing goat herds effective by restricting goat movement.

Control of specific weeds. *General brush weed control.* Goats have given effective control of spiny brush weeds such as blackberry (*Rubus fruticosus* agg.) (18, 20, 81), sweet brier (*Rosa micrantha* Sm. and *R. rubiginosa* L.) (45) and matagouri (*Discaria toumatou* Raoul) (15). In North America, goats have been successfully used for general brush weed control in abandoned farmland in Vermont (128). Rosenthal et al. (101) claimed that goats could be rented in the San Francisco Bay area for clearing land of thistles and other difficult weeds. Goats could be used for clearing poison ivy, poison oak [*T. diversilobum* (Torr. & A. Gray) Greene #[3] TOXDI] and poison sumac [*T. vermix* (L.) Shafer #[3] TOXVX] without suffering any adverse effects (78). When goats ate these species, the toxic principle, urushiol, was not transmitted to milk or urine, but some was found in the feces. Goats have also provided good control of *Muehlenbeckia adpressa* (Labill.) Meissn. in Western Australia (81).

Blackberry. This weed, heavily armed with large, recurved spines on its stems and leaves, spreads by suckers and tip-rooting of its long, arched branches to form large, impenetrable thickets in which trapped sheep sometimes die. In Europe and parts of Australasia it invades waste places and sometimes pasture. Its roots are perennial, but its canes live for only 2 or 3 yr (1). Its attractive fruits ensure that seeds are carried long distances by birds and animals. However, only about 10% of seeds germinate (1), and seedlings are slow to establish (66).

Pasture improvement and intensified grazing by any class of livestock easily prevent the establishment of blackberry seedlings, which grow slowly and whose spines are tender when young. However, once established, blackberry is a persistent weed that is difficult to eradicate. After existing plants have been killed with herbicides, the dead canes must be cleared, and regular, uniform grazing is then essential to control seedlings and any possible root regrowth. It is a preferred feed for goats, which will browse the plant and give effective control. For complete control, the goats must be fenced onto patches of blackberry so that the intensity and duration of browsing are adequate (18, 20).

Bracken (Pteridium spp.). Bracken is a fern that spreads and survives adverse conditions through its extensive underground rhizomes and comes to dominate extensive areas of grazed land in many countries. The fronds are poisonous (113) and the stems, fronds, and even spores are carcinogenic (25). In Britain, bracken [*Pteridium aquilinum* ssp. *aquilinum* (L.) Kuhn.] increased dramatically with the replacement of cattle by sheep on rougher grazings in the 18th and 19th centuries, and increasing cattle numbers has been suggested as a means of controlling bracken (111). In New Zealand both cattle and sheep have been used to provide very good control of *P. esculentum* (Forst. f.) Cockayne over large areas (66).

Buttercups (Ranunculus spp.). Tall buttercup (*Ranunculus acris* L. #[3] RANAC) and several other species of the same genus tend to be avoided by cattle and can become dominant in pastures grazed entirely by cattle. All the species are low-growing herbaceous plants that reproduce by seed, but often have vegetative methods of spreading or of surviving adverse conditions. Sheep are less averse than cattle to grazing these species and therefore can be used to control such weeds (35, 119). Using a low stocking rate of sheep in predominantly cattle grazing systems could control buttercups in the same way as tansy ragwort (7).

Gorse. Gorse is a leguminous shrub that bears spines. It is usually untouched by sheep or cattle and in parts of some countries (Australia, Chile, New Zealand, Portugal, Spain and others) it forms dense, impenetrable thickets over large areas of otherwise productive farmland. Reproduction is entirely by seed, and individual bushes can become quite large. Establishment is from soft, slow-growing seedlings that can be controlled by uniform, hard grazing with any class of stock. However, they are often protected from grazing by the parent plants, or from debris remaining after spraying, burning, or other control attempts.

Seed production is profuse, and because the seeds are 'hard,' with a high level of innate dormancy, over 20 000 m^{-2} can accumulate in the surface soil of gorse-infested land (130) and seeds can remain dormant for over 30 yr (72). Clearing the parent gorse by burning or spraying results in a rapid, uniform growth of seedlings, sometimes as many as 3000 to 4000/m^2 (100). Large gorse plants may re-establish after burning or spraying through development of basal adventitious buds.

In pastures, gorse seedling establishment can be greatly reduced in the presence of vigorous grass-clover competition and long rotational grazing with sheep (43). In combination, these can reduce seedling numbers by 90% and total seedling dry weight by 99%. Unfortunately, gorse is always likely to become re-established, mostly from the soil seed bank, but also from nearby flowering bushes. On bare ground, or where seedlings are protected from grazing and trampling, new or surviving seedlings can survive to

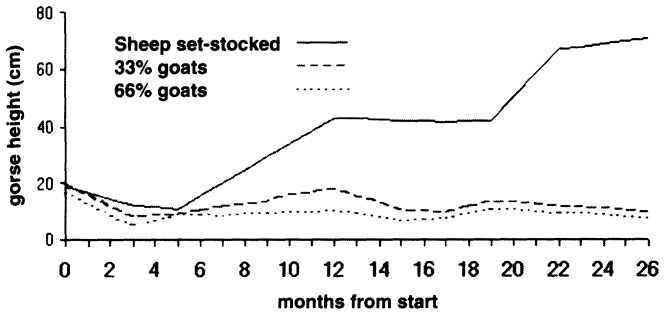

Figure 1. Effect of goat and sheep grazing on gorse (From Rolston et al., 99). Sheep set stocked (SS) at 9 to 11 stock units/ha; 33% goats + 66% sheep; 66% goats + 33% sheep, all at comparable stocking rates.

grow above the pasture, produce spines, and become resistant to sheep grazing. Gorse is readily controlled on intensively managed lowland pasture, where sheep stocking rates are reasonably high. However, less intense grazing on open pastures on less fertile hill country allows gorse to dominate.

Browsing by goats provides a well-proven biological control method for established gorse. The use of goats for control of gorse and other brush weeds in New Zealand was promoted as early as 1927 (129). Goats have been proved capable of completely removing large, dense gorse populations if they are stocked at up to 33 animals/ha. This has been demonstrated (Figure 1) in both the North (99) and South Islands (91) of New Zealand and in Australia (37). If gorse is readily available, goats actually prefer gorse to clover (Table 1) (14). In New Zealand, effective control was achieved after 2 yr, and the plants were completely killed in 4 yr. Goats browse the spiny shoots and also the bark on the stems. Radcliffe (91, 92, 93) found that goats grazing in combination with sheep developed low, rounded, green gorse bushes between which there was good, nutritious pasture establishment. Although the value of gorse as fodder is lower than for conventional grass-clover pasture, with nitrogen levels of 1.4 to 2% and digestibility of 65% (92), spring gorse protein levels are sufficient to allow stock growth (48). It has been proposed that pastures containing gorse could be managed for low-cost sustained yield of goats in combination with sheep or even cattle (93).

Hare barley and wall barley. In New Zealand and elsewhere, these are common pasture weeds, particularly in summer-dry, seasonally stressed areas. In parts of Australia they are a major component of annual pastures, even though their stiffly awned flowers and seeds cause serious damage to animals and animal products (12, 73, 106, 126). The onset of reproductive development in spring reduces palatability and creates major stock health problems, with the sharply awned seed penetrating pelts, blinding lambs, and becoming entangled in wool (29, 41, 102, 106, 107).

Most seeds show no dormancy and germinate as soon as rain falls after shedding (84), so that seed populations do not build up in the soil (88). Hare and wall barley are capable of rapid vegetative growth but do not compete well with effectively managed, established perennial ryegrass (*Lolium perenne* L.)-white clover (*Trifolium repens* L.)

Table 1. Seasonal diet selection of grass, white clover, and gorse (%) by oesophageally fistulated sheep and goats grazing swards after they had been developed by different sheep:goat grazing ratios. Percentage figures do not always total 100 because of ingestion of weeds and dead plant matter. Adapted from Clark et al. (14), with minor modifications approved by the senior author. Reproduced by permission of the New Zealand Society of Animal Production.

Sward developed by	Season	Grass[a]		White clover[b]		Gorse	
		Sheep	Goats	Sheep	Goats	Sheep	Goats
All goats[c]	Spring	72	89	26	7.4	0	0.3[d]
	Summer	42	83	54	7.6	0	0[d]
	Autumn	52	70	46	2.4	0	0[d]
	Winter	85	95	10	1.2	0	0[d]
All sheep[e]	Spring	96	6	1.1	1.5	0	90
	Summer	80	3	10	0.7	0	33
	Autumn	82	15	2	0.3	0	32
	Winter	83	0.3	0.6	0.1	1.5	95

[a]Principal feed for sheep and for goats except when goats had access to gorse or thistles.

[b]Sheep selected white clover, goats tended to reject it.

[c]Sward mainly grass and white clover with very small gorse plants.

[d]Very little gorse left for goats to eat.

[e]Sward with gorse bushes over 1 m high.

pasture growing in a fertile soil with zero water deficit (89). Typically, these grasses become a major problem in summer-dry pastures where perennial pasture species cover is reduced and growth rates are low.

Hare and wall barley cause damage to sheep only when they are flowering, so reducing this damage may be more important than controlling the weed itself. Choice of age, or breed, of sheep can reduce the adverse impacts. For example, lambs are much more susceptible than ewes to seed damage (41), Dorset Horn sheep are less affected than Merinos (29), and Romney-Border Leicester cross lambs are less affected, both in terms of eye damage and weight, than Romney-Southdown cross lambs (41). Mowing seed heads before allowing stock access can also help reduce damage.

However, the incidence of hare and wall barley in pasture can be dramatically affected by appropriate grazing management, although there are, or appear to be, marked interactions between grazing management, other pasture components, environment, and sometimes personal perspectives of the problem. These interactions probably explain most of the differences between results and recommendations in different parts of Australia and in New Zealand (29, 31, 40, 70, 73, 108, 112).

In experiments in rainfed pasture with some additional irrigation in northern Victoria, Australia (108), the basic grazing period was from the autumn break (March/April) until 20 August *(the autumn break is when autumn rains 'break' the drought at the end of summer).* Extending this basic grazing period to either 20 September or mid-October/early November did not reduce either wall barley seed set or the wall barley component of pasture in the following autumn. However, taking a silage or hay cut close to ground level in October reduced wall barley seed set by 77%. Oversowing with subterranean clover (*Trifolium subterrraneum* L.) seed before the autumn break reduced wall barley seed set the following spring by over 60%.

In rainfed phalaris (*Phalaris aquatica* L.) pasture in Australian Capital Territory (70), annual grass (including wall barley) content in the pasture was reduced by over 60% by increasing the intensity of the sheep rotational grazing *(rotational grazing involves moving stock regularly between fields, so that the pasture can recover between grazings)* from set stocked *(set stocking is when the stock are left on the same pasture for lengthy periods)* to each part of the paddock being grazed for 1 wk and then left ungrazed for 8 wk. In these experiments, increasing the sheep stocking rate *(stocking rate is the number of sheep/unit area)* from 20 to 30/ ha did not affect the wall barley content of the pasture.

On irrigated pastures in the Murray basin, Australia (73), control of wall barley was achieved by deferring grazing for 20 d after the opening autumn irrigation and then grazing at 19 sheep/ha. At Armidale, New South Wales, Australia (29) wall barley was much more prevalent in pastures grazed by Merino sheep than by those grazed with Dorset Horn sheep, there was more wall barley in tall fescue (*Festuca arundinacea* Schreb.) pastures than in phalaris pastures and fewer wall barley seed heads at a stocking rate of 16 ewes/ha, as opposed to 8 or 12 ewes/ha. The best treatment for controlling wall barley was therefore 16 Dorset Horn ewes/ha on phalaris-based pasture.

In New Zealand, there is a consensus that increased grazing pressure, especially in spring and early summer, results in a lower hare or wall barley content in pasture (31, 40). Taylor's (112) aim in de-stocking infested land in spring and summer was to make hare or wall barley plants more conspicuous, so that they could be dealt with in other ways.

Hartley et al. (40) carried out a detailed investigation of the effects of sheep grazing on wall barley population change (Table 2). Continuous set-stocking, to maintain short but not overgrazed pasture, virtually eradicated wall barley in 2 yr; periodic hard grazing achieved a similar result in 3 yr. Hard grazing in spring to prevent the grass flowering was of major importance. Lax grazing in the summer, to maintain pasture cover and impede seedling establishment, reduced wall barley the following year.

Use of five grazing management regimes to assess effects of different grazing practices and various grass

Table 2. Relative numbers of wall barley seed heads produced under four grazing regimes over three years. From Hartley et al. (40). (Reproduced by permission of the New Zealand Plant Protection Society).

Grazing regime	Pre-trial	1st year	2nd year	3rd year
Farm practice[a] (heads/m^2)	135	18.7	14.2	22.1
Farm practice[a] (%)	100	100	100	100
Continuous set-stocked[b]	111	24	0.4	0
Medium rotationally grazed[c]	98	41	18	29
Hard/lax rotationally grazed[d]	107	37	1	0.1

[a]Twenty wether (castrated male) sheep/ha, increased by 50% in spring to represent lambing. Sheep set-stocked in spring (August to December) and autumn and rotationally grazed in winter and summer.

[b]Pasture maintained at 2 to 4 cm high.

[c]Pasture grazed for 1 wk out of 3 to reduce pasture cover to 750 kg/ha.

[d]As c, but grazed to 500 kg/ha in spring and autumn and less hard in summer and winter.

species or cultivars on wall barley showed that hard spring grazing reduced the wall barley content of pastures by over 90% (86).

These results show that controlling hare or wall barley by grazing management can be very effective, but the way in which this control can be achieved clearly depends on local growing conditions. However, stock management options are eliminated after the onset of hare or wall barley flowering. Even goats do not like to eat the seed heads.

Larkspur (*Delphinium* spp.). Species of larkspur, herbaceous mountain rangeland plants in parts of the United States, are a leading cause of cattle deaths on mountain rangeland due to their content of poisonous alkaloids (94). Sheep are more resistant to larkspur poisoning than cattle and can be used to graze larkspur infested pastures before cattle are allowed access (94, 95). Under some conditions, sheep utilize large amounts of larkspur, which can be a nutritious source of feed. Intensive management of sheep by bedding or holding them on larkspur patches may cause heavy, non-selective grazing of the weed (94).

Leafy spurge (*Euphorbia esula* L.). Leafy spurge, a perennial, herbaceous plant of pasture and range land in parts of the USA, can be controlled by both sheep and goats (56, 60), although it is avoided by cattle because of its latex content (60). Under some circumstances, sheep can also be poisoned (56). Effective control with sheep may take 4 yr. Grazing should be started early in the season, and a mature stand should be mowed before being grazed (56). Both sheep and goats pass ingested seeds in the fecal material (55), but sheep were more effective than goats in reducing germinability and viability of ingested seeds. Animals should be confined for 5 d, until all viable seeds have passed through the digestive system, before moving on to clean pastures.

Previous training of sheep appears to be important when using them for control of this, and possibly other, weed species. Lambs with previous experience of eating leafy spurge, when compared with naive lambs, had a higher relative preference for leafy spurge, spent more time grazing it, and were more likely to be effective control agents (122). Similarly, lambs exposed to mountain mahogany (*Cercocarpus montanus* Raf.), considered palatable to most ruminants, subsequently consumed more of it than did naive lambs (110).

Paterson's curse. This hairy annual herb is common across Australia, especially in pastures in the southern areas. Its rosette habit and large tap root make it a competitive weed in pastures. Its leaves contain an alkaloid that makes it unpalatable to cattle and can make it poisonous to sheep and horses. However, Paterson's curse can be almost eliminated by high grazing pressure with sheep (13).

Rushes (*Juncus* spp.). These species form low-growing clumps that steadily extend outward. They are extremely common weeds of waste places and often occur in pastures, especially in wetter areas and in less-intensively grazed hill pastures. They are a problem only because most species are not readily grazed and they occupy pasture space, reducing livestock production in proportion to the space occupied (39). High producing, well-drained, intensively grazed pastures are not readily invaded. Once established, however, rushes are hard to control selectively.

Sheep mob-stocked (concentrating large mobs of sheep onto a fenced area for a few days) at high stocking rates provided better control of rushes than when they were set-stocked (98). Goats provided even better control (Table 3). A minimum of 12 goats/ha was needed for severe suppression, and some species were grazed in preference to others (98). In a Welsh trial, 20 to 60 goats/ha grazing red fescue (*Festuca rubra* L.)-white clover pastures from June to October reduced the proportion of *Juncus effusus* L. tussocks with living stems. The greatest reduction occurred in shorter pasture, and weed suppression was maintained for 3 yr after the trial (52).

Sweet brier (*Rosa micrantha* Sm. and *R. rubiginosa* L.). Sweet brier is a very spiny weed, related to the garden rose. In New Zealand, it can form dense, impenetrable thickets up to 3 m high. Sweet brier forms multi-stemmed plants that continue production of new stems from basal juvenile canes. Mature plants flower profusely and seeds are borne in fleshy orange hips that are often eaten, and spread, by birds and stock. Ingestion helps break seed dormancy and seedlings are small, leafy, and slow-growing (59).

Both feral and angora goats can be highly effective as biological control agents for sweet brier (45, 63). In a

Table 3. Mean height of rush clumps following grazing by goats and sheep beginning in early 1979. From Rolston et al. (98). Table reproduced by permission of the New Zealand Plant Protection Society.

	Plant height		
	Feb. 1980	July 1980	Feb. 1981
	cm		
All goats, set stocked	40	14	20
66% goats, 33% sheep, set stocked	54	28	38
33% goats, 66% sheep, set stocked	96	84	93
All sheep, set stocked	86	104	105
All sheep, mob grazed	48	43	60

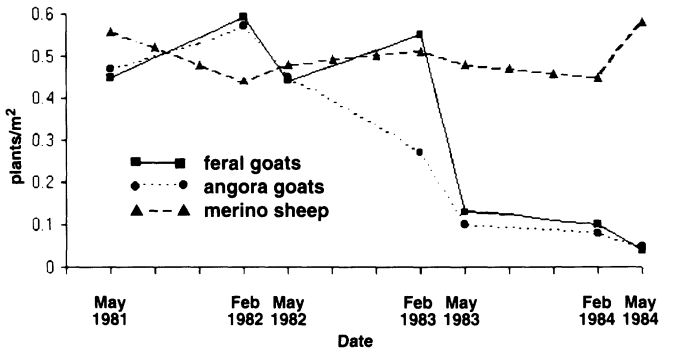

Figure 2. Effect of feral and angora goat and Merino sheep grazing on sweet brier. Animals were set-stocked at comparable stocking rates. From Holgate and Weir (45).

grazing trial in Central Otago, New Zealand, goat grazing reduced living brier to negligible proportions within 2 yr while Merino sheep had little effect (45) (Figure 2). Goat grazing increased clover content in the pasture swards, and also reduced brier plants in a 50-ha block of short tussock grassland.

Tansy ragwort (*Senecio jacobaea* L.). This is a significant pastoral weed in many countries and is frequently listed in legislation as a noxious weed that should be eradicated (9). However, the world-wide spread of tansy ragwort and its persistence on agricultural land suggest that containment is a more realistic objective than eradication.

Tansy ragwort is not common in seasonally stressed, summer-dry pastures and is more clearly associated with dairy than sheep production (66). Despite its occurrence over a wide range of edaphic and climatic conditions, tansy ragwort can be controlled by effective management of stock, and is rarely a major problem in high-producing, well-managed pastures on heavier soil types (66).

Tansy ragwort is toxic to stock and health problems included photosensitization, jaundice, weight loss, and impairment of liver function (71). Cattle and horses usually refrain from grazing it in standing pasture but will readily consume it in hay and silage (66). The weed can dominate cattle-grazed pastures. Sheep are less averse to grazing this species and are less affected than cattle by the toxic principle (71).

Tansy ragwort is considered to be a biennial with a tendency to become a multi-crown perennial if subjected to repeated, partial defoliation (9, 28, 83). Small lengths of root are capable of vegetative propagation to produce new plant individuals, but most new plants establish from seed. Plants establishing by vegetative propagation are more competitive than seedlings because of the increased mass of stored reserves.

There have been no major studies on the effect of tansy ragwort invasion on pasture production, either in terms of utilizable dry matter production or of animal production. Preferential grazing that avoids tansy ragwort plants, observed in cattle (66), reduces pasture utilization. For this reason the introduction of sheep to graze in association with cattle has been advocated (103). Since increased density or pasture cover was negatively correlated with the survival of tansy ragwort seedlings (9), rapidly growing pasture species are essential for tansy ragwort suppression, especially at the seedling stage of tansy ragwort (34). Stimulating growth of inherently low fertility pastures by phosphate and nitrogen fertilizer may significantly reduce the population of tansy ragwort seedlings and small rosettes (117).

Pasture utilization and, in particular, grazing management have a major effect on tansy ragwort persistence. Early summer grazing with sheep has been effective in reducing tansy ragwort stands (23, 36, 66, 105), although consideration should be given to tansy ragwort-induced stock health problems. Cattle grazing cannot be advocated for this reason and may be counter-productive, as intensive grazing pressure usually opens up swards for easy colonization by tansy ragwort and other weed species. Mechanical removal of tansy ragwort by cutting or grubbing (digging out individual rosettes) may reduce visually obvious tansy ragwort only in the short term. Shoots may regrow from crowns and from complete or partial root systems. Regular defoliation promotes the establishment of a perennial habit and the persistence of tansy ragwort.

Recent research (7) suggests that a low stocking rate of sheep in a predominantly cattle grazing system can give effective control of tansy ragwort. Ewe hoggets (one year-old sheep), set-stocked or mob-stocked at 1.5 or 3 stock units/ha, were used to control tansy ragwort in a bull beef grazing trial. Set stocking caused higher tansy ragwort mortality than mob-stocking and 3 stock units/ha resulted in greater mortality than 1.5 stock units/ha. The sheep seemed to suffer no damage, and this technique offers the potential of controlling tansy ragwort in bull beef systems, and also on dairy farms.

Thistles. There is a large number of species, collectively described as thistles, that invade pasture. With the notable exception of Canada thistle [*Cirsium arvense* (L.) Scop. #[3] CIRAR] which produces vegetative ramets from fragmented roots, most species reproduce only by seed. This-

tles usually pass through a low growing rosette stage followed by a period of stem elongation that raises the flowers well above ground level. Thistles are weeds primarily because they reduce pasture production through the smothering and competitive effects of rosettes and the prickly leaves that discourage close grazing and hence cause poor pasture utilization. In summer tall, dense flowering stalks can discourage stock movement and make stock handling very difficult.

Pasture management is often important for limiting invasion of pastures by thistles, and the accumulated volume of knowledge on the biology and control of musk thistle (*Carduus nutans* L. #[3] CRUNU) (22, 87) can probably be extended to other pasture-invading thistles.

Direct measurements of loss of pasture production caused by musk thistles have been made by harvesting herbage from under thistle plants and from concentric areas extending out from the edge of the rosette (118). Rosette to early bolting plants had little effect on pasture growth, other than beneath the rosette. The effect on herbage production was greatest in late summer when some plants had reached maturity and were senescing, when calculations showed that 1000 musk thistle plants/ha reduce total pasture production by 13.3%. This is a significant effect from a relatively low population of musk thistle plants.

It has been shown that the effects of musk thistle on pasture species are partly allelopathic in nature (123, 124, 125). Musk thistle seeds, seedlings, and vegetation all reduce the growth of one or more pasture species, without seriously affecting the growth of musk thistle itself.

Pasture management is the key to reducing the effect of musk thistle (24). Continuous pasture cover may reduce seed germination and also kill young seedlings and developing rosettes. Studies have shown that complete pasture cover significantly reduces seed germination (54, 77, 79). There is a major practical advantage in maintaining continuous pasture cover in autumn and spring, when the major seed germination events occur. However, in practice this may be difficult in seasonally stressed pastures where musk thistle is typically a major problem. The selection of site-adapted, persistent pasture cultivars that are resistant to invertebrate pests assists in reducing musk thistle establishment and invasion.

Overgrazing in late summer and early autumn opens up the sward, reducing the possibility of complete pasture cover during the critical seed germination period in autumn. There are several ways to avoid overgrazing including reductions in stocking rates, removing grazing animals completely from weaker pastures, rotational grazing, and the provision of adequate feed alternatives such as alfalfa (*Medicago sativa* L).

Cattle and sheep will often eat the flower heads off some thistles, presumably because of the sweetness of their nectar. Goats also attack thistle flower heads first, even on heavily-spined heads like blessed milk thistle [*Silybum marianum* (L.) Gaertn. #[3] SLYMA].

Cattle provided some control of yellow star thistle (*Centaurea solstitialis* L. #[3] CENSO) (115), which becomes spiny only when flowering, but the control achieved through grazing management was much less than that achieved with herbicides. Sheep grazing the same species increased flower head densities (114). However, sheep have been successfully used to control other thistles, at least partially. Italian thistle (*Carduus pycnocephalus* L. #[3] CRUPY) and slenderflower thistle (*C. tenuiflorus* Curt. #[3] CRUTE) have been controlled in Tasmania, Australia, by periodic grazing. In autumn and autumn/winter ungrazed plots, pasture competition caused the thistles to become etiolated and lush, with softened prickles (5).

Canada thistle, a perennial thistle which spreads and overwinters by means of its extensive root system and whose control with herbicides is inconsistent, can be successfully controlled by sheep grazing, or by combining herbicides with subsequent grazing (Table 4) (42, 68). Control by grazing alone requires intensive grazing of the young, soft, aerial thistle shoots in spring, not usually

Table 4. Effect of one year's sheep grazing treatments on populations of Canada thistle shoots. Adapted from Hartley et al. (42). Table reproduced by permission of the New Zealand Plant Protection Society.

Spring treatment	Summer treatment	Thistle shoots in Sept. 1982	Thistle shoots in Sept. 1983
		Nos./m^2	% of those in Sept. 1982
Lax set-stocked	Lax rotationally grazed	3.4	131
	Medium rotationally grazed (MRG)	3.4	70
	MCPB[a] + MRG	2.1	7
	Thistles mown + MRG	1.6	65
Hard set-stocked throughout		2.3	56
Lax rotationally grazed throughout		2.3	169
Medium rotationally grazed throughout		2.3	54
Hard rotationally grazed throughout		1.8	5
Least significant difference (5% level)			42

[a]MCPB [4-(4-chloro-*o*-tolyoxy)butyric acid] applied at 1.5 kg ai/ha in December 1993.

Table 5. Total flowers/plant in late summer (February; New Zealand) for thistle species grazed by goats and sheep for 2 yr. Adapted from Rolston et al. (98). Table reproduced by permission of the New Zealand Plant Protection Society.

	Flowers/plant		
	Bull thistle	Canada thistle	Marsh thistle
All goats, set stocked	1	0	—
66% goats, 33% sheep, set stocked	0.1	0	3
33% goats, 66% sheep, set stocked	1	0	2
All sheep, set stocked	35	1.1	61
All sheep, mob grazed	8	1.9	31

possible because of pasture feed surpluses at that time. However, late spring or early summer mowing or herbicide application, followed by hard, monthly grazing, also gave extremely good thistle control. The often-reported inconsistent control resulting from herbicide treatments may be due to variability in grazing intensity after herbicide application. Cattle seem to push into patches of this thistle more effectively than sheep and, at higher stocking rates, may improve the control afforded by treatments like mowing (44).

Sheep have given some control of bull thistle (38). Rotational grazing, as opposed to set stocking, provided better control of existing thistles, but allowed greater establishment of new seedlings. There was also an interaction between sward species and grazing management in the effect on thistle survival, with velvet grass (*Holcus lanatus* L.) being much more competitive when it was not grazed.

Goats eagerly devour flowering thistle plants (Table 5) but are not attracted to the vegetative rosette stage. Thistles known to be controlled by goats include artichoke thistle (*Cynara cardunculus* L.) (47, 62), blessed milk thistle (10), bull thistle (98), Canada thistle (98), distaff thistle (*Carthamus lanatus* L.) (80), marsh thistle [*Cirsium palustre* (L) #[3] CIRPA] (98), musk thistle, Scotch thistle (*Onopordum acanthium*) (47, 62), *O. illyricum* (11) and yellow star thistle (114). Control of distaff thistle by 7.2 goats/ha increased from 13% in the first year of a grazing experiment in Western Australia to 100% by the fourth and fifth years. Goats, unlike sheep, continued to eat the flower heads once they had dried, and less than 0.5% of viable seeds passed through their digestive systems, compared to about 1% in sheep (80).

CROP WEED CONTROL

In Asian smallholder farms, weeds of food crops form the great bulk of feed for animals (69) and weeds also contribute to animal feed in African farms (76). In neither case can the animals concerned be truly regarded as 'grazing' animals. Carter (13) noted how grazing animals in the pasture phase of a rotation can reduce seed set by plant species that have the potential to be weeds in the cropping phase. Amor (2) also pointed out that sheep are used to reduce seed production of weeds (and pasture species) in pastures before the cropping phase of the rotation. Grazing also has been one of the control techniques recommended to help prevent the development of herbicide resistance (6).

Sheep have been used to graze the early phases of autumn-sown cereals in the South Island of New Zealand, at least partly for weed control, although grain yields tend to be reduced by grazing (65). Sheep are also often used to 'clean up' weed growth in orchards and vineyards.

Pigs have been suggested as a means of controlling purple nutsedge (*Cyperus rotundus* L. #[3] CYPRO) on small holdings in Panama (32). In this case the pigs probably dug up, and may have eaten the purple nutsedge bulbs, rather than grazing the vegetation. Chickens (*Gallus gallus*) have been used to give complete control of the same species within 2 yr in very small pens (c. 67 m^2), but in a larger (c 0.2-ha) pen, they only controlled the weed in relatively small areas (67). Eight geese (*Anser anser*) in 0.2-ha plots did not control purple nutsedge if no crop was present, but 16 geese in unweeded cotton (*Gossypium hirsutum* L.) in the same size plots provided extremely good control of the weed infestation within 2 yr (67).

Geese have been used for weed control in peppermint (*Mentha* × *piperita* L.) in Oregon, and in Oregon and California for weed control in garlic (*Allium sativum* L.), tomatoes (*Lycopersicon esculentum* L.), cucumber (*Cucumis sativus* L.), cotton, orchards, and vineyards (64). Weeder geese have also been reported in strawberries (*Fragaria* × *ananassa* Duch.), corn (*Zea mays* L.) (101) and potato (*Solanum tuberosum* L.) (58).

WEED CONTROL IN TREE CROPS

Both sheep and cattle are used regularly for weed control in various tree crops, including forest crops. Grazing has been proposed as a management tool in native woodland (27). Only relatively recently, though, have stocking rates and the economics of such systems been studied.

Cattle have been used for weed control and meat production under oil palm (*Elaeis guineensis* Jacq.) in Malaysia (74). By grazing cattle under a controlled system, a

substantial cost saving on weed control is achieved, and a profit is made from the cattle.

Weeds in plantation forests can reduce tree growth and are often a fire hazard. Grazing animals have been used for weed control in plantations in several countries (49, 50, 61, 82, 104, 109). In one study (61) of Californian plantations of young ponderosa pine (*Pinus ponderosa* Laws.) and Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), grazing animals were found to consume large amounts of competing vegetation, without causing any statistically significant increase in pine diameter or height after 9 yr. In another study in Oregon (104), effects of controlled sheep grazing on Douglas fir growth, tree diameter, and height growth were measured. Sheep removed some new tree lateral branches and terminal leaders. Grazing proved very effective in reducing 'weedy' red alder (*Alnus rubra*) establishment and growth. The net effect of grazing (taking into account the negative effects of browsing together with the positive effects of reduced competing vegetation) was to increase Douglas fir height and stem diameter.

Grazing animals can be used for controlling a range of weed species in young forestry plantations in New Zealand (127). Weeds successfully controlled include pampas grass (*Cortaderia* spp.), bracken, gorse, toetoe [*Cortaderia fulvida* (Buchan.) Zotov], and shrub hardwoods (127). The most notable success was in the control of pampas grass with beef cattle (19, 127). Sheep and cattle have also been used effectively for control of bracken and gorse in radiata pine (*Pinus radiata* D. Don) forests elsewhere in New Zealand. This has provided substantial cost savings in silviculture, and revenue from grazing benefits (8, 33). Trials in Western Australia showed that 8-9 goats/ha were able to graze blackberry and several other weeds to a height of a few cm within 1 year in pine plantations (81).

Cattle have been used for weed control in Caribbean pine (*Pinus caribaea* Murelet.) plantations in Costa Rica (109). In pines planted at 2.5 by 2.5 m, a quadratic model calculated using 1984 data predicted use of a maximum number of 0.89 animal units (350 kg liveweight)/ha/yr for weed control in 4.5-year-old plantations. Grazing started at plantation ages of 2.5 yr and over and no plantations older than 9.5 yr were grazed. Following studies on cattle grazing in a naturally regenerating mixed conifer shelterwood in California, cattle grazing strategies maximizing timber, wildlife and livestock production on California forest range have been described (49).

Sheep grazing for the biological control of unwanted vegetation in regenerating conifer plantations has been successfully tested in Oregon (57), where Douglas fir forests were grazed with little or no damage to conifer regeneration, except in younger plantations in spring.

WEED CONTROL IN WASTE PLACES

Sheep and cattle are often used to control unwanted vegetation around farm buildings, along farm tracks, and in other 'waste' places. At least in New Zealand, and possibly elsewhere, cattle are commonly used to graze roadside vegetation at some times of the year. This 'weed control' makes roadsides neater and probably safer, but leads us again to consideration of when a species is a weed (3).

THE FUTURE

Pressure from consumers in developed countries is likely to force agricultural production systems increasingly to rely less on pesticides and more on 'natural' methods associated with food production. Agencies concerned with control of weeds on a national or regional scale are beginning to doubt the value of reliance on herbicides alone, and herbicide resistance has developed in some weed species. These influences will mean more ready acceptance of alternative methods of weed control, including grazing animals, especially in pastoral systems yielding animal protein.

Superficially, such systems appear more sustainable. Farming systems carrying more animal species, more diverse pasture systems, a wider range of crops, and using combinations of weed control methods, including grazing animals, insects, mycoherbicides, chemical herbicides, and improved crop and forage species are generally considered more sustainable. The need for 'integrated weed management' is likely to become much more urgent and future research into weed control in pastoral production systems in developed countries should concentrate on this aspect.

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