# final report

Project code: B.WEE.0150

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Date published: February 2014

PUBLISHED BY
Meat & Livestock Australia Limited
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NORTH SYDNEY NSW 2059

# New approaches to weed management

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

# Abstract

Weeds represent a large economic cost to the Australian grazing industry in terms of production loss and direct cost of control. Success in controlling priority weeds is challenged by complexity of control approaches and scale of infestations. A review of innovative approaches to weed control examined evidence and opportunity for new ways to manage weeds that exploited plant and animal management. Four areas were considered key to this purpose: grazing management, physical removal, livestock selectivity and altering pasture phenology, quality and growth. The most promising approaches to emerge from the review were considered for technical feasibility and likelihood of success against a number of criteria. The top two weed control approaches recommended for future R&D were use of plant growth regulators to selectively prevent development of seedheads and increase grazing preference and training of livestock to alter feed preferences towards weed consumption.

# Executive Summary

A review of literature, reports and discussion with key informants was undertaken to look for evidence and opportunity for new ways to manage weeds that exploit plant and animal management. The review process focused on novel or innovative approaches to weed management from the perspective of viewing the weed as a potential resource rather than a liability. As such, the review does not include a detailed summary of the known approaches to weed management. The most promising approaches to emerge from the review were:

- Use of plant growth regulators to exploit plant species variation in phenology to selectively vary plant (weed) growth and quality and consequently increase grazing preference for weeds.
- Supplements and/or provision of a range of plants available to livestock to influence acceptance of weeds through effects mediated by interactions with antinutrients, changing protein, energy or macro/trace mineral availability or other interactions.
- Altering feed preferences of livestock through training which may be amplified through social learning (ideally with young animals) with the prospect of being fixed through epigenetic change.
- Trampling by livestock.

The technical feasibility and likelihood of success of these weed control approaches were assessed by consideration of 12 attributes that covered the aspects of technical merit, time span and on-going duration of effects, range of geographic application and weed types, effects on livestock production, labour, infrastructure and cost. Three of the four weed control approaches were considered worthy of R&D investment with the top two approaches being (i) use of plant growth regulators; and (ii) altering feed preferences of livestock through training. Trampling of weeds by livestock was not considered of sufficient merit and is not recommended for further consideration.

# Table of Contents

# 1.0 Background

The Terms of Reference for this project were based on the background that weeds represent a large economic cost to the Australian grazing industry in terms of production loss and direct cost of control. Success in controlling priority weeds is challenged by complexity of control approaches and scale of infestations. Complexity of weed control is associated with varied forms of weeds (i.e. herbaceous, woody, annual or perennial) and interaction among management approaches (i.e. chemicals, fertiliser, biological control, grazing). Despite significant investment in weed research, weeds remain an issue, which led to the commissioning of this review by Meat & Livestock Australia (MLA).

The comprehensive review of innovative approaches to weed control contained in this report was shaped by the direction from MLA to look for evidence and opportunity for new ways to manage weeds that exploit plant and animal management. Therefore the review does not deal with the known practices and instead has a heavy emphasis on managing weeds by modifying livestock and/or the weed itself. This emphasis was based on the premise that weeds can be assessed as a potential feed resource rather than (always) a liability. Producers have had information about standard weed control measures for decades and yet weeds continue to impose a large economic cost to the grazing industry. Adoption of existing and novel approaches by producers will come down to the internal decision of benefit and cost. The approaches identified in the review need to be feasible to apply on- farm, environmentally sustainable, improve feedbase productivity and decrease cost of production. These aspects were considered in the second stage of this project providing recommendations for candidate work areas.

# 2.0 Project objectives

Project objectives provided in the Terms of Reference were:

1) A comprehensive review of novel / innovative approaches that are / can be applied to weed management, recognising the varied Australian contexts (northern and southern geographic differences; intensive and extensive production systems; weeds that are woody, herbaceous, annual and perennial). Where candidate approaches may be better suited to a particular context, this should be stated (e.g. extensive systems / rangelands, woody weeds; high rainfall herbaceous pasture weeds etc.)

2) A scoping report with recommended candidate work areas including:

    a. assessment of technical feasibility and likelihood of success
    b. priority areas to further scope or progress to testing
    c. potential investment partners and research providers for the project

# 3.0 Methodology

## 3.1 Objective 1

Weed control approaches included in this review must have had a component of using livestock and dealt with utilisation of the weed as a potential feed resource. By definition, approaches to control toxic weeds were not included in the review unless the innovative approach could reduce toxicity and permit safe livestock consumption. The overarching focus was on improving pasture and livestock productivity while managing weeds. The decision was made to concentrate on general principles for functional groups (i.e. herbaceous, woody, annual, perennial) but examples from within these groups have been provided as an example of the approach. The purpose of the review was to identify novel and innovative approaches to weed management (and not simply review existing practices) as the basis for developing recommendations for further R or D.

Information was collected in a number of ways including (Table 1):

- Emails or media seeking information
- Key informants
- Literature both published and unpublished

Table 1: Sources of information for the review

| Key Informants | Literature | Web addresses |
|---|---|---|
| Juan Villalba (Associate Professor, Utah state University) | Comprehensive search of national and international literature (see reference list), conference proceedings and RDC project reports. | Kathy Voth (Livestock for Landscapes; http://www.livestockforlandscapes.com/) |
| Bruce Maynard (Principal, Stress Free Stockmanship) | | Bruce Maynard (Stress Free Stockmanship; http://stressfreestockmanship.com.au/). |
| Brian Sindel (Professor University of New England) | | Friday Feedback (Meat & Livestock, Australia) |
| Chook Kealey (Practitioner, Low Stress Stock Handling) | | |
| Stuart Smith (DPIEW Tasmania) | | |
| Mark Trotter (Senior Lecturer University of New England) | | |

The key areas included in the review covered the principal topics (Table 2) where livestock may be involved in managing weeds.

Table 2: Key areas included in the review

| | | |
|---|---|---|
| **Grazing management**<br>• Stock density<br>• Sheep/cattle/goats/other browsers or grazers<br>• Paddock design and water placement<br>**Physical removal**<br>• Fire<br>• Slashing | **Livestock selectivity**<br>• Supplements<br>• Training livestock | **Altering pasture quality, growth and phenology**<br>• Soil fertility<br>• Growth regulators<br>• Sub-lethal herbicides |

### 3.2 Objective 2

Assessment of the feasibility and likelihood of success of the candidate weed control approaches was conducted by the project team by considering a range of attributes relating to technical, applicability, immediacy, durability, labour and cost (Tables 3 and 4).

# 4.0 Results: review of new approaches to weed management

Unless the underlying causes for the weed being present are understood and actions taken to address these causes, the weed is likely to reinfest and actions amount to only a short term fix.

### 4.1 Grazing management

<u>4.1.1 Stock density</u>

The terms stock density and stocking rate have multiple definitions within the literature and for clarity are defined here. Stock density refers to the number of animals per hectare in a paddock at a given time and in southern areas is defined in terms of dry sheep equivalent (DSE)/ha and in northern areas as livestock units (LSU)/ha. The attraction of using DSE arises from the general assumption that 1 DSE consumes 1 kg of pasture each day (expressed on a dry matter basis) and is easily amendable to use in pasture budgets. As an example, a mob of 500 steers (say each with a DSE value of 8) will have a total DSE value of 4,000 (500 steers x 8 DSE/steer) and when grazing in a 7 ha paddock, the stock density will be 571 DSE/ha (4,000 DSE/7 ha): the assumption is that the mob will be consuming herbage at the rate of 571 kg/ha/day. Stocking rate refers to the number of animals per hectare in a group of paddocks or across a farm and is expressed using the same units of DSE/ha or LSU/ha. If for the example, the 500 steers were grazed on a total area of 400 ha then the stocking rate across the total area will be 10 DSE/ha (4,000 DSE/400 ha). Where a group of animals is continuously grazed in one paddock without change in the number in the group for a season/s or year then stocking density will be the same as stocking rate.

Traditionally grazing management to aid in weed control has focused on punitive treatment of weeds by 'flogging' the pasture and thereby 'forcing' animals to consume the weed. It is now accepted that this treatment does not provide any long-term benefit for weed control and paradoxically accelerates loss of desirable species within the pasture (Earl and Jones 1996) because under such treatment the desirable species experience repeated defoliation and greatest utilisation. There may be exceptions to this trend where a population of annual grasses (e.g. *Vulpia* spp, *Avena fatua*) recovers only slowly are periodic heavy defoliation (Tozer and Chapman 2011) timed close to initiation of flowering (Carter 1990). Susceptibility of weeds during various phenological stages (Rinella and Hileman 2009), manipulated by herbicides and/or growth regulators is discussed later in this review. In general, such positive effects of grazing are largely co-incidental, confined to small areas and limited in value because of an inability to apply the treatment across a large area and variation in the timing of phenological events within species in a paddock.

After discounting the role of high rates of pasture utilisation as a reliable method of weed control, the causative effects of stock density on manipulating pastures can be attributed principally to trampling and to a lesser extent to changes in the spatial distribution of animals within a paddock (largely manifest as more even utilisation of pasture within a paddock rather than a direct effect on weeds *per se*.). Trampling of weeds (especially woody weeds) such as blackberry (*Rubus fruticosus*) and bracken fern (*Pteridium esculentum*) and to a lesser extent perennial grass weeds (e.g. *Imperata cylindrica*) is practiced by graziers. The experience of the authors of this report is that stocking density needs to be at least 500 DSE/ha and preferably 1,000 DSE/ha or more contributed by cattle rather than smaller ruminants (because of a greater force per unit area exerted by their hooves) to have an effect. Graziers who are unable to reach such stock densities within a paddock use lick blocks or other supplements to attract livestock to congregate in weedy areas and trample the vegetation. Trampling reduces an overburden of weed herbage and causes physical damage to plants, and the associated effects from urine and dung deposited during the event, coupled with increased sunlight radiation available to lower pasture strata, results in increased herbaceous growth. The success (or otherwise) of trampling is not well recorded in the literature and depends on pasture management after the disturbance to encourage the growth and hence competitiveness of desirable pasture species. Trampling is part of the disturbance regimen that livestock (especially cattle) impact on the pasture ecosystem and if allowed to reduce ground cover, can increase —rather than decrease— weed infestations and the soil seedbank of weed species (Renne and Tracy 2007). In this manner, trampling is not desirable when it leads to pugging of wet soils.

Trampling (300–800 DSE/ha) with cattle was used by Grace et al (2002) to reduce the population of saffron thistle (*Carthamus lanatus*) by targeting the rosette stage in autumn and when flowering stems were present in the spring. When considered together, trampling reduced the number of saffron thistle plants by 30% but in comparison, good ground cover reduced the number of plants by 96% as compared to bare ground. It's likely that trampling is underused as an aid for the control of some weeds but its benefit is likely restricted to patches rather than widespread weed presence.

#### 4.1.2 Sheep/cattle/goats/other browsers or grazers

It is common practice among graziers to graze different species of livestock on their farms as an aid for weed control (Trotter 2007) because of differences in the pattern of preference and avoidance of plants (Thomas 2010). For example sheep and goats readily consume oxeye daisy (*Leucanthemum vulgare*), fleabane (*Conyza spp*), Patterson's curse (*Echium plantagineum*), fireweed (*Senecio madagascariensis*) and St John's Wort (*Hypericum perforatum*) and other plants (Lacey et al 1984) whereas cattle do not. Goats are also more likely to include shrubs (including those species containing secondary plant metabolites (see later section) at a greater proportion in their diet than sheep (Rogosic et al 2008). Cattle are better able to consume large low quality perennial tussock grasses. The authors have had reported to them that camels are used successfully in southern Queensland in the control of galvanised burr (*Sclerolaena birchii*).

The practice of using a number of livestock species for weed control and pasture utilisation is well established but implementation depends on an assessment of the costs and benefits of different livestock enterprises including labour requirements, infrastructure (e.g. fencing), profitability and cost of control. It is possible that multi-species grazing may become more effective if coupled with other weed control approaches that alter plant phenology and form or change dietary preferences of livestock and these are discussed later in this review.

#### 4.1.3 Paddock design and water placement

Paddock design and water placement (i.e. distance to water from within a paddock) have effects on weed control through pasture utilisation. High rates of pasture utilisation occur closest to water sources and this is especially prominent in pastoral regions of Australia (McIvor et al 2010) and can predispose to weed encroachment through creation of bare ground or shrub encroachment away from water sources. Novel approaches concerning water placement to aid weed control were not found in preparing this review.

Paddock design includes concepts of aspect, prevailing wind direction and shape of the paddock (length x width ratios) as a means for encouraging more homogenous utilisation of pasture to improve competitiveness against weed encroachment. For example, south facing slopes in Victoria and South Australia will often be underutilised by livestock and have greater herbage mass composed of less palatable plants when compared to slopes with other aspects. North facing slopes are often over utilised by livestock and when coupled with greater sunlight radiation are more prone to bare ground. For both reasons of under and over utilisation, pastures with southern and northern aspects are prone to weeds. Paddocks designed (if possible) to avoid containing both southern and northern aspects provide the chance to better manage pastures creating less chance for weeds to encroach. Novel ways of using paddock design elements for weed control were not found in the process of this review.

## 4.2 Physical removal

### 4.2.1 Fire

Fire is regarded as an important and the most economically viable option for the control of woody weeds in rangelands. Burning of native pasture has the effect of reducing herbage mass and subsequently increasing the nutritional quality of the pasture regrowth (Orr et al. 2005). In a survey of 375 northern Australian beef producers Bortolussi et al. (2005) found the majority (67-100% between regions) routinely used fire either to reduce woody weeds, reduce dry herbage mass and stimulate quality of pasture. However, low rainfall and poor pasture regrowth following a fire has an adverse effect on animal production (O'Reagain et al. 2007).

In the absence of an effective fire regime open grassland woody species may increase (DERM 2011). Species of greatest significance are prickly acacia (*Acacia nilotica*), mimosa (*Acacia farnesiana*) and gidgee (*Acacia cambagei*) (Burrows et al. 1990). Others species of importance include the regrowth of eucalypts (*Eucalyptus* and *Corymbia* spp.) and wattle (*Acacia* spp.) as well as parkinsonia (*Parkinsonia aculeata*), brigalow (*Acacia harpophylla*) and mesquite (*Prosopis* spp.).

Exclusion of fire over a 20 year period may result in the succession from open woodland to closed forest with a reduction in herbage mass production of the grasses (Burrows et al. 1990). While fire rarely kills established plants, it reduces seedlings and the soil seed bank (Lonsdale and Miller 1993) and burns away most of the wood suppressing sucker development. Fire management in combination with grazing is critical in maintaining the tree grass balance (Child et al. 2010, Scott et al. 2010).

Rubber vine (*Cryptostegia grandiflora*) is a species impacting woodlands and riverside areas throughout northern Queensland. It is relatively fire sensitive provided the stem base of each plant is heated. Late dry season burning will yield high intensity fires that may kill most juvenile plants and 50–70% of adult plants (Grice 2001).

In any situation the type of burn will be determined by the amount of fuel available, the primary fuel being perennial grasses (McIvor et al. 2010). In the high rainfall zone, fire is used frequently in native pastures to control woody species, primarily *Eucalyptus* spp. and the removal of a bulk of dry material of perennial grass weeds to stimulate herbage growth (Lodge and Whalley 1989). The primary target species are Blady grass (*Imperata cylindrica*), African lovegrass (*Eragrostis curvula*), Coolatai grass (*Hyparrhenia hirta*) and Chilean needle grass (*Nassella neesiana*).

The success of fire alone and in combination with grazing is well documented for the control of woody weeds but no novel or innovative uses for fire alone or in programs with modifying livestock grazing behaviours were detected in this review.

### 4.2.2 Mechanical

Mechanical methods of control include clearing, cultivation, slashing and mulching. In northern Australia clearing of woody weeds is common in advance of sowing pastures (Ash et al. 1997). Cultivation may destroy or damage existing plants and reduce seeding number but the soil disturbance inevitably creates bare ground and enhances germination of seeds present in the soil seed bank.

Slashing or mulching may be used to reduce a bulk of unpalatable herbage mass or reduce the opportunity of species to set seed. The cutting height is an important consideration in this process. Ideally the cut should be of sufficient height to achieve the desired effect without damaging the desirable pasture species.

Mechanical removal of weed herbage is often used as a means to increase feed quality by reducing the amount of dead and low quality herbage. It typically indicates that the rate of utilisation by livestock has been substantially below the growth rate of the weed during the growing season and therefore slashing/mulching is required. On its own, there are no convincing reports that slashing/mulching provides a permanent reduction in the population of weeds. More convincing, are reports from graziers where slashing/mulching followed by a change to livestock grazing has provided longer term benefits. For example, removal of existing dead herbage by mechanical means followed by higher rates of utilisation of the weed either through physical impact (see previous section) achieved by high stock density (e.g. > 500 DSE/ha) or changes to feed preferences through supplementation (see later section). It is these follow-on actions, rather than the mechanical removal of weeds, that offers some prospect for a new approach to weed control.

## 4.3 Livestock selectivity

### 4.3.1 Supplements

The role of supplements to increase intake of low quality pasture has long been recognised (Preston and Leng, 1987) with the key nutrients being nitrogen, phosphorus and sulphur. The action of these nutrients is to stimulate rumen microbial fermentation of ingested pasture, resulting in higher digestibility and increased feed intake and production. Nitrogen can be provided as non-protein nitrogen (e.g. urea), rumen degradable protein (e.g. unprocessed pulses or oilseeds) or as rumen undegradable dietary protein (e.g. oilseed meals). Phosphorus has typically been provided through calcium-phosphate powder or less typically as concentrated phosphoric acid injected via water medication. Sulphur has been provided through elemental sulphur, salts of sulphur (e.g. sodium sulphate) or indirectly through molasses.

Traditionally the strategy of using supplements has occurred when overall diet quality is low rather than as a means to change preference of livestock towards consumption of lower quality plants within the pasture. As such, the approach may be useful for stimulating intake and improving the efficiency of feed conversion when the majority of the diet is of low quality. For example, provision of nitrogen supplements is used with African lovegrass (*Eragrostis curvula*) and Coolatai grass (*Hyparrhenia hirta*), which are perennial grasses that can form thick pasture swards of low quality over the non-growing period of autumn and winter.

More recently, supplements have been viewed as a means of changing feed preferences by providing relief from negative post ingestive feedback or providing positive and conditioned responses. For example, Dziba et al (1997) reported that the frequency of feeding by sheep on big sagebrush (*Artemisia tridentate*), which contains secondary plant metabolites including terpenes, was doubled by provision of energy and protein supplements. Secondary plant metabolites are part of the defence system for some plants and many shrubs (including weeds) and, because these are toxic to many livestock species, lessen grazing pressure. Provenza and Balph (1988) suggested it might be possible to increase preference for plants (also weeds) with secondary metabolites if supplements could be provided that help livestock to more rapidly eliminate or metabolise the toxic compounds. Consistent with this framework, Dziba et al (1997) concluded that the greater preference for big sagebrush, was a direct result of the supplements providing compounds that allowed the sheep to better detoxify the terpenes.

The role of detoxifying or deactivating compounds that bind secondary plant metabolites, or antinutrients, and the interaction between these metabolites has been of interest for some time (Makkar 2003). Perhaps the best known example is the use of polyethylene glycol (PEG) to increase intake of and production from feeds (e.g. Mulga; *Acacia aneura*) containing high levels of condensed tannins (Pritchard et al 1992). Condensed tannins have a high affinity for proteins and these complexes lower protein availability and mineral absorption in grazing sheep, goats and cattle. PEG has an even higher affinity for condensed tannins and the tannin-PEG complexes increases nutrient and mineral availability to livestock, resulting in greater feed intake and production.

Interest in detoxifying compounds and the interactions among antinutrients (that result in detoxification) has seen animal behaviourists explore their role (through supplements or other plants) in altering feed preferences (Provenza and Balph 1988). For example, researchers at Utah State University are actively working to control medusahead (*Taeniatherum caput-medusae*) through grazing, seeking to determine the "ideal" supplement to increase preference for the weed (Juan Villalba *pers. comm.*) . Medusahead grass is currently spreading through North America at a rate that concerns natural resource managers because it displaces native vegetation and creates a fire hazard. Medusahead is a fast-growing winter active annual grass with seeds covered in barbs and possessing a long awn. The plant accumulates silica as it matures and the litter deters growth of native vegetation. This description of attributes also applies to many grass plants considered weedy in Australia (e.g. *Sporobolus* spp, *E. curvula*, *H. hirta, Avena fatua, Vulpia spp*). The overarching hypothesis in this area to influencing acceptance of "unpalatable" plants by grazing livestock is that the range and characteristics of other plants in the sward (or supplements) influences acceptance of particular species (Rogosic et al 2008). Hence provision of another feed source may alter acceptance of medusahead (also think other weeds) either through interactions with antinutrients, changing protein, energy or macro/trace mineral availability or other interactions.

This concept has largely been ignored in Australia but is probably apparent in the benefit that small amounts of cereal grain (Franklin-McEvoy et al 2007) provide to production of sheep grazing saltbush (*Atriplex* spp). The role that supplements (either provided or as other pasture/rangeland plants) provide in regulating feed preferences of livestock is related to the concept that the level of familiarity and/or novelty with a feed source also influences preference. This aspect is discussed in the next section.

<u>4.3.2 Training livestock</u>

Feed preferences of livestock are affected by their past (feed) experiences. The most common way in which dietary experience is used on Australian farms is in accelerating the acceptance of supplementary feeds by young and inexperienced stock (e.g. weaners). Typically, managers place a few experienced animals (generally older) with the weaners knowing that consumption of the supplement by the experienced animals provides a social basis for encouraging a more rapid acceptance of the supplement by the weaners. There are, of course, two concepts at play in this simple example: prior experience and social learning.

Livestock generally prefer a diet which is composed of green rather than dead material and leaf rather than stem and this preference results in animals selecting a diet that is higher in nitrogen but lower in crude fibre than the pasture as a whole. There is a large amount of variation between animals within this general preference pattern (Arnold 1964) some of which can be explained by dietary experience. For example, sheep reared in a pastoral region have been demonstrated to have a greater preference for lower quality grasses (e.g. *E. curvula*) than sheep reared on sown temperate pasture (Arnold and Maller 1977). Similarly, lambs reared on African love grass (*E. curvula*) until five months of age, subsequently showed greater preference for, and higher intake and digestibility of, low quality sorghum hay, than lambs that had been reared on green forage oats (*Avena sativa*) (Distel et al 1994). The reverse of these examples is also observed, where sheep reared on high quality sown pastures with experience of white clover (*T. repens*) exhibit greater preference for white clover than sheep reared in pastoral regions (Arnold and Maller 1977). Whereas feed preferences in adult sheep are long-lived, preferences in young animals are more labile; at least up till one year of age (Provenza and Balph 1988).

Early in the life of sheep and cattle (essentially in the period around weaning) has been identified as the period when feed preferences are most readily influenced. Influences include learning from the dam (Chapple and Lynch 1986 cited in Provenza and Balph 1988), other members of the flock/mob and from trial and error. Early life is also the period when dietary training is most effective and when conditioned aversions (training animals not to consume plants or feeds) or preferences (training animals to consume plants or feeds) are most readily achieved. Kathy Voth (Livestock for Landscapes) is a private consultant in the USA who has developed a training program (based on the work conducted at Utah State University, where she worked for three years) to change feed preferences towards meeting management goals. This includes training animals to consume weeds that are generally avoided such as thistles, other broadleaved weeds and shrubs.

The basis of the training program is to expose animals to a range of nutritious feeds of varying physical forms (e.g. loose, pellet) to provide positive post-ingestive feedback. The point is to reinforce that sampling new feeds/plants has a 'good' outcome: in other words it aims to overcome inherent phobia of unfamiliar feeds. Training involves a routine of providing feeds twice daily to small (e.g. n<50 head cattle) groups of animals over a 10 day period. Feed type changes frequently and the avoided 'weed' is slowly introduced with other nutritious feeds over the last three days of the program. Background checks (typically from the literature) are required to determine if the weed contains antinutrients or is toxic so as to inform the training program and choice of feeds. Pairing the 'weed' with feeds that have already had a positive association established, results in greater preference for the weed. On its own this training program appears promising but not suited to large-scale grazing properties (*suggested by Bruce Maynard, Stress Free Stockmanship, who claims de-stressing livestock leads to a change in feed preference to include weeds such as thistles and serrated tussock*) but this ignores the notion of social learning. Kathy claims that the altered feeding behaviour of the trained animals results in changes in feed preferences of other animals with which they graze. There is support for this concept as the bite rate of low bite rate cattle has been reported to increase when co-grazing with high bite rate animals (Provenza and Balph 1988).

There are at least two key aspects of using supplements to alter feed preferences to result in greater consumption of weeds. The first is the notion that the negative effect of antinutrients on feed intake (and hence growth) of livestock can be diminished by providing access to other feeds or supplements because of chemical interactions that may inactivate the antinutrient or allow greater detoxification and/or elimination from the animal. The second notion is that preference for weeds can be accelerated through a training program (ideally with young animals) with results amplified through the herd/flock through social learning. In this way, the investment in training is amortised over generations of animals. There is however, little information in the literature or in reports providing evidence for altered feed preferences lasting for years or indeed generations and remains to be confirmed. The concept of 'permanent' change in preference does align this area of interest with foetal programming and epigenetic changes as the basis for long-term effects.

## 4.4 Altering pasture quality, growth and phenology

4.4.1 Soil fertility

Soil fertility has effects on weed control through the promotion of the growth of desirable species by providing a competitive advantage to these pasture species over the weeds in the pasture. Many of the pasture species sown have been developed under moderate to high soil fertility regimes. In contrast, many of the plants considered to be weeds are adapted to low fertility situations and so have a competitive advantage under such conditions. For example, Hosking (1986) stated that weedy species such as flatweed (*Hypochoerus radicata)* and dandelion (*Taraxacum vulgare)* are reasonable indicators of potassium deficiency in Victorian pastures. He also nominated rib grass (*Plantago lanceolata*) and Bartsia (*Parentucelli latifolia*) as species that invade potassium deficient pastures.

The concept of soil fertility acting as a screen for plant species frequency and production is apparent from the following example. In contrast to the observations of Hosking (1986), Tilman et al (1999) found that high potassium status soils increased the content of dandelion. They found that dandelions have a higher potassium requirement than grasses and that in low potassium situations were consequently at a competitive disadvantage to grasses. This may not contradict Hosking's observations, as Asher and Ozanne (1967) found that in solution culture, sub clover required four times the amount for maximum growth that silver grass (*Vulpia myuros*) and annual ryegrass required. If the potassium requirement of clovers was also greater than the potassium requirement of dandelions then it would be expected that under high potassium levels sub clover would be favoured over dandelions. The key then to predicting the response to fertility gradients is an knowledge of the other species in the pasture and in the soil seed reserve and the requirement for the nutrient under examination.

Shovelton (pers. comm.) has evidence that low fertility pastures in north east Victoria, are more likely to be invaded by flat weeds. The following photograph (Figure 1) shows the impact of molybdenum, applied in a strip, in promoting clover growth and consequently restricting flat weeds and grasses.

Figure 1: Impact of molybdenum application on flatweed content of a pasture (Source: J Shovelton). Note that the flowers of flat weed are only obvious in the non- molybdenum areas

There are many examples where the role of soil fertility is cited as assisting in the control of weeds through the promotion of more desirable species which provide competition to the weed species. This concept applies not just for annual grasses and broad-leaf weeds but also to perennial grasses. For example, Badgery et al (2008) reported that omission of fertilizer from pastures favoured Serrated Tussock (*Nassella trichotoma*) growth.

King and Priest (1999) examined the influence of soil fertility (pH and phosphorus) on the competitive advantage of silver grass (*Vulpia bromoides*) and barley grass (*Hordeum leporinum*). They concluded that much stronger competitive pressure is exerted by annual grass weeds on pasture species at low soil fertility. However the effect was less marked with barley grass than with vulpia. Similarly, annual ryegrass (Wimmera) is adapted to high fertility soils and in low fertility situations can be seen growing in urine patches or areas of high fertility. Generally the dominant annual grass species in these low fertility soils are *Vulpia* spp. While of reasonable quality during their vegetative phase, silver grass matures early leaving a residue of low quality dry feed and a significant negative impact on animal performance. The change from a silver grass dominated pasture to one dominated by Wimmera ryegrass through the correction of soil fertility has been observed by one of the authors (J Shovelton pers comm) and is consistent with the observations of King and Priest (1999).

4.4.2 Growth regulators

The use of plant regulators to manipulate plant growth so as to encourage animals to eat weeds through spray grazing has been used for over 40 years. Because this practice is well established it will not be dealt with in this review. Rather, this section will review other growth regulating chemicals that have the ability to modify plant growth and may have a role in enhancing the control of weeds through encouraging grazing of them.

Notwithstanding the ability to train animals to selectively graze specific plants (discussed earlier); animals will generally select a diet on the basis of digestibility (Freer et al 2012) and rate of potential intake (Kenney and Black 1984). The strong relationship between digestibility and intake is used as a basis for estimating diet quality in the Grazfeed model (Freer, et al 2012)

Plants as they mature decrease in digestibility and if there are differential dates of entering reproduction (i.e. heading), those species that mature earlier (and decline most rapidly in digestibility) are less likely to be eaten than those that mature later. The variation in plant phenology coupled with changes in digestibility, and hence grazing preference, offers scope for manipulation.

Velini et al (2010) lists a series of chemicals which while normally used as herbicides, at low application rates have been found to beneficially modify plant growth, development or composition. A practical example of this was reported by Hill et al (1996). Bent grass (*Agrostis castellana)* is a major weed of the high rainfall areas of south eastern Australia and New Zealand. It is a rhizomatous perennial grass which if not managed, dominates pastures particularly as a result of wet summers and eventually produces unpalatable dry and rank feed. The extensive rhizome system in a dominant bent grass pasture accumulates nutrients which are unavailable to other pasture plants and has an anti-wetting effect on the soil which, along with the dry carry-over trash, hinders the germination of desirable species following the autumn break. Conventional control methods have relied on multiple herbicide applications and cultivations and re-sowing to improved pasture species. This approach is costly and often fails to achieve satisfactory establishment results due to poor control of dormant buds on the bent grass rhizomes.

In a contrasting approach, Hill et al (1996) found that low rates of glyphosate ( 0.135 kg a.i./ha) applied 2-6 weeks before the emergence of the first seed head, reduced bent grass seed head numbers by 99.5% and kept the plant in a vegetative state. This reduced the dry matter production on the sprayed treatments and because the treatment kept the bent grass in a vegetative state over summer, feed quality was improved and livestock selectively grazed the sprayed areas (Figure 2). Digestibility and crude protein content of the regrowth improved by 20% and 70% respectively due to treatment.

Figure 2: Selective grazing of sections of a bent grass pasture that were sprayed with low rates of glyphosate prior to seed head emergence. (DPI, Victoria)

This treatment should not be confused with either “spray-topping” which aims to sterilise seeds after seed head emergence or “hay freezing” which aims to preserve the feed value of the existing vegetation. The technique is more similar with “spray-grazing” which is typically used to control broad-leaf weeds (e.g. thistles).

The technique has also been used in demonstrations for the prevention of seed head formation in annual grasses in Tasmania (Stuart Smith, pers. comm.). Spraying with low rates of glyphosate just prior to floral initiation was successful in preventing seed head formation in silver grass, barley grass and soft brome. If timing was right, as little as 50 ml/ha was found to be effective. The time of application varied between species in accordance with phenological stage and species not targeted were unaffected. Application in the first half of September was found to be effective for silver grass. In the demonstrations, application was based on a physical examination of the growing point to determine when it changed from vegetative to reproductive. From a practical perspective, guidelines based on the phenology of the plants would need to be developed.

Aside from these examples, most of the work on supressing seed head production has been undertaken for turf. A number of chemicals are registered. The two classes of chemicals which may have selective capacity in pastures are those that interfere with gibberellins early in their biosynthetic pathway (e.g. Paclobutrazol – Trimmit® and Flurprimidol - Cutless®) and those that are mitotic inhibitors (e.g. Mefluidide – Embark®) (Gooch, 1998)

Flurprimidol has been shown to provide extended foliar suppression on both warm and cool season turf grasses. When applied in spring to couch grass (*Cynodon dactylon*) over seeded with perennial ryegrass, it reduced the post dormancy growth of the couch (Schmidt and Henry, 1989) and may have provided a competitive advantage to the ryegrass. Paclobutrazol is a soil active product and while it retards growth has been found not to affect flowering (Marshall 1988).

Mefluidide has been shown to provide season-long suppression with cool season grasses (Anon, cited by Gooch, 1998). Brookes and Holmes (1985) investigated the effect of Mefluidide applied to a perennial ryegrass/white clover dairy pasture in mid-October, on dry matter production and quality. Mefluidide application had no effect on feed quality for two grazing sequences – late November and early December. However feed quality on the treated plots was greater at the third grazing cycle in late December. Mefluidide application however depressed pasture growth rates by 29% for 3-4 weeks creating a tension between herbage mass and quality.

Turner et al (1990) and Martin (1988) found that Mefluidide treatment of tall fescue in early spring prolonged higher-quality herbage into midsummer and resulted in greater forage intake and animal performance. One of the aspects which resulted in improved quality was that the application reduced seed head emergence by 95%. However, Mefluidide once again significantly reduced dry matter production of the sward.

There are a number of chemicals that have the ability to delay or prevent the emergence of seed heads. Almost always this seems to be accompanied with some reduction in growth either of the target species or the accompanying pasture species. The technique of reducing seed head emergence is likely to be of most benefit in situations where the weed is perennial, where it is dominant and where there is some underlying pasture base that can respond once the weed is suppressed.

# 5.0 Most promising novel approaches applied to weed management

The key aspect of this review was to look for evidence and opportunity for new ways to manage weeds that exploit plant and animal management. Four areas were considered key to this purpose and included: grazing management, physical removal, livestock selectivity and altering pasture quality, growth and phenology. The most promising approaches to emerge from the review which were considered for technical feasibility and likelihood of success as part of the second objective of this project were:

- Use of plant growth regulators to exploit plant species variation in phenology to selectively vary plant (weed) growth and quality and consequently increase grazing preference for weeds.
- Supplements and/or provision of a range of plants available to livestock to influence acceptance of weeds through effects mediated by interactions with antinutrients, changing protein, energy or macro/trace mineral availability or other interactions.
- Altering feed preferences of livestock through training which may be amplified through social learning (ideally with young animals) with the prospect of being fixed through epigenetic change.

- Trampling by livestock.

# 6.0 Technical feasibility and likelihood of success of novel weed management approaches

## 6.1 Use of plant growth regulators

The potential for using plant growth regulators to selectively vary plant (weed) growth and quality and consequently increase grazing preference for weeds was ranked highest (91% of maximum score) for technical feasibility and likelihood of success. The major strengths encouraging the development of this approach were considered to be a quick-moderate effect on weeds, benefit for grazing livestock, a low cost of on-farm implementation, low-moderate demand for additional labour and the ability to use existing infrastructure. The review indicated that existing products (e.g. glyphosate) were able to be used at low rates to selectively effect weed phenology and this would be a good springboard for further exploration of other products: including those used in the turf industry as detailed in the review. A broad understanding of chemical action and weed phenology exists but this will require a greater level of detail to emerge from R&D.

It is suggested that R&D in the area of plant growth regulators has two components, namely (i) annual grasses/forbs in southern regions; and (ii) perennial grasses in the north (including northern areas of southern Australia). There are three objectives for this work:

1. The primary objective is to prevent the development of weed seedheads to protect against damage to livestock caused by awns and to increase grazing preference.
2. The secondary objective is to reduce viability of weed seeds in those (few) seedheads that may continue to develop.
3. The third objective is to establish a regimen that has little or no effect on non-target desirable species.

Initial focus in southern Australia should be given to annual species (e.g. Barley grass – *Hordeum* spp, Great Brome - *Bromus diandrus*, Silver grass – *Vulpia* spp, Geranium – *Erodium* spp). In northern Australia, initial focus should be given to perennial grass weeds that contain damaging awns or dominate pastures through livestock avoidance (e.g. Chilean Needle Grass – *Nassella neesiana*; Serrated tussock – *Nassella trichotoma*, African Lovegrass – *Eragrostis curvula*, Parramatta grass – *Sporobolus fertilis*; *S. pyramidalis*).

An experimental model to commence the R&D work (annual species) would involve the application of differing rates of various candidate chemical regulators on select target weed species at weekly intervals. Phenology of target weeds recorded at the time of application and seedhead reduction measured post treatment could be used to retrospectively determine the optimum combination/s within the matrix of application rate, chemical regulator and growth stage of the target weed. It is likely that the timing of reproduction in target weeds will vary within a paddock due to factors including soil fertility, sunlight radiation, temperature, moisture and grazing history. Consequently, an understanding of treatment efficacy at different growth stages will be important in the commercial application of this approach. A similar model may be useful for working with perennial species but this is likely to require consideration of delayed or prolonged reproductive strategies.

## 6.2 Altering feed preferences of livestock

Altering feed preferences of livestock through training which may be amplified through social learning (ideally with young animals) with the prospect of being fixed through epigenetic change was ranked second (80% of maximum score) for technical feasibility and likelihood of success. It was considered that this approach would have broad geographic application across a wide range of weeds with effects on weed control accruing over the medium term. Benefit for livestock would depend if substitution of higher quality pasture/rangeland components occurred when the weed was included in the diet but this was not considered to be a major negative or positive attribute. Trained animals consuming weeds would provide on-going benefit for weed control but this comes at the expense of a moderate-high demand for additional labour to provide the training. Social transmission of the altered behaviour to untrained animals would amortise the labour cost over a larger number of animal units and if the behaviour was fixed in the flock/herd through epigenetic change then the labour could be considered a capital cost. Nevertheless, the labour requirement for training may be perceived as a barrier to adoption and although this approach is likely to have application for a wide range of weed types, the level of adoption is likely to be less than for plant growth regulators.

There are three components to altering feed preferences of livestock: (i) training; (ii) social transmission of trained behaviour/s; and (iii) epigenetic changes to fix genotypes underlying behavioural phenotypes. Of these components, it is the notion of epigenetic change that has the greatest uncertainty but, depending of the level and longevity of social learning, it may not be an obligatory requirement for success of this approach. The objective for this work is to reduce the population of target weeds over time (1-3 years) by increased consumption from livestock. Weed consumption could be determined from using established visual scan techniques or investigation of the potential of existing analytical techniques such as faecal NIRS or alkanes.

An initial approach to the R&D would test the concept of training and social transmission (learning). Test groups of young (soon after weaning) sheep and cattle would be trained (collaboration with livestock for landscapes training program) or not and then managed as the following groups:

- Trained animals only

- Trained animals introduced with untrained animals (ratio 1 trained:10 untrained)
- Untrained animals only
- Untrained animals introduced with trained animals (ratio 1 untrained:10 trained)

Observations would need to occur over a period of years and if young females were used, then those from trained or untrained (only) groups could be followed through gestation to determine genetic and/or behavioural changes in offspring.

## 6.3 Supplements to influence acceptance of weeds

Nutritional strategies to influence acceptance of weeds was ranked third (73% of maximum score) for technical feasibility and likelihood of success. Large variation can occur in the concentration and chemistry of plant secondary metabolites (antinutrients) in response to season, soil chemistry, provenance and grazing history and this is likely to diminish the effectiveness of this approach and the technical feasibility of the investigation. Although this approach has potential application for a wide range of weeds it is likely that it will have greater application in the shrublands where antinutrients are more commonly recorded. There is an obvious linkage of this approach with that of training animals, as feeds which provide positive post-ingestive feedback are used to train animals to consume weeds: although the feeds do not have to mediate effects through interaction with antinutrients. For these reasons, any approaches used in the R&D process to develop livestock training should consider nutritional strategies and develop close linkage with organisations active in this area.

## 6.4 Trampling of weeds by livestock

Using livestock to trample weeds was ranked last (59% of maximum score) for technical feasibility and likelihood of success. The combination of restricted geographic application (largely restricted to intensive systems), no immediate benefit for livestock and the small area over which the trampling can occur (at any one time) were seen as negative attributes. In addition, the technical feasibility of detailed R&D of livestock trampling for weed control would be problematic due to difficulty in regulating and describing the trampling effect rather than the stock density. For these reasons, trampling of weeds by livestock was not considered of sufficient merit and excluded from the list of prospective novel weed control approaches.

# 7.0 Potential investment partners and research providers

The potential of attracting investment partners was considered most likely for development of plant growth regulators but unlikely for altering feed preferences of livestock through training. The issues of existing patent protection and registered application methods (rates) will need consideration in the choice of commercial investment. Research providers with experience in plant growth regulators include Reg Hill (Private consultant) and Steve Smith (Dept. of Primary Industries, Parks, Water and Environment, Tasmania) and Mike Stephens and Associates (co-author of this report) have a strong interest integrating the approach with other farm management strategies. Other research providers with strong experience in perennial grasses (e.g. Sue Boschma, NSW Dept. of Primary Industries and Geoff Moore, Dept. of Agriculture and Food, WA) may also have interest. Research providers in Australia with interest in altering feed preferences of livestock through training would emerge from aligned fields and may include Dean Revell (CSIRO), Ralph Behrendt (Dept. of Environment and Primary Industries, Victoria) and Dennis Poppi (University of Queensland) and AIMS (co-author of this report) has a strong interest in this area. Overseas providers with activity in this area include Kathy Voth (Livestock for Landscapes, USA), Juan Villalba (Utah State University, USA) and Grant Edwards (Lincoln University, NZ) with whom collaboration should be considered.

**Table 3:** Attributes and their considering factors and scoring system used to assess the potential weed control approaches.

| Attribute | Consideration of the attribute | Scoring |
|---|---|---|
| Technical feasibility of investigation | The likelihood that a research project would successfully develop the weed control approach for commercialisation in 3-5 years | High =3<br>Mod = 2<br>Low = 1 |
| Likelihood of success of action | The likelihood of success of the weed control approach after development (i.e. assume successful development) in terms of on-farm effectiveness | High =3<br>Mod = 2<br>Low = 1 |
| Potential for investment partners | The likelihood that the weed control approach will appeal to investors during the development and/or application (sales) stage | High =3<br>Mod = 2<br>Low = 1 |
| Geographic applicability | The likely geographic range in which the weed control approach will be applicable. (*Note: this was a function of considering northern versus southern Australia, intensive versus extensive systems, rainfall and location of types of weeds*.) | Wide =3<br>Mod = 2<br>Restricted = 1 |
| Range of weeds | Consideration of application for control of perennial, annual, grass, broadleaf, shrub and woody *categories* of weeds | All = 3<br>Some =2<br>Few =1 |
| Immediacy of effect on weed | The time taken to significantly reduce the frequency and abundance of the weed/s in the pasture/rangeland. (*Note: quick = same year; mod = 1-3 years; slow = after 3 years*) | Quick = 3<br>Mod = 2<br>Slow = 1 |
| Immediate benefit for livestock | Does the weed control approach provide benefit (other than the benefits from controlling the weed/s) for livestock in the short-term either through increasing feed quality or quantity | Yes = 3<br>Perhaps = 2<br>No = 1 |
| On-going benefit after the action | The likelihood for on-going (post treatment) benefit from the weed control approach | Yes = 3<br>Perhaps = 2<br>No = 1 |
| Increase on-farm labour | The likely effect of implementing the weed control approach on labour requirements on the farm | High =3<br>Mod = 2<br>Low = 1 |
| Use existing infrastructure | Consideration of whether the weed control approach can be implemented using existing farm infrastructure or existing contractual services | Yes = 3<br>Perhaps = 2<br>No = 1 |
| Cost of on-farm implementation | The non-labour component of the likely cost of implementing the weed control approach | High =3<br>Mod = 2<br>Low = 1 |
| Likelihood of adoption | Consideration and integration of all the described attributes and other less tangible costs and benefits to arrive at an opinion of likelihood of adoption | High =3<br>Mod = 2<br>Low = 1 |

**Table 4:** Assessment of the attributes of potential weed control approaches and the overall score calculated from the sum of attribute scores.

| **Weed control approach** | **Technical feasibility of investigation** | **Likelihood of success of action** | **Potential for investment partners** | **Geographic applicability** | **Range of weeds** | **Immediacy of effect on weed** | **Immediate benefit for livestock** | **On-going benefit after the action** | **Increase on-farm labour** | **Use existing infrastructure** | **Cost of on-farm implementation** | **Likelihood of adoption** | **OVERALL SCORE** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Use of plant growth regulators to exploit plant species variation in phenology to selectively vary plant (weed) growth | high | high | high | mod | some | quick-mod | yes-perhaps | yes-perhaps | low-mod | yes | low | high | **32.8** |
| Supplements and/or provision of a range of plants to influence acceptance of weeds through interactions with antinutrients, changing protein, energy or macro/trace mineral availability or other interactions | mod-high | mod | mod | mod | all-some | mod | perhaps-yes | no | mod-low | yes | mod -low | mod | **26.2** |
| Altering feed preferences of livestock through training which may be amplified through social learning (ideally young animals) and fixed through epigenetic change | high | high-mod | low | wide | all-some | mod | perhaps-yes | yes | mod-high | yes | low | low-mod | **28.7** |
| Trampling by livestock | mod | mod | low | restricted | some-all | mod-quick | no | yes-perhaps | mod | perhaps | mod -low | low | **21.3** |

Note: Attribute scores of mod-high indicate a numerical score of 2 – 2.5 whereas high-mod indicates a score of 2.5 – 3. This principal holds for all hyphenated scores in the table.

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