Spear grass seedhead on left, Chilean needle grass seedhead on right

PROCEEDINGS

of the

Tussock Terminators Research Forum

at

Lake Hume Resort
Albury NSW

2nd – 3rd November 2005

PHOTOGRAPHS:

- Serrated tussock fence effect — *Michael Michelmore*
- Mexican feathergrass — *Linda Ayres*
- Giant parramatta grass (*Sporobolus*) — *Wayne Vogler*
- Alg Goulburn habitat — *Michael Michelmore*
- Chilean needlegrass seedhead — *Lori McWhirter*
- Chilean needlegrass (*Nasella neesiana*) —*Lori McWhirter*
- Serrated tussock (*Nasella trichotoma*) seedhead — *Michael Michelmore*

CRC Weed management
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An Australian Government Initiative
State Government Victoria Department of Primary Industries
NSW DEPARTMENT OF PRIMARY INDUSTRIES

Tussock Terminators Research Forum
Lake Hume Resort, 2-3 Nov. 2005

THE UNPALATABLE GRASS SYNDROME IN AUSTRALIA — AN AGRICULTURAL AND ENVIRONMENTAL DISASTER

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Summary. Unpalatable grasses are one of the most significant issues affecting grazing industries in Australia. The current and potential distributions of exotic stipoid grasses and weedy *Sporobolus* species are documented. The known ecology and impacts on agriculture and indigenous vegetation are presented. The exotic stipoid grasses and weedy *Sporobolus* grasses share a number of common traits - they are difficult to identify, they are competitive invaders, they are mostly unpalatable and they are difficult to control. This paper presents an overview of projects under way to address some of these issues. It also provides predictions of the potential distribution of the species in Australia based upon climatic modelling of the species distributions around the world. *Nassella trichotoma* and *N. neesiana* are declared Weeds of National Significance in Australia. This paper recommends that weedy *Sporobolus* species should also be declared as Weeds of National Significance to Australia.

Keywords: unpalatable grasses, *Sporobolus,* stipoid, *Nassella,* ecology, impacts, potential distribution, climatic modelling, CLIMEX

Can *Nassella neesiana*, Chilean Needle Grass, be incorporated into a grazing management system in Australia?

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ABSTRACT

In Australia, *Nassella neesiana* (Chilean needle grass) is considered a weed of pastures, whereas, in its native Argentina, it is a desirable component of pastures. This study made a preliminary assessment of its value as a pasture and discusses the potential for its abundance to be controlled by grazing management. As a measure of pasture productivity, regrowth herbage mass was compared between *N. neesiana* and *Festuca arundinacea*. *Festuca arundinacea* was more productive in all but one sampling period in October/ November 1995. The cumulative regrowth herbage mass of *N. neesiana* over a 50 week period was 24.3% lower than that of *F. arundinacea* (0.1986 compared with 0.2623 g cm^{-2} basal area $year^{-1}$). The crude protein of *N. neesiana* green leaf samples ranged from 12.7 to 16.6% while digestible dry matter ranged from 58 to 66%, again somewhat lower than comparable values for *F. arundinacea*. Nevertheless, these figures, combined with the fact that *N. neesiana* had a high basal cover (20%), resulted in the production of a large amount of reasonable quality feed. On a whole paddock basis average regrowth production of *N. neesiana* was calculated to be 2296 kg ha^{-1} $year^{-1}$. It is suggested that a cell grazing approach with high stock densities for one to three days followed by rest periods of 40 to 90 days, depending on seasonal conditions and anticipated seasonal growth rates, could result in a reduction in abundance of *N. neesiana* and an increase in abundance of more valuable competing perennial grasses.

Additional keywords: weed, *Festuca arundinacea*, crude protein, digestible dry matter, grazing management

INTRODUCTION

Nassella neesiana (Trin. & Rupr.) Barkworth (Chilean needle grass), a native of South America, is invasive in many Australian grasslands and land managers have had little success controlling it (Gardener 1998). Reasons for its invasiveness include its perenniality, production of large numbers of seeds, both panicle seeds and cleistogenes, effective long distance dispersal by animals and machinery, a large long-lived seedbank, seed dormancy and high seedling survival (Gardener *et al.* 2003 a, b).

Much of the anecdotal information currently available in Australia suggests that *N. neesiana* has such low palatability that stock will graze it only as a last resort (Duncan 1993, Shaw 1996). Duncan (1993) claimed that in some instances, dense infestations have reduced the stock-carrying capacity by 75%. Similarly, in New Zealand, Bourdôt and Hurrell (1989) stated that swards dominated by *N. neesiana* were of little pastoral value since the grass is not very palatable to sheep or cattle. However, evidence is currently emerging that, with the correct management, *N. neesiana* may have some utility in pastures (Grech *et al.* 2004).

In Argentina, on the highly productive Pampas Plains, *N. neesiana* is considered to be one of the most important winter-growing native species for livestock production (Hayward and Druce 1919, Rosengurtt 1946, Rosengurtt *et al*. 1970, Steibel 1980, Fernandez *et al*. 1986, Echeverria 1988). It is readily grazed, produces good quality feed, is perennial and has the ability to persist during heavy grazing and drought (Fernandez *et al*. 1986), suggesting that it is a useful pasture plant.

The genotype(s) of *N. neesiana* introduced into Australia may be less acceptable to livestock than those common in Argentina, leading to the above differences in perception about this species in the two countries. On the other hand, differences in grazing value may result from environmental differences between the two countries or differences in the way the respective grazing industries operate, including grazing management. Several varieties of *N. neesiana* have been recognised by different authors (e.g. Rosengurtt *et al.* 1970, Torres 1993). According to the keys in Rosengurtt *et al.* (1970) and Torres (1993) the material used in this study was *N. neesiana* var. *neesiana* which is also the most common variety in Argentina. It appears this is the only variety in Australia but further taxonomic investigations are needed.

During the summer months, pastures dominated by *N. neesiana* in Australia produce large numbers of unpalatable flower stalks, which are actively avoided by livestock (Gardener 1998). Where parts of a paddock are dominated by *N. neesiana*, these areas are avoided by livestock particularly when the flower stalks are present. These stalks persist on the plant for several months, often falling over and forming a dense mat that shades the underlying pasture. A grazing management approach that removes these stalks and promotes vegetative growth of *N. neesiana* and other desirable species may lead to better livestock production from paddocks infested with this species.

In set-stocked paddocks, the more palatable pasture species tend to be continually grazed, resulting in a loss of vigour or even death (Donald 1946, Earl and Jones 1996). Conversely, a grazing management strategy involving the use of large numbers of animals for short periods followed by long rests, has been shown to benefit the more palatable species in pastures (Taylor *et al*. 1980, Earl and Jones 1996). It has been known for many years that increasing grazing pressure decreases selectivity of grazing animals on pastures species (Donald 1946). In theory, with a high stock density, all the pasture species are eaten or trampled down to a similar height. When the stock are removed the more palatable pasture species have the same opportunity as the unpalatable species to grow during the rest period. If the rate of recovery from defoliation of *N. neesiana* is slower than that of more valuable competing perennial grasses then it is possible that this slower growing, less leafy component of the pasture would be at a competitive disadvantage under these conditions.

The principal aims of this work were to compare the regrowth herbage mass and the regrowth feed quality of *N. neesiana* with that of *Festuca arundinacea* Schreb. (tall fescue) throughout the year. *Festuca arundinacea* is one of the standard recommended perennial pasture grasses in temperate Australia (Ayers *et al.* 2001) and therefore, a useful benchmark. As a comparison to the regrowth herbage mass estimates, standing herbage mass (a more standard measure of pasture mass) was estimated for areas dominated by either *N. neesiana* or *F. arundinacea.* Species composition in these areas was also measured. The results then form the basis of a proposed grazing management system that could possibly reduce the abundance of *N. neesiana* and increase the abundance of more favourable species.

METHODS

Field experiments were conducted on the property, Ban Wyong, 19.5 km NNE of Guyra, on the Northern Tablelands of New South Wales, Australia (30° 03' South; 151° 37' East). The altitude on Ban Wyong ranges from 1190 to 1410 m. Soils are deep and basaltic in origin with regular stones (5-20 cm diameter) and are classified as reddish chocolate soils (Jessup 1965) or haplic ferrosols (Isbell 1996). The nearby Guyra Post Office (30° 13' South; 151° 40' East; altitude 1325 m) had a 104 year average annual rainfall of 884 mm. Experiments were conducted in a 42.3 ha paddock where *N. neesiana* and *F. arundinacea* were the two dominant species. The paddock was more or less continuously grazed at approximately 11.5 dry sheep equivalents (DSE) ha^{-1} with both cattle and sheep during the experimental period.

Regrowth herbage mass. Regrowth herbage mass was measured between 24 October 1995 and 9 October 1996. Five 2 x 2 m exclosures were used to prevent large animal grazing during the sampling periods. These exclosures were moved at each new sampling event to ensure that individual plants were subject to the same grazing pressure as in the rest of the paddock. Regrowth herbage mass was estimated using the following methods based on Lodge *et al*. (1981). At each sampling event, tussocks of *N. neesiana* and *F. arundinacea* were selected in each of the five exclosures by numbering all tussocks then randomly choosing five. Tussocks were clipped to 3 cm above the ground and marked with a small flag. After a period of between 19 and 74 days, depending on the season and growth of the grass, the regrowth of the marked plants was clipped back to 3 cm and the basal area of each tussock was traced on to a piece of transparent plastic. This area was transferred to a piece of paper and put with the regrowth sample in a paper bag. The five exclosures were then moved to a new location and five new tussocks of each species were clipped and marked for the next regrowth harvest. The corresponding basal area was measured with an area meter (Delta-T area meter). The samples were dried at 65°C for 72 hours and then weighed. Regrowth herbage mass was expressed as average dry weight of green leaf produced per unit basal area of tussock per day. The area chosen for this experiment was in a part of the paddock dominated by *N. neesiana* (see below) but had sufficient plants of *F. arundinacea* for sampling.

Paddock herbage mass. There were two distinct communities within the experimental paddock. The first was dominated by *N. neesiana*, which was generally ungrazed during flowering and was on slightly better drained soils (Community A). The rest consisted of heavily grazed areas, without much *N. neesiana* and dominated by *F. arundinacea* in lower, poorly drained situations (Community B). The percentage of the paddock comprising these two communities was estimated from aerial photographs. On 20 December 1995, parallel runs were made in a light plane over the experimental paddock at 70 m above ground level. Using a 35 mm camera, a series of 36 oblique photographs was taken from the plane. These photographs were developed into 15 x 10 cm prints and used for analysis. At approximately the same place in each of the 36 photographs, a transparent grid of 5 by 10 cells was overlaid that corresponded to an area of 10 x 25 m. Hence, a total area of 0.9 ha was surveyed. The cells dominated by *N. neesiana* (flowering plants appear as a unique red-brown colour) were counted (Community A). The remainder of the paddock was classed as Community B. This process was undertaken independently by two of the authors and the results were averaged to obtain estimated cover of *N. neesiana* for the whole paddock.

The proportion of Community A covered by *N. neesiana* tussock bases was estimated on 4 January 1996 by clipping 20 (50 x 50 cm) quadrats to 3 cm then tracing all tussock areas in each quadrat onto a transparent plastic sheet. Basal area was measured as above. The 20 quadrats were chosen by walking diagonally across the paddock throwing the quadrats at approximately 30 m intervals into *N. neesiana* dominated areas. To calculate total regrowth herbage mass over 50 weeks all the regrowth herbage mass estimates for *N. neesiana* were summed then converted to a paddock scale by multiplying by proportion of the paddock dominated by *N. neesiana* and the proportion of that area covered by tussock bases.

Protein and digestibility. At each sampling of herbage mass all clipped plant material from the 25 tussocks of each of *N. neesiana* and *F. arundinacea* was pooled together and analysed for crude protein and digestible dry matter. These samples comprised green regrowth and represent the highest quality feed of both *N. neesiana* and *F. arundinacea*. The samples were ground using a Wiley mill fitted with a 1 mm screen. Samples were processed at NSW Agriculture, Camden. Crude Protein (CP) and Acid Detergent Fiber (ADF) were determined using Near Infrared Reflectance (NIR) spectroscopy (AOAC 1990) and estimates of Digestible Dry Matter (DDM) were derived from these values (Oddy *et al.* 1983). Each 20 g sample was sub-sampled three times and the values presented are their averages.

Pasture composition. Three permanent 20 m transects were set up in each community. Within each transect, ten (50 x 50 cm) quadrats were positioned at 2 m intervals. The total herbage mass and the proportions of the different species in each community were estimated using BOTANAL (Haydock and Shaw 1975, Tothill *et al.* 1992). The estimates from the three transects in each community were averaged. The three sampling dates were 15 December 1995, 21 March 1996 and 27 August 1996.

RESULTS

Rainfall. At the field site, there were 1258 mm of rainfall between 1 October 1995 and 30 September 1996 with all months except March (0 mm) and April (29 mm) having above average rainfall (Fig. 1a).

Regrowth herbage mass. The following measurements of pasture quantity, quality and composition are based on data from one paddock, on one farm for one year. *Festuca arundinacea* produced more ($p<0.0002$) regrowth herbage mass than *N. neesiana* at all sampling events except in October/November 1995 (Fig. 1b). There was a significant time effect ($p<0.00001$) with both species having slower growth rates during the cooler months (April to September). There was also a significant interaction between species and time of year ($p<0.0002$). The cumulative total over a 50 week measurement period showed that *N. neesiana* produced 24.3% less regrowth herbage mass than *F. arundinacea* (0.1986 ± 0.0202 compared with 0.2623 ± 0.0252 g cm^{-2} basal area).

Paddock herbage mass. From aerial photographs, an average of 60.3% (58.4 ± 3.8% Observer 1, 62.2 ± 3.7% Observer 2) of the paddock was classed as *N. neesiana* dominant (Community A). The remainder was dominated by *F. arundinacea* (Community B) or remnants of *Eucalyptus viminalis* Labill. woodland. In January 1996, the average basal cover of *N. neesiana* in Community A was 20.0%. However, when measured over a 12 month period in an adjacent area, the mean size of the basal tussocks fluctuated in both *F. arundinacea* and *N. neesiana* (Fig. 1c). Both species had a smaller tussock basal area between November and February. The total regrowth herbage mass of *N. neesiana* over 50 weeks was calculated as follows:

19096 kg ha^{-1} $year^{-1}$ x 0.603 (proportion of paddock) x 0.20 (proportion of basal cover) = 2296 kg ha^{-1} $year^{-1}$.

Regrowth quality. The crude protein of the regrowth of *F. arundinacea* ranged from 13.0 to 18.8% whilst that of *N.*

neesiana ranged from 12.7 to 16.6 % (Fig. 1d). The crude protein of *F. arundinacea* was consistently higher at all sample periods except in March 1996 and peaked in June and October 1996 for *F. arundinacea* and *N. neesiana* respectively.

The digestible dry matter of green leaf material of *F. arundinacea* ranged from 62 to 69% whilst that of *N. neesiana* ranged from 58 to 66% and was consistently lowers (Fig. 1e).

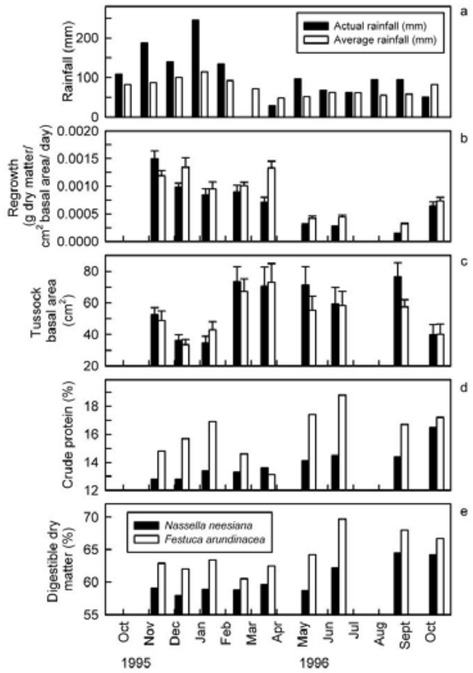

Figure 1(a) Rainfall at Ban Wyong during the sampling period compared to the 104 year average at the nearby Guyra Post Office. **(b)** The comparative regrowth herbage mass produced by tussocks of *F. arundinacea* and *N. neesiana* that had been clipped to 3 cm throughout the sampling period. The vertical bars represent standard errors. (**c**) Basal tussock areas of *F. arundinacea* and *N. neesiana* over a year. Vertical bars represent standard errors. (**d**) The crude protein of tussock regrowth of *F. arundinacea* and *N. neesiana* throughout the sampling period. (**e**) The dry matter digestibility of tussock regrowth of *F. arundinacea* and *N. neesiana* throughout the sampling period. solid bars = *N. neesiana*, open bars = *F. arundinacea*

Pasture composition. *Nassella neesiana* was the dominant species in Community A as a proportion of average standing herbage mass whereas *F. arundinacea* was dominant in Community B (Table 1). Although species diversity was similar in both communities, the proportions of species other than *N. neesiana* and *F. arundinacea* were higher in Community B, particularly *Trifolium repens* L. (Table 1). In Community A, *N. neesiana* had the highest standing herbage mass at each sampling occasion with a maximum of 4719 kg ha^{-1} in March (Table 2), with much of that being flower stalks. Conversely, *F. arundinacea* was dominant in Community B with a March maximum of 1518 kg ha^{-1}. Community B was always more heavily grazed resulting in lower standing herbage mass.

Table 1. Proportion of standing herbage mass averaged over three sampling events of two communities - that dominated by *N. neesiana* (A) and that dominated by *F. arundinacea* (B).

	Community A (%)	Community B (%)
Nassella neesiana	76.9	0.3
Festuca arundinacea	12.1	52.1
Trifolium repens L.	1.8	11.7
Cynodon dactylon (L.) Pers	0.3	6.4
Bothriochloa macra (Stued.) S.T. Blake	1.4	4.8
Lolium perenne L.	1.0	4.4
Poa pratensis L.	0.1	2.8
Digitaria sanguinalis (L.) Scop.	1.0	2.6
Phalaris aquatica L.	0.2	1.6
Microlaena stipoides (Labill.) R.Br.	0.5	0.0
Annual monocots	2.5	8.2
Perennial monocots	0.8	4.1
Annual dicots	1.3	0.7

Table 2. Comparative standing herbage mass yields in two communities dominated by *N. neesiana* (A) and by *F. arundinacea* (B).

	Community A: Standing herbage mass (kg ha^{-1})				Community B: Standing herbage mass (kg ha^{-1})			
	Nassella neesiana	*Festuca arundinacea*	Others species	Total	*Nassella neesiana*	*Festuca arundinacea*	Others species	Total
Dec 1995	2821	243	356	3420	20	996	1083	2099
Mar 1996	4719	681	906	6306	0	1518	1878	3396
Aug 1996	2482	625	272	3379	0	620	341	961

DISCUSSION

The rainfall during the summer of 1995/96 was well above average and the rate of regrowth of both species was higher than during the subsequent winter. However, no rain fell at the study site during March and after the highest regrowth rate for *F. arundinacea* during that month, the regrowth rate for both species was reduced for the duration of the winter, probably due to low temperatures. The regrowth rate of both species increased again before the last harvest in October. An important aspect of these data is that the regrowth rate of *F. arundinacea* was greater than that of *N. neesiana* in all sample periods except in October, 1995. The growth period before each sampling varied between 19 (October, 1995) and 74 days (August 1996) and the data in Fig. 1b were calculated on the growth per cm^2 of tussock basal area per day. The regrowth of both species after clipping to 3 cm would be in the early part of the sigmoid growth curve for both species (Hunt 1982) and the question remains whether the differences between the two species would have increased or decreased had the growth periods been longer. The only period when the regrowth rate of *N. neesiana* was greater than that of *F. arundinacea* was in October 1995 when *N. neesiana* was running up to head.

Set stocking of large paddocks nearly always results in an uneven distribution of grazing pressure, with the repetitive use of some parts of the paddock and the consequent neglect of the remainder (Norton 1998). With larger paddocks and lower stock densities, this uneven grazing is accentuated and larger proportions of the paddocks are neglected. In paddocks with a range of plant communities present, the livestock tend to heavily graze preferred communities and neglect those dominated by less palatable species (Norton 1998). The result is that unpalatable species in the neglected parts of a paddock are rarely grazed and tend to increase in abundance but are somewhat suppressed in the heavily grazed patches.

In the present study Community B, represents the more heavily grazed part of the paddock and Community A, with its greater abundance of *N. neesiana,* was the more neglected. Stock rarely grazed in the parts of the paddock occupied by Community A, even after the good spring rainfall of 1996, because of the proliferation of *N. neesiana* flowering stalks. Community B generally occurred in the lower, poorly drained parts of the paddock. The greater standing herbage mass contribution of *F. arundinacea*, *T. repens* and other species in Community B probably resulted from a combination of the differences in the grazing pressure, water availability and soil characteristics in the lower parts of the landscape. The consistently lower standing herbage mass in Community B was most likely a result of higher grazing pressure, although the differences in site quality might be confounding factors. How could this patchiness be reduced? Norton (1998) concluded that one strategy for reducing patch grazing and achieving more even spatial utilisation of available forage is a reduction in paddock size. If this more even utilisation is to be achieved, it would have to be during those times of the year when the *N. neesiana* is not producing unpalatable flowering stalks.

Crude protein and digestible dry matter of *N. neesiana* (12.7 to 16.6 % and 58 to 66% respectively) were consistently lower than in *F. arundinacea* (13.0 to 18.8% and 62 to 69%) but still high enough to support good levels of animal production as defined by McClymont (1969) and Thompson and Poppi (1994). Voluntary intake, as well as the quality of the feed material, determines animal production. Assuming that the genotypes of *N. neesiana* in Argentina and in Australia are the same, it is likely that vegetative material of this species would be eaten by livestock. During the low rainfall period in March/April *N. neesiana* maintained its crude protein whilst *F. arundinacea* declined by more than 4% but increased rapidly again in May and June. The feed values reported for *N. neesiana* are not much lower than those found in a fertilised pasture sown with introduced species, where crude protein and digestibility ranged from 9.4% and 65% respectively in summer and autumn to 18.8% and 85% in spring (Ayers *et al.* 2001). Similarly, Fernandez *et al.* (1986) found that *N. neesiana* produced good feed in winter and spring, especially with sufficient rain, with crude protein ranging from 6.3 to 18.3%.

Improved soil fertility may also increase feed quality of *N. neesiana*. In a trial run by the Matheson Landcare Group (near Glen Innes NSW) between June 1996 and December 1999 average crude protein of bulk *N. neesiana* leaf samples in an unfertilised control was 7.7% (Gardener 2001). The application of 125, 250 and 500 kg of nitrogen (34%) fertiliser ha^{-1} resulted in average crude protein levels of 8.3, 9.4 and 10.5% respectively. The addition of superphosphate and elemental sulphur fertiliser gave values only slightly higher than the unfertilised control. Similarly, Grech *et al*. (2004) found that clipping and the addition of fertiliser increased the feed value of *N. neesiana*, making it more palatable and potentially able to be used in a rotational grazing system. However, in comparison to *Dactylis glomerata* L. the response was generally lower (Grech *et al*. 2004).

Crude protein and digestible dry matter levels reported in this study were consistently high because samples were of green regrowth from clipped plants. Conversely, bulk feed would be of lower quality as it has a higher proportion of dead leaf material and flower stalks that have lower crude protein and digestibility. Typical crude protein levels for bulk samples of *N. neesiana* from this site were between 8 and 11% and 4.5% for flower stalks (Gardener 1998). These results highlight the need to keep *N. neesiana* short and productive through appropriate grazing management.

'Cell grazing' or 'time control grazing' is only one aspect of a totally integrated farm management package (Earl and Jones 1996) and involves the rotation of grazing animals within cells. An area of the farm can be divided into between 20 and 60 paddocks or cells that are usually stocked at densities greater than 200 DSE/ha on the Northern Tablelands of NSW. For most of the growing season, graze periods range from one to three days and rest periods from 40 to 90 days (Earl and Jones 1996). The result is that each paddock is rested for 95 to 98% of the year and the stocking rate and the length of the graze and rest periods are adjusted according to property goals, seasonal conditions and anticipated seasonal growth rates. Pasture conditions are monitored continuously and the rotation re-planned as the year proceeds. If a goal is to advantage those species that compete with a weed such as *N. neesiana*, then the graze and rest periods can be designed for this purpose depending on rainfall conditions throughout the year. The rest periods between clipping in this experiment were generally shorter than commonly used in cell grazing on the Northern Tablelands (Earl and Jones 1996).

The key to whether short periods of intense grazing followed by relatively long periods of rest can swing the competitive advantage away from *N. neesiana* and towards more desirable perennial grasses depends to some extent on their relative growth rates during recovery from defoliation. Given the reproductive efficiency of *N. neesiana* (Gardener *et al.* 2003 a, b) and the difficulty in controlling this species by conventional means, grazing management may offer a lower cost and longer term approach to reducing its abundance in grazed pastures where it is widespread. It has proved effective in reducing the abundance of the annual weed saffron thistle (*Carthamus lanatus*) in pastures of the Northern Slopes on NSW (Grace *et al.* 2002).

The production of unpalatable flowering stems remains the key restriction to the utilisation of *N. neesiana* in pastures. The total annual regrowth herbage mass of 2296 kg ha^{-1} $year^{-1}$ for *N. neesiana* was largely green leaf material because the experimental plants were clipped regularly and not allowed to flower. On the other hand, flower stalks observed (not measured) to be the major component of the standing herbage mass of 4719 kg ha^{-1} measured in March 1996. Ayers *et al.* (2001) found similar peaks in total herbage mass in the January to March period. The main flowering period of *N. neesiana* is from November to March (Gardener *et al.* 2003 a) but the persistence of flower stalks until August reflects their low level of palatability and high level of animal avoidance.

The abundance of *N. neesiana* has been reduced successfully at a Sustainable Grazing System site (Meat and Livestock Australia) on a commercial grazing property east of Glen Innes (the dominant species were *Dactylis glomerata*, *F. arundinacea*, *N. neesiana and Paspalum dilatatum* Poir.) (CRC for Weed Management Systems 2001). High densities of cattle and sheep for short periods followed by long rests were shown to reduce the dry weight contribution of *N. neesiana* in the pasture whilst increasing the other more desirable pasture species. Furthermore, the habit of *N. neesiana* was changed from a rank unpalatable tussock to a shorter, greener more palatable form (CRC for Weed Management Systems 2001).

CONCLUSION

Nassella neesiana is a long-lived perennial that can survive the hazards of a variable environment. It has high basal cover and can produce large quantities of reasonable quality feed even during low rainfall conditions. Whilst the feed quality and quantity of regrowth of *N. neesiana* in this study is based only on one paddock on one farm for one year, it is postulated that its relative abundance in a grassland can be reduced and that of other more desirable species increased, by appropriate grazing management.

ACKNOWLEDGEMENTS

Our sincere thanks go to Michael and Bar Mulligan of "Ban Wyong" for providing land and facilities for this research. The financial support of the Meat and Livestock Australia is gratefully acknowledged as well as assistance from the Co-operative Research Centre for Weed Management Systems.

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Finding the Best amongst Best Bets: A Conceptual Model

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Summary An optimising model was developed and used to determine the optimal mix of supposed best-bet control techniques to deliver the desired minimum amount (ha) of weed control. This conceptual model was developed in a standard linear programming (LP) format that allows computation of the optimal solution given a set of constraints. The main goal of the analysis is to examine financial implications of the model-chosen mix of control techniques when considered as the basis of a weed management plan. The model was solved given five types of infestation (by density & landscape aspect), types w1 through w5, each requiring a specified minimum number of hectares to be controlled. The model has four different supposed best-bet control techniques over which weed-control dollars could be allocated. Each of the techniques offers various combinations of types of weed infestation controlled (ha) per dollar spent for each of them. Scenarios were modelled to examine how improvements in cost-efficiency of a control technique would impact on the optimal solution. A more productive weed management plan for one species identified not by pure extrapolation of known information but through quantitative models such as LP is likely to benefit the management of other weed species by increasing the availability of funds.
Keywords: Best bets, cost efficiency, linear programming, optimising model, weed control techniques

INTRODUCTION

Optimisation is the process of choosing the actions that result in the best outcome. Optimising models are formulated to either maximise or minimise a specified variable subject to a number of constraints. The largest or smallest value of the objective function e.g., farm profit, production cost, is called the optimal value, and a collection of values of decision variables that gives the optimal value constitutes an economically optimal solution. Solving an optimisation problem can help provide answers to critical questions about current and future actions and decisions and the outcomes that they produce. A review of the literature on economic models of decision-making including optimisation of investment in pest management at farm level is found in Mumford and Norton (1984) and for weed research in Australia in Vere *et al.* (1997).

The optimising model proposed in this paper is kept simple to maintain a focus on the key questions of interest. Which amongst the supposed best-bet weed control techniques should be used to constitute the economically optimal weed management plan? How much funding should be allocated to a chosen technique to fulfil the desired minimum level of weed control?

One concept that is relevant in defining the conceptual model is cost-efficiency. A simple index similar to that in Lindsey *et al.* (2005) is used in this paper to measure cost efficiency amongst the best-bet control techniques. It should be noted that in the current index, factors including economies of scale and changing input prices that influence such measures (Cooke and Sundquist 1989) are not isolated. Untangling these factors is outside the scope of this paper and therefore is not dealt with further.

Here, a compilation of cost efficiency data on recommended best-bet techniques of weed control options could be drawn initially from weed researchers and extensionists. In particular, the forum being convened amongst weed managers from all over Australia to determine effective control methods for serrated tussock (*Nassella trichotoma*), Chilean needle grass (*Nassella neessiana*) and sporobolus is targeted for collecting such information. The current analysis meanwhile was based on hypothetical values.

MATERIALS AND METHODS

Sample problem To explore the conceptual model in some detail, a sample problem was needed. Let us consider the problem faced by a public land management agency tasked to control invasive pests including weeds. The specific issue here is how to choose the best combination amongst four possible control technique options to apply in say a 200-ha public park infested by weeds, given five types of density and landscape aspect: w1 through w5. The agency has to formulate an economically optimal weed management plan for the current year to control a minimum (model constraints, WCm) of 20, 40, 40, 50 and 50 ha of type w1 to w5 infestation respectively at the lowest total cost (objective function, Min TC) (Table 1).

Two models were examined here, a base and an alternative. The base model hypothetical values tested for the four weed control techniques have varying (known) cost efficiency indices (CEIs) ranging from zero to three (Table 1). A cost-efficiency index can be calculated by dividing the area (ha) of weeds controlled (per type) by the cost of the applied control technique then multiplied by a common multiplier say \$100. A CEI value of three indicates a technique is highly effective for that particular type of infestation density and landscape aspect. For example, in the first row (T1) a \$100 investment would control 3 ha of type w1, none of type w2 and w3, 2 ha of w4 and 1 ha of w5. The remaining rows of Table 1 can be interpreted in a similar manner. Note that these are hypothetical values only and were set for the purpose of the analysis.

Table 1. Base model hypothetical values.

Technique	CEI ($ha^{-\$'00}$) by Type					Allocation
	w 1	w 2	w 3	w 4	w 5	(\$)
Technique, T1	3	0	0	2	1	s 1 >= 0
Technique, T2	2	0	2	1	1	s 2 >= 0
Technique, T3	2	2	1	1	1	s 3 >= 0
Technique, T4	1	1	1	3	3	s 4 >= 0
WCm	20	40	40	50	50	Min TC

CEI = cost efficiency index; WCm = desired minimum weed control (ha); w*n* = type of infestation by density & landscape aspect; s*n* = unknown amount of dollars to be allocated for each of the chosen control technique. Variable s*n* can take a value equal to or greater than zero.

Extrapolative approach To provide a solution to this sample problem we might simply decide (i.e. use our judgment by projecting known information) which techniques to apply and then allocate an arbitrary amount of dollars to each and see how they turn out. However, what we would really like is a solution that satisfies what is necessary under the weed management plan at the lowest cost. Logically such a minimum cost solution to this decision problem must exist. Even if we keep guessing we can never be sure whether we have found this minimum cost solution or not. Rather than continue guessing we can also approach the problem in a structured logical fashion.

LP approach Linear programming (LP) models were formulated to find the best value of the objective function, subject to a number of linear constraints. The mathematical representation of the sample problem analysed here is set out below. This is presented in a standard LP format that include an objective function that we are trying to optimise, the input-output coefficients, model constraints and a reminder that all decision variables sn are non-negative.

Our objective is to minimise total cost (TC) of the weed management plan, which is the sum of costs of the chosen control techniques. The input-output coefficients and model constraints are represented as left-hand side (LHS) and right-hand side (RHS) respectively, in the matrix below.

			(LHS)	(RHS)	
3s1	+ 2s2	+ 2s3	+ s4	>= 20	(Type w 1)
		+ 2s3	+ s4	>= 40	(w 2)
	2s2	+ s3	+ s4	>= 40	(w 3)
2s1	+ s2	+ s3	+ 3s4	>= 50	(w 4)
s1	+ s2	+ s3	+ 3s4	>= 50	(w 5)

Values in row one refer to those for type w1 weed infestation, row two refers to those for type w2 and so on. Again note that input-output coefficient of the variables in this model is in the form of cost-efficiency index. Standard linear programming formulation requires all variables to be non-negative hence the constraints s1, s2, s3, s4 >= 0 was imposed.

The numerical solution to this model was produced using the algorithm of a computer software package What's Best! An optimal solution is the identified set of variable values which are feasible (i.e. satisfy all the model constraints) and which lead to the optimal value of the objective function.

RESULTS AND DISCUSSION

Extrapolative approach Let us say we allocate $5000 (Table 2) to the weed management plan and distribute $2000, $1000 and $2000 each to T1 to T3 respectively (Figure 1). This seems like a good guess as it resulted in meeting the minimum area controlled for all infestation types (Table 2). We can say that such a solution is feasible because the model constraints WCm are met. However is it still possible to meet the minimum level of control at a cost lower than $5000? Can we do better?

Table 2. Extrapolative approach solution.

	Best-bet techniques selected	Control (ha) by type of density & landscape aspect w 1	w 2	w 3	w 4	w 5	Allocation ($)
Guess work	T1	60	0	0	40	20	s 1 = 20
	T2	20	0	20	10	10	s 2 = 10
	T3	40	40	20	20	20	s 3 = 20
	WCc	120	40	40	70	50	TC = 50
	WCm	20	40	40	50	50	

WCc = minimum weed control (ha) calculated; WCm = minimum weed control (ha) desired; TC = arbitrary value of total cost.

To explore the answers to these questions, two LP models were formulated to determine the best mix of best-bet control techniques that should constitute the weed management plan for the study area at the lowest cost. The LP base model was run using hypothetical values shown in Table 1. An alternative scenario where the application of technique T3 on infestation types w1 and w2 becoming more cost-efficient because of a technology improvement occurring was simulated as LPa model. To do this the CEI values for technique T3 under infestation types w1 and w2 in the base model (Table 1) were changed from two to three to represent the increase in cost efficiency. 'Without' (LP base model) or 'with' (LPa model) such an increase, the optimal combinations of control techniques were T2, T3 and T4 at a total cost of $3222 and $3000 respectively (Table 3).

Note that the extrapolative approach solution chose T1, T2 and T3 leaving out T4 (Table 2) with the management plan costing the agency much higher ($5000). Note also that under LP base model scenario the calculated total area WCc of type w1 infestation controlled when T2, T3 and T4 were employed exceeded the desired minimum WCm (Table 3) with the rest (w2 through w5) being sufficiently met i.e., WCc = WCm.

In a way, the LPa model enabled sensitivity analysis of the optimal solution to a change in conditions i.e., higher cost efficiency, to be performed. Sensitivity analysis is an examination of impacts of reasonable changes in the base model assumptions. In other words, this is an attempt to explore how much say, a one-unit change in cost efficiency would affect total cost (objective function). As mentioned earlier uncertainty in prices of inputs could impact on CEI and hence, such improvement can be negated when price increase.

Do the chosen optimal mix of best-bet control technique change when technology improvements in one technique occur? Results (column 'best-bet techniques selected' Table 3) would indicate no change in solution i.e., techniques T2, T3 and T4 comprising the optimal mix. Note however that with improvements in technique T3 (LPa model) the optimal value of TC* is now $222 cheaper ($3222 less $3000) and with an extra 4 ha (60 less 56 ha) of type w1 controlled as additional benefit. Both model solutions satisfy the desired minimum level for the rest of the constraints, i.e., rows WCc = WCm, for columns w2 through w5.

Table 3. LP optimal solution.

	Best-bet techniques selected	Control (ha) by type of density & landscape aspect w 1	w 2	w 3	w 4	w 5	Allocation ($)
LP base model	T2	15.6	0.0	15.6	7.8	7.8	s 2 = 7.78
	T3	31.1	31.1	15.6	15.6	15.6	s 3 = 15.56
	T4	8.9	8.9	8.9	26.7	26.7	s 4 = 8.89
	WCc	56	40	40	50	50	TC* = 32.22
	WCm	20	40	40	50	50	
LPa model	T2	20	0	20	10	10	s 2 = 10
	T3	30	30	10	10	10	s 3 = 10
	T4	10	10	10	30	30	s 4 = 10
	WCc	60	40	40	50	50	TC* = 30
	WCm	20	40	40	50	50	

LPa = an alternative scenario where CEI values in row T3 columns w1 and w2 (Table 1) were increased from two to three; TC* = optimal value of total cost.

Also, with improvements in technique T3 (LPa model) from the level of LP base model, the optimal solution was to increase funding for T2 from $779 to $1000, reduce allocation for T3 from $1560 to $1000 and raise funding for T4 from $889 to $1000 (Figure 1). These results appear consistent with real-world expectation suggesting the conceptual model is structurally valid. Meanwhile, an attempt to test the validity of the current LP model following the procedures presented in McCarl and Apland (1986) is not provided here.

CONCLUSION

Results indicate that the application of the conceptual model appears beneficial to weed managers of public land when potential savings in the cost of a weed management plan are considered. Deciding on the best mix of control techniques that meets the desired minimum level of control for each particular type of weed infestation at the lowest cost possible is very easy and quick to do when well-defined quantitative models such as the one described here is applied. Simple extrapolation appears less desirable for the weed management agency to rely on as guide for making its fund allocation decisions.

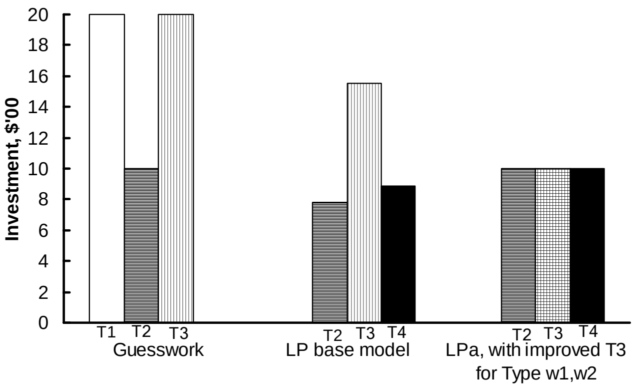

Figure 1. Best amongst best-bet weed control techniques. Each column is the amount of investment in each chosen technique.

In this analysis, hypothetical data were used to examine a sample problem that may or may not reflect a real-world situation. This is an obvious weakness of the model. Testing the model to see if it works as planned before using it for prediction will be the next stage. This will be done once on-ground data become available and fitted onto the model. Finally, it is reasonable to expect that a more productive weed management plan for one species that is identified through an LP model presented here is likely to benefit the management of other weed species by increasing the availability of funds.

ACKNOWLEDGMENTS

The funding support provided to this project by the Victorian Department of Sustainability and Environment (DSE) is highly appreciated. Thanks also to the organisers of the 'Tussock Terminators' forum for inviting the author to present this paper and Trevor Hunt and Helen Quinn for the discussions toward improving this paper.

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Chilean needle grass (*Nassella neesiana*) – integrated grazing for success

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Keywords. Chilean needle grass, Cocksfoot, Phalaris, spraytopping, slashing, burning, fertiliser, feed value, clipping, resowing, grazing management, sheep, cattle.

INTRODUCTION

Concern about the invasion of pastures in southeastern Australia by Chilean needle grass (*Nassella neesiana*; CNG) began to mount in the 1970s. Native to temperate South America, CNG can completely over-run pastures resulting in canopy cover of up to 60%. Such infestations lead to a substantial reduction of stock carrying capacity during late spring and summer when the weed produces large quantities of unpalatable flower stalks. By the 1990s many farmers in New South Wales and Victoria found that they had expanding cover of CNG in their paddocks. Moreover, the weed has been invading conservation areas comprising native grasslands, grassy woodlands and riparian vegetation in many areas.

The main problem encountered in the management of pastures dominated by CNG is the production of large numbers of unpalatable flower stalks during summer, which are actively avoided by stock, and have sharp seeds which can penetrate the hides of sheep. As *N. neesiana* is palatable for much of the year, grazing management of this species has been identified as a potential management tool requiring investigation. The project aims to maximise the feed utilisation of CNG, whilst limiting the production of viable seeds, using a range of cultural techniques and grazing strategies that incorporate different classes of stock

MATERIALS AND METHODS

A PhD study has been initiated to investigate management options for CNG infestations. This project comprises of two national projects; The CNG regional best practice management project and the long term grazing and utilisation for CNG project. Descriptions of the trials conducted as part of both projects are outlined below;

Chilean needle grass Regional Best Practice Management. Five 'on farm' demonstration trials of management techniques for CNG have been established. These cover the plants' distribution ranging from Greenvale and Toolleen (Victoria), to Goulburn and Glen Innes (NSW). The trial sites evaluate pasture sowing, cropping and chemical control strategies integrated with grazing management (strategic, set stock or lockup) and its effect on pasture composition

Trial layout. Trials in three of the regions consisted of 10 treatments (table 1), the exception being Glen Innes with 12 treatments (table 2). The treatments were applied in replicated blocks of fenced off plots. Each site had a 'monitor sensors' automatic weather recording station to monitor the local climate. The weather stations recorded relative humidity, air temperature, rainfall, leaf wetness, solar radiation and soil moisture.

Table 1. Treatments as applied at Greenvale, Toolleen and Goulburn 2003.

Treatment	Grazing regime	Fertiliser	Spraying	Resow
1	Set stock	N	None	N
2	Set stock	N	Flupropanate	N
3	Lock up	Y	Flupropanate	Y
4	Lock up	Y	None	Y
5	Lock up	N	Flupropanate	N
6	Lock up	N	None	N
7	Strategic	Y	Flupropanate	Y
8	Strategic	Y	None	Y
9	Strategic	N	Flupropanate	N
10	Strategic	N	None	N

Table 2. Treatments as applied at Glen Innes 2003

Treatment	Grazing	Spray	Resow	Crop
1	Set Stock	None	None	No
2	Set Stock	Selective (Glyphosate)	None	No
3	Set Stock	Glyphosate	Sow pasture	No
4	Set Stock	Glyphosate	Sow pasture	Yes
5	Strategic	Selective (Glyphosate)	None	No
6	Strategic	Glyphosate	Sow pasture	No
7	Strategic	Glyphosate	Sow pasture	Yes
8	Set Stock	Spray-top	None	No
9	Strategic	Spray-top	None	No
10	Strategic	None	None	No
11	Set Stock	Flupropanate	None	No
12	Strategic	Flupropanate	None	No

Sowing procedure. Soil tests were taken to determine the correct fertiliser and pasture seed mix to sow at each site. Only treatments that were to be sown down to pasture seed were fertilised, except at Glen Innes where all treatments received fertiliser. Pasture seed was sown by aerial broadcast at Goulburn 2003 whilst a direct drill seed drill was used at Greenvale, Toolleen and Glen Innes. Pasture seed was sown to a depth of 15-20mm using the seed drill. Plots that had a 'cropping' treatment at Glen Innes were sown to pasture after a season of conventional (utilising cultivation) summer cropping with soybeans.

Spraying procedure. Plots were sprayed using a hand held or ATV mounted boom sprayer. Goulburn, 'spray' plots were boomed sprayed prior to sowing with flupropanate at 2l/ha on the 31st October 2002 and 1st November 2002 respectively. At Greenvale and Toolleen none of the sown plots were sprayed prior to sowing (2003). 'Spray' treatments two and nine at Toolleen and Greenvale were boom sprayed with Flupropanate at 1.5l/ha 4th July 2003 and 17th July respectively. Treatment five was boom sprayed with flupropanate at 1.5l/ha on 21st October 2003.

Grazing regimes. 'Set stock' plots were open ended such that they received the same grazing pressure as the experimental paddock. This form of grazing was flexible to allow for destocking during periods of severe flowering, and for management of other paddocks on the farm. 'Strategic' grazing plots were grazed for short periods on an as needed basis to reduce the production of flower heads and limit grazing selectivity. 'Lock up' plots are ungrazed and totally exclude grazing stock.

Trial measurements. The botanical composition and CNG seedling emergence was recorded in each plot on a seasonal basis. The botanical composition was measured using a 'pasture comb' that consisted of 10 tynes, measuring 1m and length spaced 10cm apart, each with 10 machined groves spaced 10cm apart. The comb was placed in the same position in each plot for each measurement. The classes recorded for Greenvale and Toolleen, were CNG, Desirable perennial grass, annual grass, broadleaf weed, vegetative litter, soil, rock, legume. At Goulburn, Forbs were also recorded. Individual types of grasses were also recorded at Glen Innes. The grass classifications included were Tall fescue, Phalaris, Cocksfoot, Button grass, Soft Brome, Winter grass.

CNG seedlings were counted using a 25x25cm quadrat subdivided by fine wire into 25, 5x5cm divisions. Seedlings were counted from the same three positions in each pen on a seasonal basis. In each position, nine designated divisions were assessed for the presence of live CNG seedlings.

Feed Evaluation of Chilean needle grass (Fertiliser addition with Clipping and Glyphosate Spraytopping). Perceptions that CNG had a low feed value were in contrast with certain observations made by producers of stock maintaining condition when grazing CNG. These trials were established to quantify the feed value of CNG throughout its growing season, under fertiliser and clipping regimes, or glyphosate spraytopping regimes. CNG feed value was compared to Cocksfoot (*Dactylis glomerata*; fertiliser treatments), or Phalaris (*Phalaris aquatica;* spraytopping treatments).

Measurements. The regrowth of CNG, cocksfoot and phalaris plants was used to assess the Feedvalue of the grasses. Samples were cut using and shears and analysed for crude protein (percentage of dry matter; CP), metabolisable energy (MJ kg^{-1} dry matter; ME), digestible dry matter (percentage of dry matter; DDM), neutral detergent fibre (percentage of dry matter; NDF), and total plant dry matter (percentage of wet weight; DM).

Treatments. Clipping treatments were applied when pasture mass was sufficient for grazing on an ongoing basis throughout the growing season. Fertiliser treatments were applied during spring 2003 with nitrogen fertiliser applied as a split application of Urea (table 3).

Spraytopping treatments were applied during spring 2003 whilst the CNG seedhead was forming. Glyphosate was applied using a boom sprayer with plant samples taken 2 weeks after spraying (table 4).

Table 3. Treatments applied for Chilean needle grass fertiliser clipping feed evaluation trial, Greenvale (2003)

Treatment	Phosphorus (kg/ha)	Nitrogen (kg/ha)	Clipping
1	Control	Control	No
2	0	0	Yes
3	22^A	0	Yes
4	0	92^B	Yes
5	22^A	92^B	Yes

^{A} 250kg/ha single super phosphate (8.8%P 11%S 19%Ca)
^{B} 200kg/ha urea (46%N) –split fertiliser applications of 100kg/ha over spring 2003

Table 4. Treatments applied for Chilean needle grass spraytopping feed evaluation trial, Geelong (2003)

Treatment	Growth stage at application	Glyphosate (grams a.i./ha)
1	No spray	-
2	Seedhead development – head at leaf sheath base	128
3	Seedhead development – head at leaf sheath base	255
4	Seedhead emergence	128
5	Seedhead emergence	255

Comparison of Stock Class for Chilean needle grass grazing (Sheep and Cattle grazing in set stock and full rotational systems). CNG can be a valuable winter feed when in its vegetative state, yet it is unpalatable once flowering occurs. Grazing is considered to be one means of reducing the production of seedheads. Selective grazing by livestock means that CNG plants are often not grazed, therefore allowed to produce seedheads, if grazing pressure is not sufficient.

This trial was designed to identify, the type of grazer (sheep or cattle) that minimises the production of seedheads through grazing, the grazing method (simple rotation vs set stock) for each class of stock to that reduces seedhead production, and the type of grazer (sheep or cattle) with the greatest production potential when grazing CNG. Thus the trial aimed to maximise utilisation of CNG and maintain animal productivity, whilst minimising the production of unpalatable seedheads.

Treatments. Sheep and cattle were grazed separately in full paddock set stocked or rotational grazing systems. The trial started in spring 2004 stocked at 12DSE/ha at Greenvale Victoria.

Measurements. The trial consisted of 5 treatments replicated twice (table5) along the sides of a valley. Each treatment was stocked equivalent to 12 DSE made up of cows and calves or sheep with lambs at foot. Both the boundary and internal fences (grazing cells) for the cattle treatments were electric wires, whilst sheep proof mesh (Ringlock 7/90/30) was used for all fences of the sheep treatments. Rotation length started at 8 weeks (2 weeks in, 6 weeks out) during September and October and was shortened to a 4 week cycle (1 week in, 3 weeks out) during November and early December. All cells and paddocks had water troughs fed by gravity from a header tank.

All stock were weighed, stratified and randomly allocated to their treatments by 30th August 2004. Animal health and production was measured monthly. Liveweight was recorded monthly for both sheep and cattle with young stock included in weighing after birth.

Pasture composition was recorded using a 100 point 1x1m quadrat recording basal observations. The basal measurements were recorded into 7 categories – CNG, Perennial desirable grasses (phalaris and cocksfoot), Broadleaf weeds (cape weed), other annual grasses, legumes, vegetative litter, bare soil.

Available Pasture mass and pasture growth (kgDM/ha) was measured using a rising plate.Available pasture mass was measured across all plots and cells at the time when rotationally grazing stock were shifted into a new grazing cell.

Species growth rates were calculated using BOTANAL, a dry weight ranking method Reproductive stems of all pasture species were harvested prior to CNG seedfall using hand shears. Stems were sorted and CNG panicle seeds and stem cleistogenes removed. The quantity of panicle seed per treatment was calculated by weight of complete seed (R^2 = 0.95) with cleistogene seeds counted individually.

Table 5. Type of grazer and grazing management method used – Stock class grazing trial, Greenvale 2004

Treatment	Graze regime	Grazing stock
1	*Control*	Control
2	Set Stock	Cattle
3	Rotational	Cattle
4	Set Stock	Sheep
5	Rotational	Sheep

Time of burning. Burning has been known to sterilise weed seeds both on the plant and in the soil seed bank. This trial was conducted at Greenvale Victoria to evaluate the effectiveness of burning at different times throughout the summer and autumn (2004/05) in reducing the viability of above ground seed and also seed in the soil seedbank.

Treatments. The trial consisted of 3 burning times replicated 3 times (table 6). Each treatment plot consisted of a 20x20m area, marked by steel posts with a 2m buffer between plots. Burning was undertaken using a drip torch filled with a fuel mixture of 50% petrol and 50% diesel. Plots were strip ignited from the leeward side relative to the wind.

Measurements. Soil cores to a depth of 25mm were taken from all plots prior to seedhead development in spring 2004. Further cores were taken after burning for the autumn treatment.

Pasture mass (kgDM/ha) was measured prior to burning by cutting and drying a 25x25cm pasture cut at ground level using hand shears.

All weather data was taken at the time of burning using an automated weather station located in Greenvale (2km) and was also correlated with Melbourne international airport (6km). The weather stations recorded relative humidity, wind speed, wind direction, and air temperature
Reproductive stems were harvested prior to seedfall. Stems were sorted and panicle seeds removed with the quantity of panicle seed per treatment calculated by regression based on seed weight.

Pasture composition was recorded using a 100 point 1x1m quadrat recording basal observations. The basal measurements were recorded into 7 categories – CNG, Perennial desirable grasses, Broadleaf weeds, other annual grasses, legumes, vegetative litter, bare soil. Seedling occurrence was measured using a 9sectors of a 25x25cm quadrat divided into 5x5cm sectors over winter 2005.

Table 6. Burning frequency and corresponding physiological growth stage of Chilean needle grass.

Treatment	Burn time	Growth stage
1	Control	-
2	Seedfall	Seedfall
3	Summer	Dormant – Post seedfall
4	Autumn	Starting Vegetative growth

Time of slashing. Slashing provides a means of reducing dry matter produced during the reproductive phases of growth. Although slashing has been known to reduce the occurrence of panicle seeds, CNG has been observed to regenerate a new seedhead quickly post slashing. Slashing can also be a vector for the spread of CNG. This trial evaluated different times of slashing in relation to the growth stage of CNG with respect to panicle seed production and changes to the pasture sward. The trial was conducted at Greenvale, Victoria.

Treatments. The trial consisted of 7 treatments replicated 3 times (table 7). Each treatment plot consisted of a 5x20m area, marked by steel posts. Slashing was undertaken by a 3 point linkage rotary slasher to a height of 50mm. Time of slashing corresponded to different physiological growth stages of CNG during seeding. The physiological growth stages of CNG were determined by observing CNG plants in the control plots that had not yet been slashed.

Measurements. Pasture mass was measured using a rising plate meter. Pasture mass was measured pre and post slashing for all plots.

Reproductive stems were harvested prior to seedfall on 14th December 2004. Plots that had been slashed in December were not harvested. Stems were sorted and panicle seeds removed with the quantity of panicle seed per treatment calculated by weight.

Pasture composition was recorded using a 100 point 1x1m quadrat recording basal observations. The basal measurements were recorded into 7 categories – CNG, Perennial desirable grasses, Broadleaf weeds, other annual grasses, legumes, vegetative litter, bare soil. Pasture composition was recorded and seedling ocurrence was measured.

Weather data was recorded using a local automated weather station located in Greenvale (2km) and was also correlated with Melbourne international airport (6km). The weather stations recorded relative humidity, wind speed, wind direction, and air temperature.

Table 7. Slashing frequency and corresponding physiological growth stage of Chilean needle grass.

Treatment	Slashing frequency	Slash time	Growth stage
1	None	Control	-
2	Single	Oct	Swollen/emerging
3	Single	Nov	Emerged/flowering
4	Single	Dec	Seedfall
5	Double	Oct & Nov	Combinations of above
6	Double	Nov & Dec	Combinations of above
7	Triple	Oct, Nov & Dec	Combinations of above

Pasture species competition. Pasture competition can make soil resources unavailable to weed species thus reducing the growth of weeds. This trial evaluated the competitiveness of 3 pasture species (*Phalaris aquatica, Dactylis glomerata, and Festuca arundinacea*; sown at different sowing rates with different fertiliser application rates) in an established sward of CNG.

The experiment was conducted in a cell grazed paddock at Wildwood Victoria, on the property 'Grevisfield.' The trial plots were made up of 30 grazing cells across 15 lanes of a 16 lane grazing system operating on a 90-100day rotation stocked equivalent to 35DSE/ha.

Treatments. The trial consisted of 10 treatments replicated 3 times (table 8). Each treatment plot consisted of a 45x20m area (one grazing cell), bordered by a single electric wire. The plots were boom sprayed with 900g a.i./ha glyphosate on 5th May 2004. Sowing was undertaken using an all terrain disc seeder (RockHoppa by AgReCon) pulled by a tractor fitted with high flotation tyres (Trelleborg) on 19th May 2004. Sowing depth was set to 15-20mm where possible. Di-Ammonium phosphate Fertiliser was broadcast over the respective treatments equivalent to 100kg/ha on 24th May 2004.

Measurements. Pasture composition was measured prior to spraying using a 100 point 1x1m quadrat recording basal observations across all plots. The basal measurements were recorded into 7 categories – CNG, Sown grasses, Broadleaf weeds, other perennial grasses, other annual grasses, legumes, vegetative litter, rock and bare soil.

Table 8. Treatments applied for pasture species composition trial at Wildwood 2004

Treatment	Pasture Species	Seed Rate[E]	Fertiliser
1	Control[A]	-	None
2	Tall Fescue[B]	High	yes
3	Tall Fescue[B]	Normal	yes
4	Tall Fescue[B]	High	None
5	Cocksfoot[C]	High	yes
6	Cocksfoot[C]	Normal	yes
7	Cocksfoot[C]	High	None
8	Phalaris[D]	High	yes
9	Phalaris[D]	Normal	yes
10	Phalaris[D]	High	None

[A] Control plots were not fertilised or sown to any pasture species

[B] Jessup MaxP Tall fescue (*Festuca* & Goulburn Subterranean clover.

[C] Kara Cocksfoot (*Dactylis glomerata*) & Goulburn Subterranean clover.

[D] Holdfast Phalaris (*Phalaris aquatica*) & Goulburn Subterranean clover.

[E] Seed rates

Jessup MaxP Tall fescue (Goulburn sub clover) Normal rate 22kg/ha (6kg/ha)
High rate 44kg/ha (12kg/ha)

Kara Cocksfoot (Goulburn sub clover) Normal rate 7kg/ha (6kg/ha)
High rate 14kg/ha (12kg/ha)

Holdfast Phalaris (Goulburn sub clover)
Normal rate 8kg/ha (6kg/ha)
High rate 16kg/ha (12kg/ha)

Note: Sub clover seed was lime coated and inoculated. Seed rate is expressed as equivalent sowing rate of bare seed.

ACKNOWLEDMENTS

These studies are funded by the Natural Heritage Trust and the CRC for Australian weed management, in collaboration with DPI Victoria, DPI New South Wales, The University of New England, and The University of Melbourne. Other collaborators for specific trials include Hume City Council, AgReCon Machinery, Hume Turf and Machinery, Grech Agriculture and Country Fire Authority Victoria.

Onground support and assistance has been provided by Aaron Dodd (WeedsCRC studentship/DPI VIC), Caroline Ayres (DPI VIC Cadetship), James Winters (Latrobe University hons), Andrew Barritt (WeedsCRC), Tamara Threlfall (DPI VIC), Michelle whitely (DPI VIC), Noel Campbell (DPI VIC), Bruce McGregor (DPI VIC), Kym Butler (DPI VIC), Julio Bonilla (DPI VIC), Linda Iaconis (DPI VIC), Natasha Baldyga (DPI VIC/ Whittlesea council), Jeff Wilkie (DPI VIC),Lori McWhirter (DPI NSW), Dale Chalker (DPI NSW), Jeff Lowien (DPI NSW), Fred Phan (DPI NSW)

All trials are conducted on private land with cooperative and generous landholders. The efforts of Ian Souter (The Elms, Greenvale), Tid and Sally Alston (Oaklands, Oaklands Junction), Len and Jenny Karmel (Redgum park, Greenvale), John and Allen McKenzie (Sunbury), Robyn and Brett Kissel (Grevisfield, Wildwood), Roger and brian Hickson, Peter Sastrom (Toolleen), Col and Andrew Say ('Euroa', Glen Innes) and (Dambreezy, Goulburn) are much appreciated.

Management Strategies for Giant Parramatta Grass

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Summary Giant Parramatta grass (GPG; *Sporobolus fertilis*) is one of five weedy Sporobolus species found in Australia. Practical paddock and property scale weedy Sporobolus grass (WSG) control strategies are required for extensive grazing land. The eight treatments tested are set stock (SS); SS + flupropanate 1.5 L/ha October 2003 (SS+F); rotational grazing (RG); RG+F; SS + year round 10% urea/molasses block (SS+Block); RG+P (20kg P in Autumn from single super); Best Management Practice (BMP)+P (RG+F+P+ improved grass and legume); BMP+2P (BMP+P+20kg P in spring). Grazing commenced in January 2004 and results for the first 12 months are presented. Changing grazing strategies from set stock to grazing in order to minimise summer seed set of GPG increased the amount (kg/ha) of the more desirable Paspalum (*P dilatatum*). Application of flupropanate removed GPG from the pasture and allowed an increase in the amount of Paspalum, Carpet grass (*Axonopus affinus*) and native *Bothriochloa decipiens* . Flupropanate also reduced pasture dry matter and stocking rate (from 1.3 to 1.1 steers/ha/an). Feeding 10% urea/molasses blocks year round to animals grazing GPG increased weight gain/ha during 2004 from 112 to 165kg. Most of this improvement occurred over winter and spring. Both BMP treatments had stocking rates of 1.6 steers/ha/yr compared with the SS treatment of 1.3.
Keywords: Giant Parramatta Grass, Sporobolus fertilis, grazing management, supplementation.

INTRODUCTION

All five weedy Sporobolus species are unpalatable summer growing perennials that out compete more desirable species in pasture, native grasslands, woodlands and riparian areas for the rats' tail sub group.

Current management methods need to be refined to control WSGs in extensive areas or where intensive methods, such as wick-wiping or cropping are not suitable. This experiment was designed to compare the effectiveness of eight management options which range in complexity from do nothing to treatments with improved pasture species, soil fertility and grazing management.

MATERIALS AND METHODS

The experimental site "SouthPark" is located on Boormans Lane in lower Southgate NE of Grafton. The property is heavily infested with giant Parramatta grass. The trial area comprises 32 1.5ha paddocks. Each of the eight treatments (Table 1) is replicated 4 times. Grazing of the trial area commenced in January 2004 when the four month withholding period for flupropanate sprayed pasture had expired.

A giant Parramatta grass advisory committee (GPGAC) was formed from local producers and advisors at the start of the trial. Their role was to ensure all treatments are practical, with individuals in the committee benefiting from observing the conduct of the trial and learning from fellow committee members.

The GPGAC approved a set-stock rate of 2 steers/1.5ha and agreed that the minimum pasture dry matter for the rotational paddocks be 2.5t/ha. For paddocks with "improved" pasture species a seeding down time was allowed in late summer or autumn each year.

RESULTS

Rainfall in 2004 was reasonable from January through March and again in late October through December. The rainfall in the period from April to September was well below average (Figure 1). An initial attempt (March 1) to establish legumes in treatments seven and eight was frustrated by slugs eating seedlings as they germinated. A second attempt in April failed due to lack of moisture.

Table 1. Treatments.

Treatment No	1	2	3	4	5	6	7	8
	Set Stock	**Flupro-panate (F)**	**Rotational Grazing (RG)**	**F and RG**	**Block 10% urea year round**	**Fertiliser**	**BMP[A] 20kg P**	**BMP 40kg P**
Pasture species	GPG + naturalised grass	GPG + naturalised grass	GPG + naturalised grass	GPG + naturalised grass	GPG + naturalized grass	GPG + naturalized grass	Sown grass + legume[C]	Sown grass + legume
Flupro-panate	Nil	1.5 l/ha Year 1	Nil	1.5 l/ha Year 1	Nil	Nil	1.5 l/ha Year 1	1.5 l/ha Year 1
Fertiliser[B] Program	Nil	Nil	Nil	Nil	Nil	20kg P/an applied in autumn	20kg P/an applied in autumn	40kg P/an applied in Aut & Spr
Grazing strategy	Set stocking	Set stocking	Rotational grazing	Rotational grazing	Set stocking	Rotational grazing	Rotationa l grazing	Rotationa l grazing

[A]BMP = Best management practice; Flupropanate was applied in October 2003. [B]Fertiliser = single super; Treatments 6, 7 and 8 had 2.5 t/ha of lime applied in December 2003 and the first super application occurred in March 2004. [C]A legume mix containing 0.9 (kg/ha) Aztec Atro, 0.9 Burgundy bean, 1.5 Claret red clover, 1.5 Waverly white clover and 1 of Tonic plantain was sown on March 1 and resown on April 8 2004. The sown grass is setaria (3 of 4 replicates) and a mix of Rhodes grass, paspalum and bahia grass (replicate 4) in treatments 7 and 8.

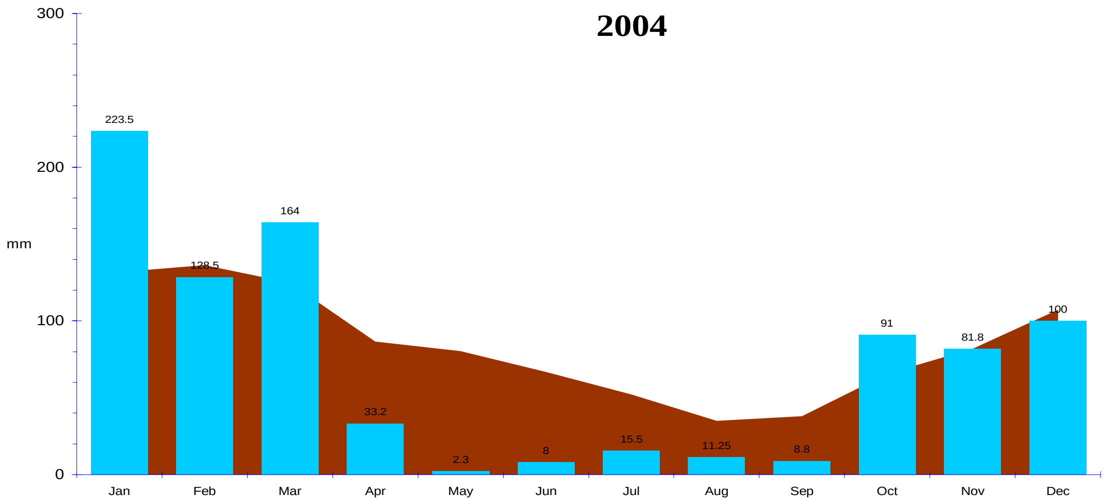

Figure 1. Monthly rainfall for Grafton Research Station in 2004 (approx 12 km from Southpark). The 2004 rainfall was 868mm and mean monthly rainfall is shown as a shaded area.

Set Stock Treatments (1, 2 &5). The steers in the set stock paddocks were initially supplied by the collaborator (Jan-Oct 2004). On the 21st October he asked for the steers to be removed from the experiment to allow him to fatten them more rapidly for sale. It took until the 21/11/2004 to replace them. In the intervening period other animals were used to maintain the stocking rate set by the GPGAC.

Set Stock The average weight gain for steers on treatment 1 was 230g/day (Table 2). Steers on this treatment gained weight between January and May, but tended to lose weight between May and October (on average 8kg). Thereafter the steers gained weight up until January 2005.

There was on average 5.2t of dry matter/ha in the SS paddocks throughout 2004 (Figure 2). By March the feed in the set stock paddocks was rank and starting to hay off. By late May very little of the GPG remained green and the majority of the pasture dry matter was senescent GPG seed heads.

Flupropanate. By January 2004 between 40 and 60% of the pasture dry matter was dying or was dead in the sprayed paddocks. This meant that from the start, animals in these paddocks had less feed (Figure 2). The remaining live plant biomass, predominately paspalum, was of superior quality to the GPG being consumed in the unsprayed paddocks. As a consequence weight gains of the steers in these paddocks were initially higher than in the unsprayed GPG paddocks.

By May 2004 this advantage had disappeared as the available feed in three of the four sprayed paddocks dropped towards the 2.5t/ha level at which the cattle were to be removed. Cattle on this treatment gained weight from January to May and then maintained their weight through winter and spring. They started to gain weight again in November through to January 2005.

During the first 12 months (Jan 04 to Jan 05) steers were removed from the set stocked sprayed paddocks 16% of the time over winter and spring. Three out of the 4 paddocks had to be spelled throughout the year due to lack of feed (at or below 2.5t dry matter/ha). Paddock no. 6 had approximately 70% GPG at the start of the experiment and had steers removed for 125 days during the first year due to low feed availability.

The average estimated dry matter of 3.6t/ha for the flupropanate treatment may overstate the amount of feed available. During 2004 there remained a considerable bulk of dead or dying GPG which made estimating dry matter yields difficult.

Block. The cattle on this treatment gained almost 50% more than the un-supplemented Set Stock treatment with an average weight gain of 339g/d. The benefit from the blocks was most evident between May and October. Retaining access to the blocks over summer was less valuable for improved gain. The blocks cost 82.5c/kg and the steers ate on average 98kg each. The improvement in weight gain attributable to the blocks was 37kg/head which meant each kg of gain cost $2.17.

Pasture Composition. In the initial Botanal (August 2003) GPG comprised on an average of 48% of the pasture dry matter for treatments 1-6. The improved paddocks (treatments 7 and 8) had an average of 7.5% GPG.

Table 2. Effect of treatment on steer weight gain (kg) for 2004.

Treatment	Jan-Oct	Nov-Jan	Total	kg/ha
Set Stock	47	36	84	112
Flupropanate	65	34	99	132
Block	79	45	124	165

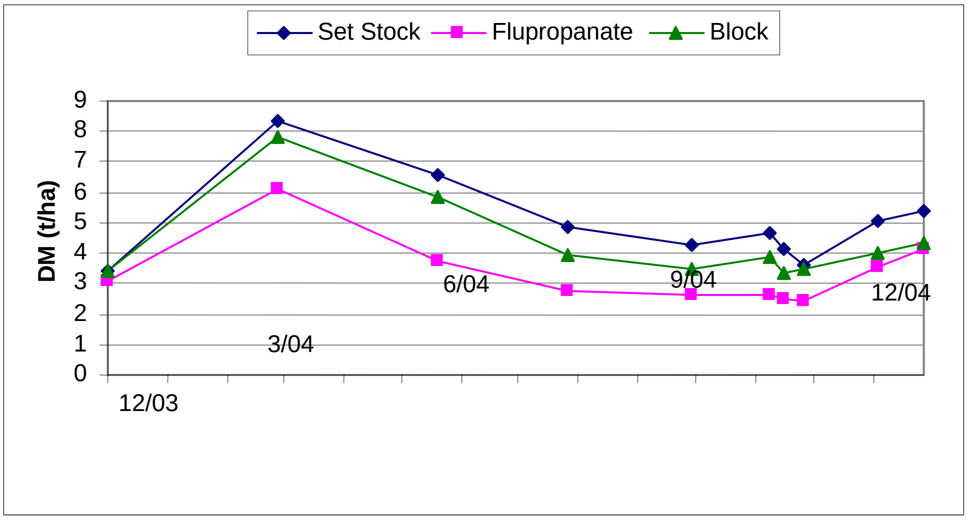

Figure 2. Dry matter in Set Stock treatments

By May 2005 all the GPG was dead in the sprayed paddocks. In comparison the unsprayed Set Stock treatment had 52% of pasture dry matter coming from GPG. By changing the grazing management from set stock to rotational (Jan-May 2004) the proportion of GPG in the pasture dry matter fell to 35%. Both the fertilized and unfertilized rotationally grazed treatments had similar pasture composition.

Other pasture species. As the proportion of GPG fell in the sprayed and rotationally grazed treatments it was replaced primarily by paspalum. In the rotationally grazed unsprayed paddocks the proportion of Carpet grass dry matter increased. But, in sprayed paddocks the proportion of Carpet grass fell by 10-25%. Flupropanate reduced the amount of GPG and carpet grass and allowed the native grass (primarily *Bothriochloa decipiens*) to increase by around 10%. Also increasing after spraying were a range of broadleaf weeds (from 1 to 8%) and Fireweed (trace to 4%). Apart from the removal of GPG with spraying the species composition of the improved pastures remained stable. It is too early to measure any effect of super on pasture composition.

Grazing management. The rotationally grazed paddocks containing GPG were grazed hard over a period of 26 days. A minimum pasture dry matter of 2.5t/ha had been set by the GPGAC and all paddocks were above this level when the cattle were removed after this first grazing.

The initial strategy used was to spread the limited number of animals available for grazing over all the rotational paddocks in small groups. Because the paddocks had not been grazed for some time they had high amounts of dry matter which was declining in quality rapidly. The stocking rate during the initial grazing period for the SS and Fertiliser treatments were 19 and 17 steers respectively/day.

This strategy was hard on the animals and they started looking for fresh feed within a week. The animals were not eating to their capacity and their condition suffered for it. The bulk of rank GPG was significantly reduced during this grazing (by 2-3t/ha) and then the paddocks were rested for 18 days. The pattern of grazing throughout 2004 is shown in Table 3.

Table 3. Seasonal grazing pattern[A] and annual stocking rate for 2004.

Treatment	Jan-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Jan	Total	Steers /ha/yr
Set Stock	78	184	184	163	104	713	1.3
Flupropanate (F)	78	184	140	91	104	597	1.1
Rotational (R)	496	187	15	102	46	846	1.6
RF	187	183	18	91	43	521	1.0
Block	78	184	184	143	104	693	1.3
Fertiliser	438	208	18	110	54	828	1.5
BMP mod P[B]	193	396	15	132	126	861	1.6
BMP high P	250	366	18	126	119	878	1.6

[A]Grazing days = No of animals x days grazing; 730 grazing days = 2 steers/day/annum
[B]BMP = Best management practice (see Table 1)

A second brief (2 days) and moderate (20-23 steers/paddock) grazing was conducted in March 04 followed by a 4-5 week break. The cattle were given a lengthy break from the experimental paddocks to graze other parts of the property. In this break the pasture recovered considerably, allowing most of the GPG to go to head.

The sprayed GPG paddocks were lightly grazed (7 steers/paddock/day) in the first grazing compared to the unsprayed paddocks. All the pasture including the flupropanate tolerant species such and *Bothriochloa decipiens* and Paspalum were affected by the 1.5 L/ha applied in October 2003. Much of the GPG was still dying off in February and March 2004 and some dead GPG still remains 15 months after spraying. By autumn 2004, most of the GPG had died and broadleaved weeds especially fireweed germinated and started to fill the gap left by GPG.

The improved paddocks (treatments 7 and 8) were grazed lightly in Jan/Feb 2004. The Setaria was affected by the flupropanate with some plants showing discolouration and deformation of the leaves. Whilst the plants were under stress due to dry conditions these symptoms were more obvious. Approximately 10% of the setaria plants were severely affected by the flupropanate and died. The kill of the GPG in these paddocks was good. There were no mature GPG plants evident by May 2004. The improved paddocks recovered more rapidly than both the unfertilised and fertilised GPG paddocks. As a consequence the stocking rates of the improved paddocks were approximately four steers/paddock/day compared with two on the rotationally grazed GPG (Mar-May). Grazing for all rotational treatments was very low over winter 2004.

DISCUSSION

The issue of poor weight gain for steers on treatment 1 is clearly not due to the amount of available feed but is due to feed quality. The leaves and stem of rank GPG are very tough. As a consequence cattle avoid rank GPG where possible.

Feeding studies which measured intake of chaffed and urea supplemented GPG hay made from either over-wintered rank GPG or fresh regrowth showed steers increased their intake from below to above maintenance when offered fresh regrowth hay. This result highlights the importance of keeping GPG short and green for animal performance.

The first year's attempts to prevent GPG from going rank through grazing management have shown this to be a difficult task. This is especially so when grazing pressure is limited by cattle numbers. Producer concerns for animal welfare as a result of the need to dramatically increase stocking rates for short periods of time to prevent pasture growth outstripping cattle intake have also hampered our ability to meet treatment goals. More work is required to develop general principles for good grazing management for GPG given the above restrictions.

The principle of supplying nitrogen to cattle when the pasture is nitrogen deficient in this nutrient is well established. However, the value of year round supply of 10% urea/molasses blocks for cattle grazing GPG infested pastures has not been determined. Steers in three out of the four paddocks to which blocks were supplied benefited from the additional nutrients. In Paddock 23, the poorest of the paddocks, there was no weight gain benefit from supplementation. Interestingly this paddock was also the only one that had to be spelled in autumn 2005 (ie pasture dry matter had fallen below 2500 kg/ha).

The economics of supplementation year round improves by 40c/kg to $1.77 without paddock 23. The cost/kg gain between May and October was only $0.97 (not including the steers in Pad 23 that lost weight). In that 156 day period (May-Oct) the average gain was 46kg or 295 g/day. By supplementing with urea molasses blocks, weight gain was economically improved and has allowed the steers to utilise more of the poor quality standing feed provided by GPG.

No benefit has been observed from applying 20kg/ha of P to the rotationally grazed pastures infested with GPG. Improvements in soil P status and hence pasture growth can take some time to occur especially in soils with a high P sorption capacity such as we have at this site.

The BMP and the unsprayed rotationally grazed treatments were stocked at higher rates than the Set Stock control treatment during 2004. The next 2 years will give an indication as to whether these stocking rates are sustainable or not.

Flupropanate has proven to be an effective chemical control for GPG as expected. What is interesting from this work is the extent to which overall pasture production is reduced post spraying and the need to carefully manage sprayed pasture to prevent re-infestation of GPG and other weeds. Sprayed pastures have been relatively slow to recover post spraying. Sixteen months post spraying and these paddocks have more bare soil and broadleaved weeds and in particular fireweed than their unsprayed counterparts. Application of N fertilizer may be useful post spraying to speed up pasture recovery and limit the re-establishment of GPG and other weeds.

The removal of GPG through the application of flupropanate has increased the amount of the desirable species Paspalum. Unfortunately, it has also increased the amount of relatively unpalatable native *Bothriochloa*. More desirable natives such as Kangaroo grass (*Themeda*) are rarely seen in either the sprayed or unsprayed paddocks. In effect, spraying has removed one unpalatable species and replaced it with another. Over sowing sprayed paddocks with desirable species could be considered.

ACKNOWLEDGMENTS

Thanks go to Alex and Pam McLeay the owners of "SouthPark" for the use of their land and support for this research. The contributions of members of the GPGAC are also greatly acknowledged. This work has been made possible with funding from MLA (NBP.308).

Options for control of *Nassella trichotoma* on the Northern Tablelands of New South Wales

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Summary. Extensive work has been carried out to determine the management strategies that best control *Nassella trichotoma* (serrated tussock) throughout the south eastern regions of Australia and New Zealand. *N. trichotoma* infested areas on the Northern Tablelands of New South Wales (NSW) in the early 1960s and it went unnoticed and uncontrolled for many decades. Since the recognition of *N. trichotoma* on the Northern Tablelands as a weed of significance, measures have been taken for its control and management. Many of the ideas for control have been taken from the practices that are used on current infestations in the south eastern areas of Australia and in New Zealand. The variation in the environmental conditions and characteristics of infestations between these southern areas and the Northern Tablelands are the motive for development of more specific management options.

A trial was conducted near Armidale on the Northern Tablelands of NSW over two years, from 2003 to 2005. Seven treatments were targeted at managing *N. trichotoma*, whilst one treatment was the control where no management technique was implemented. The treatments were: permanent grazing with spot spraying; permanent grazing and chipping; permanent grazing with no control; permanent grazing and chipping followed by seed addition; pasture improvement, grazing excluded with chipping and seed addition; short rotation with chipping, seed addition and a low rate flupropanate application by boom to target seedlings; and a long rotation with chipping and seed additions. All active control measures such as chipping and spot spraying were implemented in spring and sowing of pasture improvement was implemented in autumn. The grazing rotations were in place for 18 months of the trial. The stocking rate was 5 dse ha^{-1}, which is slightly lower than usual so pastures could remain competitive throughout the two dry years experienced during the trial. The aim of these treatments was to develop techniques that could be easily adopted by any landholder with minimal effort but maximum effectiveness.

Results indicate that neglecting to control *N. trichotoma* leads to rapid and significant increases in population numbers. This can change the infestations from light and scattered to more dense and widespread. Sowing an improved pasture appears to achieve the best results for management of *N. trichotoma*; however in drought affected seasons, secondary weeds proved to be a significant problem during pasture establishment. The competitiveness of desirable pasture species in a longer rotation allowed some reduction in *N. trichotoma*. However, due to the increased pasture biomass, detection of individuals when chipping was limited when implemented as a control option. The shorter rotation proved more successful toward the end of the two years combined with low rates of flupropanate boom spraying to remove seedlings which may have been missed in chipping.

Reasonable control and containment of *N. trichotoma* on the Northern Tablelands will only be achieved if the landholder is willing to persist in managing infestations on their property. Vigilance in detection and persistence in control are the ways to improve the *N. trichotoma* situation in the future. In addition an area-wide approach is also required, given the ability of the weed to spread over long distances by wind.

Keywords *Nassella trichotoma*, spot spraying chipping, pasture improvement, rotational grazing

The ecology and management of serrated tussock (*Nassella trichotoma*) in native pastures

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Summary. Serrated tussock (*Nassella trichotoma*) is a hardy long-lived perennial grass weed that produces large amounts of wind dispersed seed making it extremely difficult to manage. The weak link in the plants life-cycle is its poor seedling vigour. A perennial native pasture that has a ground cover of >90% and herbage mass of >1.5 t DM ha^{-1} will inhibit the establishment of serrated tussock seedlings.

A survey of farmers in serrated tussock infested areas identified several physical and management characteristics of successful farms that has been able to prevent the wide spread invasions of serrated tussock, despite it being present on the property for > 20 years with heavy neighbouring infestations. There was less tussock on properties where machinery could easily access most paddocks and where a high pasture cover was maintained. Current farm structures where most paddocks are grazed and only one or two rested, make it difficult to manage pastures to maintain enough ground cover to prevent serrated tussock invasion, particularly in dry seasons. It is important to be able to rest pastures and budget feed using some form of rotational grazing, so decisions about destocking or confinement and feeding to maintain the crucial amounts of ground cover needed to limit serrated tussock invasion can be made.

Future research is needed in several critical areas and a new research project funded by Australian Wool Innovations (AWI) and Meat and Livestock Australia (MLA) has started at Charles Sturt University, Orange in partnership with the NSW Department of Primary Industries.

Keywords: Serrated tussock, *Nassella trichotoma*, farmer survey, whole-farm management, future research

INTRODUCTION

Serrated tussock (*Nassella trichotoma*) is an unpalatable perennial grass weed that invades disturbed or degraded pastures. A competitive perennial pasture that has >1.5 t DM ha^{-1} and <10% bare ground can dramatically reduce the opportunity for serrated tussock seedlings to establish (Badgery, 2004). Preventative management (i.e. grazing management, fertiliser and pasture establishment in suitable areas) can increase the competitiveness of pastures and maintain the minimum herbage required to reduce invasion. However, often significant changes are needed in whole-farm management to make this possible across a substantial area of the property. A survey was done of central and southern tablelands of New South Wales to identify: how farmers are currently managing serrated tussock; the factors associated with successful management; their knowledge of preventative techniques; and the on-farm limitations to better management.

MATERIALS AND METHODS

Four hundred survey points were randomly identified across the central and southern tablelands of NSW on a map of the 1997 serrated tussock area using ARCView®. Local councils within the survey area were then contacted to identify the property owners for each survey point. Points were excluded that fell on government owned land (*e.g.* national parks and state forest), that were too small (the minimum property size for the survey was 100ha), or when there was an excess of points within a council area. Initial contact was made over the phone by either a representative of the local councils or the surveyor, to determine whether the property manager was willing to participate. In total 54 properties were surveyed; approximately one-third each in the Bathurst, Goulburn and Cooma regions. The survey was done by face-to-face interviews on the property, which involved a questionnaire and paddock inspections.

RESULTS & DISCUSSION

Information was collected on the physical attributes of the property, the management programme and the farm manager's perception of various issues.

Physical conditions. Two physical factors, the number of years serrated tussock had been present on the property and the presence of heavy infestations on neighbouring properties, were found to be closely associated with the amount of serrated tussock at the time of the survey (Figure 1). There were seven properties that had successfully managed to keep serrated tussock at a low level (≤0.1%) despite these conditions.

Four physical factors (Cooma region, rainfall, low amounts of shale soil and accessible area) were found to be different on the 'successful' properties compared to the rest (Table 1). The most important of these factors is likely to be accessible area because it affects the identification and control of serrated tussock infestations. Also, there is no suitable integrated management system for inaccessible areas making them more difficult to manage than accessible areas.

Management factors. The seven 'successful' properties had three management factors that were different from the other properties. Interestingly these were all components of grazing management rather then factors associated with the control of the weed. The 'successful' properties were more likely to reduce livestock numbers in a drought; less likely to feed livestock; and had a higher proportion of steer trading. This suggests that conservative pasture management that results from these practices, particularly in a drought when pasture damage is more likely to occur, is a major factor preventing serrated tussock from dominating their properties.

Preventative management. There was a high awareness of the key issues needed to prevent serrated tussock from invading (81% believed high ground cover and less bare ground left by spraying could prevent invasion) and there was a desire to make a change (71% would reduce grazing pressure to limit invasion), but very few were actively making changes to their management. Drought was a major factor (33%) that farmers perceived would limited them from using more active forms of grazing management. Farmers may be less inclined to use better pasture management to prevent serrated tussock invasion because it is not easy for them to visually assess whether it has been successful compared to herbicides that kill the plant, unless the area previously had a heavy infestation or there is a stark fence-line contrast between a heavily infested and uninfested area.

Property structure. Most properties were run very similarly. On average there were 1.85 paddocks for every mob of livestock, indicating paddocks are rested rarely, especially once gates that are left open are taken into account. Some form of rotational grazing is required so that paddocks can be rested long enough to recover from grazing and enable desirable species to become competitive with the tussock. Grazing needs to be planned so that there is less chance of pastures being grazed below the critical biomass needed to prevent serrated tussock invasion. Appropriate pasture management includes reducing livestock numbers early during a drought to prevent damage across the whole property.

Table 1. The mean and standard error for responses from 'successful' and other properties. The probability is shown and only responses where P<0.05 are presented

Response	Successful[1] Properties	Other Properties	Prob
Cooma Region (%)	71.4 ± 18.4	25.5 ± 6.4	0.01
Average Rainfall (mm)	593 ± 48.4	693 ± 15.1	0.02
Shale Soils (%)	1.7 ± 1.7	37.2 ± 5.5	0.02
Accessible Area (%)	91.7 ± 5.0	70.6 ± 3.9	0.05
SR below normal (%)	55.3 ± 14.3	24.9 ± 3.8	0.01
Feed Livestock (%)	57.1 ± 20.2	88.6 ± 4.8	0.03
Steers (%)	28.7 ± 15.0	5.9 ± 2.3	0.01

[1] Successful properties had ≤0.1% serrated tussock, where it had been present for ≥20 years and had heavy infestation on a neighbouring property.

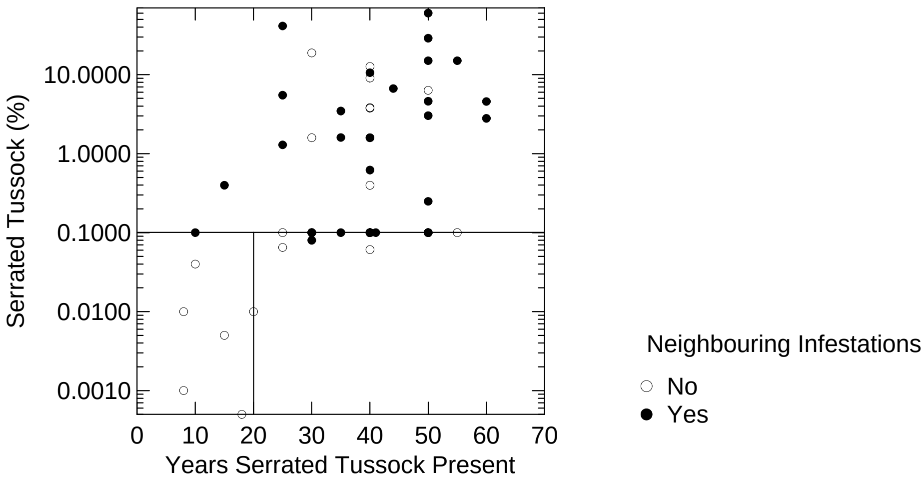

Figure 1. The level of serrated tussock (%) on a property compared to the number of years it had been present and the presence of neighbouring infestations. 'Successful' properties had ≤0.1% serrated tussock, where it had been present for ≥20 years and had heavy infestation on a neighbouring property.

CONCLUSION

Successful management of serrated tussock, involves the selective control of adult plants and the maintenance of competitive pastures, even during droughts. Quite often properties are not structured to allow for pastures to be rested and recover from grazing. Reducing mob numbers is essential for this to occur across a whole property. In essence many farm management decisions have an impact on the management of serrated tussock, not just those directly related to its control. From this survey three areas were identified that require future research to:

1) quantify the amount of ground cover and pasture DM needed to prevent serrated tussock invasion in different areas of the landscape (e.g. ridge tops v lower slopes) and in different environments (e.g. low v high rainfall) to confidently recommend appropriate pasture management,

2) develop an integrated weed management (IWM) strategy for intractable low fertility and inaccessible areas that do not have a perennial grass base by reseeding native or introduced species that are suited to these conditions after herbicide control,

3) weaken adult serrated tussock plants from low input management so that they are more susceptible to pasture competition promoted by appropriate grazing management.

A new research project funded by Meat and Livestock Australia (MLA) and Australian Wool Innovations (AWI) will examine these three areas.

ACKNOWLEDGMENTS

I would like to thank all of the local councils for there time and effort in helping locate the survey sites. I would especially like to thank all of the farmers who took part in the survey.

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Monaro Grassland Research and Demonstration Project

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Summary. Native pastures dominate the Monaro region and the continued healthy functioning of these grasslands is vital from environmental, economic and social perspectives. The Monaro Grassland Research and Demonstration Project is investigating a variety of management regimes to increase land productivity whilst retaining or enhancing the natural resources of the Monaro.

Ninety hectares of grazing trials have been established on basalt and granite soils near Cooma along with legume, perennial grass and herb species trials. These complementing trials aim to promote sustainable grassland management whilst investigating potential legumes, grasses and herbs for use in Monaro pastures. A small revegetation trial has also been established to investigate alternate methods of *Nassella trichotoma* management in non-arable locations.

Keywords: Monaro, native grassland, sustainable management.

INTRODUCTION

A predominant land use of the Monaro region is the grazing of native pastures. The continued healthy functioning of these grasslands is vital from environmental, economic and social perspectives. The Monaro Grassland Research and Demonstration Project being carried out by the NSW Department of Primary Industries in conjunction with the Southern Rivers Catchment Management Authority (SRCMA) and NSW Department of Environment and Conservation (DEC) is investigating land management strategies to increase native grassland productivity without compromising the unique biodiversity and other natural resources found on the Monaro.

Combined research / demonstration sites have been established within the SRCMA biodiversity pilot area during 2003/04. All of these trials require long-term maintenance and monitoring, as they are investigating relatively slow ecological changes in a harsh and variable environment. Robust results are unlikely to become available before 3-5 years. There are 4 sets of experiments:

1. Two large scale grazing trials, one on basalt derived soil and another on granite, are exploring the productivity gains possible in native grasslands on the Monaro through the use of fertiliser and legume addition. These trials are monitoring the impact of these inputs on pasture and animal productivity and also on the stability of the native perennial grass base and overall grassland biodiversity.

2. Small plot trials will evaluate the suitability of a range of possible legumes and alternative perennial grass and herb species as useful agricultural species in the Monaro environment. These trials are conducted adjacent to the grazing trials.

3. A trial investigating the potential of revegetation of low productivity, non-arable land with early successional native grass, shrub and tree species as a potential long-term control method for serrated tussock infestations on such sites.

4. A variety of recycled organic materials will be evaluated for product effectiveness as both an alternative fertiliser and as a revegetation and establishment aid.

MATERIALS AND METHODS

1. Native Grassland Grazing Trial

Two grazing trials have been established on separate properties on the Monaro, 'Oakvale' and 'Idaho'. The granite soil at 'Oakvale' supports a pasture dominated by *Austrostipa* and *Austrodanthonia* while the basalt soil at "Idaho" supports a strongly Poa sieberiana dominant pasture.

Sites were selected based on soil type, aspect, uniformity, suitability for the development of the necessary trial infrastructure and location within a pilot area created by the Snowy Monaro Biodiversity Conservation Strategy (SMBCS).

Each site has nine, 5 hectare paddocks which have been blocked in sets of three to allow for topographical differences over each of the sites. Each site also has a meteorological station, sheep yards and adjoining laneways.

At 'Idaho', treatments consist of a control with no seed and fertiliser (nil), a district common practice treatment of 125kg/ha Gypsum (low) and a combined 125kg/ha Gypsum and 125kg/ha superphosphate treatment (high). The 'Oakvale' treatments are a control (nil), a recommended 125kg/ha superphosphate (low) and 250kg/ha superphosphate (high).

Subterranean clover seed was applied to all the fertiliser treatment paddocks at the rates of 2kg/ha Mount Barker, 4kg/ha Seaton Park LF and 4kg/ha Goulburn. Treatments were spread on both sites on the 21st March 2005.

Paddocks are set stocked with initial stocking rates based on prior paddock history. If and/or when pasture production and sheep fat scores diverge significantly between treatments, increases in stocking rates will be considered to utilise the available feed and improve the gross margins for the respective treatments. Commencing stocking rates are 3 DSE/ha on 'Idaho' and 2.4 DSE/ha on 'Oakvale'.

Botanical analysis (BOTANAL) methods are carried out 7 times a year on each of these sites at 6 week intervals in spring, summer and autumn and every 8 weeks during winter. Measurements are made of the pasture composition, herbage mass (kg DM/ha), green and dead forage on offer (kg DM/ha) and ground cover (Tothill *et al*. 1992). Three observers walking independent random paths and using 50 quadrats/ person/ paddock are used for this activity. Forage quality is measured following each pasture monitoring date using FeedTest.

Frequency of each species present is measured once a year in mid to late spring. Working in pairs, 4 people identify all plant species in 80 randomly selected quadrats per paddock.

Phenological development will be monitored for the principal pasture species and nominated weed species at each site. Monitoring techniques will follow procedures recommended by Sanford *et al.* (1998).

Grazing enclosures have been built in each of the grazing paddocks at both Idaho and Oakvale. These enclosures will allow the effects of different grazing management regimes on botanical composition to be studied and recorded. Each enclosure consists of 4 small pens 10m by 10m.

One pen is permanently open and is managed by set stocking, another is permanently closed to show the response to fully removing livestock from the system. The other 2 pens will be managed for grazing, one strategically rested for 4-6 weeks over spring in an attempt to increase native forbs abundance, the other strategically grazed in a cell grazing manner by mob stocking the pen at predetermined dates.

Sheep liveweights and fat scores are recorded after each pasture recording. Wool dyebands are inserted into the mid-side of each sheep every 3 months after shearing to allow for monitoring of wool growth. These are removed pre-shearing for analysis.

2. **Monaro Legume Evaluation Trial**
The 54 different legume cultivars being trialed were sown into prepared plots at both of the grazing trial locations on the 1st April 2005. Along side these plots are 32 perennial grass cultivars and 10 different herb varieties which along with the legumes, are all being assessed for potential suitability and ability to survive on the Monaro. Germination rates have already been recorded (plants/m^2).

3. **Monaro Innovative Control of Serrated Tussock Trial**
A site for this trial was chosen on a steep hillside backing onto the Snowy River. The site has shallow slate soils and a moderate serrated tussock (*Nassella trichotoma*) infestation commonly seen in woodland areas such as this one. 16 plots (15m x 10m) have been established and fenced to prevent sheep from entering the trial area.
Native tree, shrub and grass species seeds have been sourced from across the country and include 5 *Eucalyptus* species, 8 *Acacia* species, *Casaurina*, *Bursaria*, *Callistemon*, *Davesia*, *Dodenea*, *Callitris*, *Cassinia* and several grass species.
These species are being applied using 3 different application methods: broadcast, broadcast with disturbance and a mulching option, all to be imposed late 2005.

4. **Monaro Recycled Organics Trial**
A site for this trial was chosen on a property close to Cooma. Two trials are being established, one on an existing *Austrostipa* sp. pasture, the other on a newly established *Phalaris* based pasture.
Extensive soil testing will take place to measure changes occurring in physical, soil organic and nutrient properties. The quantity a quality of pasture herbage mass will also be measured.

RESULTS

1. **Native Grassland Grazing Trial**
Initial data collection has provided the benchmark information required for the trial. BOTANAL recordings for "Idaho" (Table 1.) and "Oakvale" (Table 2.) are shown as an average across all paddocks.

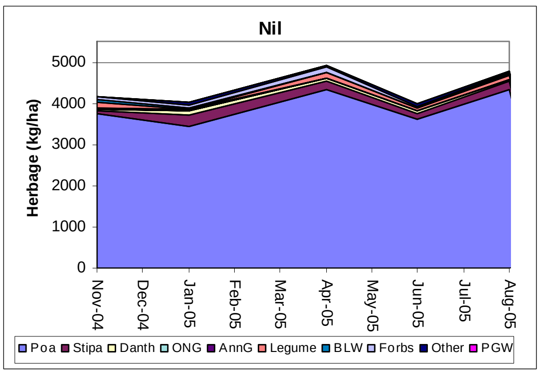

Figure 1. Available herbage composition in control paddocks at 'Idaho', Bungarby, NSW.

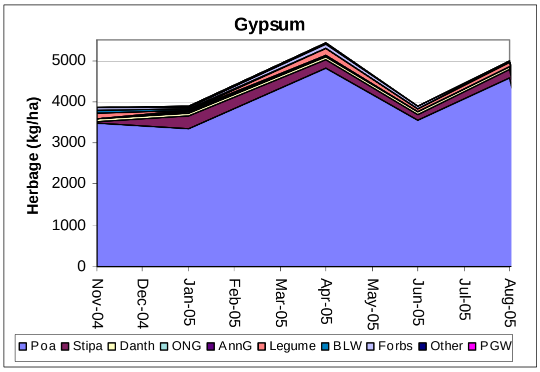

Figure 2. Available herbage composition in paddocks treated with gypsum at 'Idaho', Bungarby, NSW.

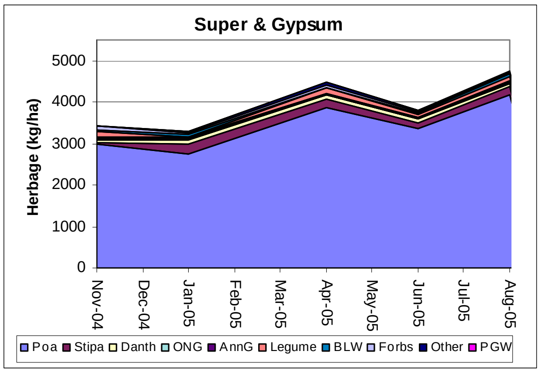

Figure 3. Available herbage composition in paddocks treated with both gypsum and superphosphate at 'Idaho' Bungarby, NSW.

Table 1. BOTANAL pasture information to date, "Idaho" Bungarby, NSW.

	Average Available Herbage (kg/ ha)	Average Available Green (kg/ ha)	Average Ground Cover (%)
Nov. 04	3817	753	73
Jan. 05	3732	966	80
Apr. 05	4948	1053	77
Jun. 05	3895	885	83
Aug. 05	4832	1272	84

The most dominant species *Poa sieberiana* made up 89, 85, 88 and 90% of the available pasture recorded in November 2004, January, April and June 2005 respectively. The *P. sieberiana* dominance in the 'Idaho' paddocks across all treatments is noted in figures 1 to 3.

Table 2. BOTANAL pasture information to date, "Oakvale" Berridale, NSW.

	Average Available Herbage (kg/ ha)	Average Available Green (kg/ ha)	Average Ground Cover (%)
Jan. 05	1219	423	78
Mar. 05	1612	597	87
Apr. 05	1455	565	79
May 05	1296	388	73
Sep 05	1027	351	85

On the granite soil site "Oakvale", both *Austrostipa* and *Poa sieberiana* made the most significant contribution to the feed pool in January 2005 (27, 21%), March 2005 (29, 18%), April 2005 (42, 16%) and May 2005 (45, 23%) overall. However during summer and early autumn, *Austrodanthonia* species represented up to 20% of the available pasture. These compositional changes are expected to further change between treatments beyond those noted in figures 4 to 6.

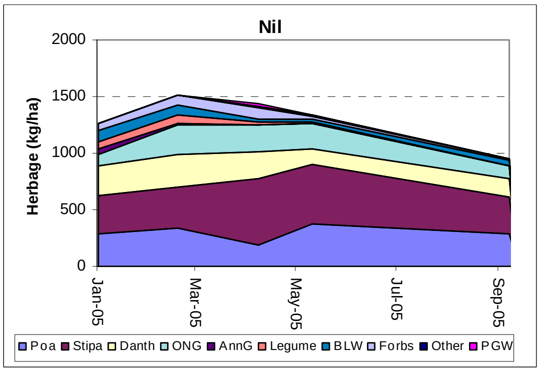

Figure 4. Available herbage composition in control paddocks at 'Oakvale' Berridale, NSW.

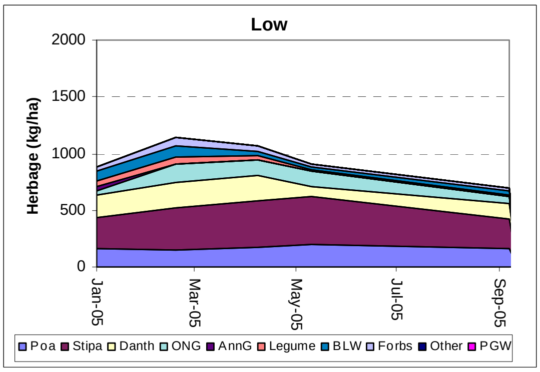

Figure 5. Available herbage composition in paddocks treated with recommended fertiliser program at 'Oakvale' Berridale, NSW.

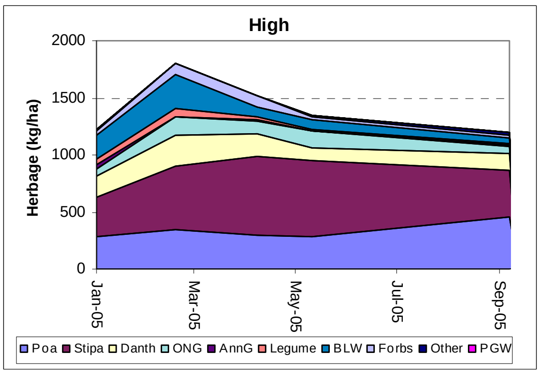

Figure 6. Available herbage composition in paddocks treated with high fertiliser program at 'Oakvale' Berridale, NSW.

A total of 77 plant species were recorded at "Idaho" with up to 16 species recorded in individual quadrats. 19 native forbs species were recorded at greater than 1% across the whole site as well as 10 species of broadleaf weeds, 4 species of annual legumes, 4 species of annual grasses and 12 species of native grasses. The presence of any perennial grass weeds such as *Nassella trichotoma* and *Eragrostis curvula* were noted however showed up in less than 1% of the total quadrats recorded.

"Oakvale" was found to be a more diverse site with a total of 122 plant species found within the paddocks and a maximum of 20 recorded in individual quadrats. 19 species of native forbs were recorded with one species in particular, *Crassula colorata* (dense stonecrop) present in over 75% of all quadrats. This site also recorded at greater than 1% presence, 15 species of broadleaf weeds, 8 species of annual legumes (including a high presence of *Trifolium arvense*, haresfoot clover), 4 species of annual grasses and 19 native grass species including least 5 different *Austrodanthonia* and 2 *Austrostipa* species.

Grazing enclosures have been built and the controlled resting cell has been closed up for spring. The controlled grazing cell is yet to be grazed and will be utilised late spring 2005. Botanical composition in the cells will begin to be monitored this spring.

Livestock on both properties that have been grazed on treated paddocks are showing a response in liveweight gain and fat score. These results are not yet significant.

2. Monaro Legume Evaluation Trial

Early results have shown good establishment of several commercial species including barrel medic (*Medicago truncatula*), French serradella (*Ornithopus sativus*), Gland clover (*Trifolium glandiliferum*), balansa clover (*T.michelanium*) and biserrula (*Biserrula pelecinus*). Several experimental species have also established well and are showing good early vigour. These include thick-pod serradella (*O.unicatus*), *Medicago minima* and purple clover (*T.purpureum*). The perennial grasses have also shown good germination results (Figure 7.).

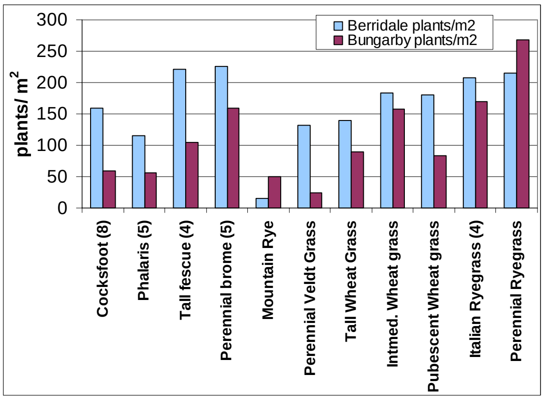

Figure 7. Germination results (May 2005) of perennial grass trial (bracketed numbers represent number of cultivars trialed, results shown are averages of all cultivars of each grass).

3. Monaro Innovative Control of Serrated Tussock Trial

No results are available at this time. Treatments are to be imposed late 2005.

4. Monaro Recycled Organics Trial

No results are available at this time. Treatments are to be imposed late 2005.

DISCUSSION

1. Native Grassland Grazing Trial

Whilst no significant treatment related results can be drawn from either site yet, the aim is to increase the presence of legume species (spread with fertiliser) and pasture production. Visibly, the clover content of the pasture at "Idaho" has increased, this is beginning to show in BOTANAL recordings and should continue to become more notable through the spring/ summer of 2005/ 2006.

Paddocks will be constantly monitored for the presence of *Nassella trichotoma* and *Eragrostis curvula*. Both of these are already present in small numbers at "Oakvale" and only *N. trichotoma* has been found at "Idaho". The trial is aiming to promote pasture production and maintain ground cover through stocking rates and fertiliser treatments, however should any treatment show to have an adverse effect on weed presence by changing the pasture composition or lowering ground cover, the treatment will be reassessed after this effect is noted.

Future information gathered from BOTANAL, frequency and phenology pasture recordings and livestock production data will be analysed and collated to produce a best practice management guide for native pastures on basalt and granite soils.

Grazing enclosures were included into the native grassland grazing trial to allow investigation of grazing regimes other than that of set stocking. Whilst these other regimes could not be studied in a similar scale of the set stocked trial, it was thought that small cells like those built into each of the grazing paddocks could allow the effects of several grazing managements to be investigated.

Initial stocking rates have not changed, but will be re-evaluated this spring. Changes in stocking rates especially in treated paddocks are more likely to occur later in the project as treatments become more established. Treatment related trends are beginning to appear for both sheep liveweight and fat score. Despite these results not yet having significance, these trends should improve over spring and produce a significant difference between treatments.

2. Monaro Legume Evaluation Trial

It is still far too early to draw any conclusions from the annual and perennial legume evaluation trial or from the commercial legume evaluation trial.

While results so far indicate that there are several species that have potential in the Monaro region, further evaluation is required over several years in order to evaluate productivity and persistence in this difficult climate. Factors such as the regeneration capacity of the annual legumes need to be closely monitored. Regeneration will be affected by hardseed breakdown patterns as well as management of dry residue. Most of the legumes under evaluation are aerial seeders (as opposed to subterranean clover which sets seed underground), therefore it is important to ensure seed is in contact with soil over the summer period so that hardseed breakdown can occur.

Perennial legumes will be monitored for persistence of the adult plant as well as recruitment from seed. Having adequate legume content in the pasture is vital for both pasture and animal productivity. Legume content of many Monaro pastures is low and this project will assist in identifying species that will offer increased benefits over legumes currently used.

All perennial grasses sown have established well. There is considerable diversity both within and between species sown in terms of the pattern of growth. These differences will potentially be able to be exploited by farmers to reduce incidence of feed gaps in the production cycle and many offer better persistence characteristics compared to previously available cultivars.

Within the phalaris, cocksfoot and tall fescue groups cultivars with summer active and summer dormant growth habits are being evaluated. Summer dormant cultivars tend to produce a larger proportion of their total production through the winter and early spring period while summer active types are less productive through the cold months. Persistence between the two types also varies with summer dormant types tending to be more persistent, but this has not been quantified in the unique Monaro environment.

Some of the less well known species showing early promise include the perennial brome group. This group are capable of very high levels of winter production compared to other grasses in the evaluation and may potentially be of significant benefit in the cold Monaro environment. Italian ryegrasses are also been evaluated and are a short-term high productivity group that may be of benefit in cleaning up paddocks prior to sowing a long-term pasture.

As with the legume evaluation, persistence and productivity will need to be monitored at least over a 3 year period before any conclusions can be drawn.

Chicory and plantain are also being evaluated and are highly palatable, high quality forages that may play a role in specialist pastures. Both require careful management to ensure they are not grazed out of pasture. Grazing of chicory should be avoided through winter to prevent crown damage. All lines sown have established in sufficient number and will be monitored for production and persistence.

Results will be used to advise the selection of species to be sown or broadcast when improving both introduced and native pastures.

3. Monaro Innovative Control of Serrated Tussock Trial

Due to the severe drought conditions experienced on the Monaro in 2004, treatments for this trial are to be imposed late 2005. The site developed a thick infestation of *Acaena ovina* (Sheep's burr) and *Echium vulgare* (Viper's Bugloss) during Autumn 2005 with the site being sprayed with Glyphosate in April to kill these and other annual weeds and decrease the groundcover to allow greater soil contact with the seed when dispersed.

A small species trial was established on site late 2004 to assess if any species were able to germinate in the existing conditions. Only a small number of legume seeds have germinated from the pasture mix sub-plots to date. Further monitoring of this trial continues.

Whilst all native tree growers contacted recommended tube-stock planting for best results, broad scale seeding options remain the best alternative for the revegetation of highly degraded and difficult landscape such as the one used in this trial. Usable results are not expected to be obtained from this trial for at least five years given the time taken for the germination and establishment of native tree and shrub species and the climatic variability that may hinder this process.

4. Monaro Recycled Organics Trial

The results from this trial will help inform Monaro Shire Councils of the preferred form for recycled organics to be used by the agricultural industry. It will also test the effectiveness of the compost product as a revegetation tool on weed infested and degraded lands.

ACKNOWLEDGMENTS

The Southern Rivers Catchment Management Authority (SRCMA) and Department of Environment and Conservation (DEC) for their involvement in, and funding support for this project.

Co-operating landholders Ross and Liz Sherlock (Oakvale), Alan and Mark McGufficke (Idaho), Andrew Struik (Snowy Bend) and Peter Davis (Yalcowinna).

Department of Primary Industries staff Luke Pope (District agronomist, Cooma), Doug Alcock (Livestock officer (sheep & wool), Cooma), Belinda Hackney (Research agronomist, Wagga Wagga), Denys Garden (Research agronomist, Canberra), Karl

Grigulis (former Research agronomist, Canberra) and David Eddy (MGCMN).

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Chilean Needle Grass — Potential Impacts and Control

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Note: parts of this paper were developed out of a partnership project with Greybox and Grasslands Nursery Inc. and funded in part by the National Heritage Trust 2003 - 2004

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Summary In eradication trials in Victoria and Tasmania, both the viable seedbank and capacity for recruitment of Chilean Needle Grass was found to be reduced to very low levels at several management sites, after four or more years of ongoing selective spray management, within typical landholder budgetary constraints. Seedbanks were also low under areas revegetated with native Kangaroo Grass. In one area which had been revegetated with Kangaroo Grass over Chilean Needle Grass five years ago, the proportion of Kangaroo Grass to Chilean Needle Grass tussocks was similar to that in the first year of their establishment, suggesting that Kangaroo Grass is an effective competitive replacement for Chilean Needle Grass. Burning Chilean Needle Grass in a drought year appeared to reduce the size of Chilean Needle Grass tussocks, and may contribute an additional strategy for control, especially if combined with herbicide spraying and strategies to minimise seed set in Chilean Needle Grass. Across measured sites in Victoria and NSW, levels of seed in the seedbank under mature Chilean Needle Grass were lower than earlier reports, suggesting that progressive management down towards full local eradication may be possible in realistic timelines and budgets.

Keywords. Nassella neesiana, management, control, eradication, native grasslands, weeds, seedbank

INTRODUCTION

This paper examines the spread and control of CNG as a case study with serious implications for the prevention, control and eradication of CNG and related weeds in South Eastern Australia, including Tasmania.

In South-Eastern and central-Eastern mainland Australia CNG is spreading at an alarming rate WONS, 2001). CNG has major effects on conservation values of remnant grassy ecosystem areas (WONS, 2001) and on production of livestock, mainly through its contamination of wool and beef hides, and on lowered green production in pasture in the dry season. Bioclimate modelling shows that CNG has the potential to spread across large areas of Eastern and Southern Australia (WONS, 2001). This includes the northern and eastern areas of Tasmania. The one known site of infestation in Tasmania occurs in Hobart, which is out of the zone of highest predicted infestation, suggesting that the potential distribution of CNG in Tasmania might be wider than previously thought.

Chilean Needle Grass has been reported to have high capacity for seedbanking and recruitment (re-establishment of seedlings) following destruction of mature plants by herbicides or ploughing. No effective method has been available to remove all of the CNG and replace it with competitive species which prevents CNG from re-establishing (Hocking, 1998). Most managers of non-farming areas, including conservation reserves, roadsides and other land infested with CNG, rely on regime of herbicide application to remove emerging CNG seedlings each year, once the original mature tussocks have been cleared. There has been no evaluation of the effectiveness of this type of program on CNG minimisation. In addition, in a few instances there have been attempts to replace CNG with native grasses, notably Kangaroo Grass. The effectiveness of this replacement has also not been evaluated.

Best management practice evaluation project. In this project we set out to:

1. Document the effectiveness for best management control of CNG in conservation and other non-agricultural areas. Best management in the context of this project was defined within the limitations of the funding/resource allocation provided by the land owner or manager for CNG and general weed control. Evaluation included the mid-term success of spray out of CNG in conservation reserves several times per year, and the removal of CNG from agricultural areas being rehabilitated by planting trees.

2. Determine the likelihood that CNG could re-establish in areas treated with best management practice control, by determining the viable seedbank, rate of recruitment and, in some cases, the long term pattern of re-invasion of CNG.

3. Evaluate the short and longer term effects of replacing CNG with native Kangaroo Grass, across a range of contexts.

4. Evaluate the effects of burning and mowing of CNG in a drought year on the survival, growth, seed production and recruitment of CNG (modification of a previous proposal to take advantage of drought and to avoid meaningless application herbicide under drought conditions).

5. Develop a simple model for how long it would take for CNG to be effectively under control, using the standard techniques employed by many non-farming land managers, when these were carefully applied by trained and skilled on-ground staff.

PROJECT SITES AND RESULTS

Several sites on the outskirts of Melbourne were chosen for evaluation. These were all sites where various types of CNG management had been under way for several years. Several other sites across Victoria have recently been included in the second stage of this project, to evaluate the extent of seedbanking under established stands of CNG, and how treatments of various types have affected these seedbanks and the potential for re-infestation and eradication. These are described briefly. The sites chosen, and the types of management that underwent evaluation, were as follows:

Laverton former RAAF Base Grassland Reserve. The site, on the outskirts of Larverton, mid way between Melbourne and Werribee, is a high quality native Basalt Plains grassland remnant with rich patches of wildflowers (forbs) amongst native grass tussocks. The site is primarily managed for conservation. The site is frequently burnt - in most cases at least every two years. Trained contractors are employed to control infestations of CNG and other weeds (e.g. Serrated Tussock, Texas Needle Grass) by targeted spraying.

At the site, patchy infestations of Chilean Needle Grass, and individual outlying tussocks, have been selectively sprayed out at least twice per year for over four years using glyphosate and a one-off application of tetrapion. The frequency of treatment was dependent on the allocation of funding from the land-owner, and was a typical frequency of treatment for this situation. For some more extensive patches where CNG had been removed, the site was oversewn with Kangaroo Grass (KG) seed harvested from nearby native remnants, using a Greybox and Grasslands Nursery Bandicoot harvester. The quality of the KG seed and the rate of sewing were not recorded. However, from estimates of similar harvested seed applied elsewhere, the rate of application of KG seed was likely to be in excess of 200 viable seeds m^{-2}.

All mature CNG plants and most seedlings detected during the walk through for spraying were successfully removed each year. The rate of error was estimated to be less than one in two hundred plants missed. Over time this error rate may have increased, as plants became smaller and more sparsely distributed. Nearly all plants were sprayed out before they had time to set seed (timing of spray applications were designed to minimise CNG seed production). However, occasionally a plant was found to have been missed in earlier sprays, and to have set seed. The viability of such seed is unknown.

While there were high total densities of CNG seed in the seedbank following treatment, very few of these (less than 10% in most cases) were filled seed. It is likely that most of the seed had previously germinated and been killed as young seedlings by the periodic herbicide treatment., leaving behind the seed husks. However, it is also likely that a large percentage of the seed had become non-viable while sitting in the seedbank over time. This conclusion is drawn from the multiple testing of the seedbank of two untreated patches of CNG lying on opposite side of the sprayed out remnant grassland. In each of these untreated sites, filled CNG seed in the seedbank was, for most samples taken, less than X% of the total CNG seed extracted from the seedbank. For more discussion on this issue, see the section below entitled 'How much viable seed is there in the CNG seedbank?'.

The densities of emerging CNG seedlings in the Spring and Summer (October-March) of 2003 were mostly consistent with estimates of viable seedbanks. Average seedling densities in treated areas which were sampled by replication ranged between 1 and 5 seedlings m^{-2}. This represents an acceptably low level of ongoing CNG seedling establishment (see Discussion below) which is likely to be even further reduced over time At the least, CNG infestation in these high quality native grassland remnants is being kept in check by this low level of maintenance.

In areas previously infested with CNG which had been sprayed out and over sewn with Kangaroo Grass Seed, both the CNG seedbank and CNG seedling establishment in Spring-Summer 2003 were similar to that for similar spray-out areas without KG establishment. KG tussock establishment at these sites was not high, compared to other similar sites which had careful preparation and management of sites. It is likely at the Laverton KG over sow sites that the densities of KG were not sufficient to deter CNG seedling establishment, especially at the low levels observed. However, the KG tussocks had not reached full maturity, and may have more of an effect in excluding CNG in the future (see evaluation below of Bendigo site, which has long term, high density KG oversewn on previous high densities of CNG).

Melbourne Airport — tree establishment area. The Melbourne Airport site, immediately to the West of the Melbourne Airport runway, is an attempt to control a major infestation of Chilean Needle Grass across a wide area which acts as a buffer zone to Melbourne Airport proper. As such, it does not constitute productive agricultural land, although in previous times it may have been so. The site under evaluation, which is part of this larger site, consists of four areas layed out in the following sequential line along a 2km stretch of what was previously mostly exotic pasture, heavily infested with CNG, and interspersed with small swathes of native grass, mostly Kangaroo Grass, native Spear Grasses and native Wallaby Grasses:

Area 1: CNG was initially boom sprayed with atrazine in 1997, then regrowth was regularly sprayed out several times each year with atrazine until 2000, and planted out seven years ago with native trees of a wide variety, established at a density of approximately one in each 25 m^2 (i.e. spacings of 5 m). Tree and shrub heights at the time of sampling ranged between 2 m and 8 m. Sampled sites were set at least 2 m from the nearest tree. After 2000, emerging CNG on the site was occasionally sprayed with glyphosate as Roundup.

Area 2: Similar to Area 1, except that CNG was first sprayed out with atrazine in 2000, and planted out 3 years ago with native trees and shrubs at similar densities to Area 1. CNG emerging in the area continued to be sprayed with atrazine until 2002, when the atrazine was replaced with glyphosate as Roundup. Tree and shrub heights at the time of sampling ranged between 1 m and 4 m.

Area 3: Similar to Areas 1 and 2, except that CNG was first boom sprayed with flupropionate in 2002, and planted out 2 years ago with native trees and shrubs at similar densities to Area 1. Tree and shrub heights at the time of sampling ranged between 0.3 m and 1 m. Emerging CNG on the site has recently been sprayed out several times with glyphosate as Roundup.

As for the Laverton Air Base site, at Melbourne Airport all mature CNG plants and most seedlings detected during the walk through for spraying were successfully removed each year. The rate of error was estimated to be less than one in two hundred plants missed. Over time this error rate may have increased, as plants became smaller and more sparsely distributed. Nearly all plants were sprayed out before they had time to set seed (timing of spray applications were designed to minimise CNG seed production). However, occasionally a plant was found to have been missed in earlier sprays, and to have set seed. The viability of such seed is unknown.

The Chilean Needle Grass (CNG) seedbank and rate of establishment of CNG seedlings in the Spring - Summer of 2003-2004 were broadly in accord, and showed progressively higher seedbank numbers and densities of establishing seedlings over the progression Area 1 to Area 3. It is clear that the rates of re-infestation of CNG are in decline as a result of this ongoing treatment, within the budget allocated by Melbourne Airport, which allows spray out to be undertaken two to three times per year. The effects of over-planting with trees is unknown at this stage, but is likely not to be major, at least in the between tree spaces, as judged by the limited canopy and below ground root growth of these trees. Also lack of effect by trees is indicated by the broadly linear reverse relationship between total time spraying has been in effect and density of CNG filled seed in the seedbank and CNG seedlings establishing during the evaluation period (if trees were having a major effect, the oldest treatments with the largest trees might be expected to have depressed CNG seed and seedlings in excess of this reverse linear relationship.

At the Melbourne Airport site, seedling densities in the longest treated areas which were sampled by replication averaged less than 2 seedlings m^{-2}. This represents an acceptably low level of ongoing CNG seedling establishment (see Discussion below) which is likely to be even further reduced over time

Iramoo Wildlife Reserve adjacent to Victoria University St Albans campus. The Iramoo Wildlife Reserve site at St Albans, on the outer Western edge of the Melbourne metropolitan area, is a low to moderate quality native Basalt Plains grassland remnant, which is significant mainly because it is the habitat of the largest documented population of the nationally threatened Striped Legless Lizard, the site contains small patches of wildflowers (forbs), including the Plains Rice Flower which is critically endangered at the national level, scattered amongst native grass tussocks. The site is primarily managed for conservation. The site is occasionally burnt in patches of quarter to one hectare - in most cases at least every three to four years.

In addition to discrete infestations of Chilean Needle Grass, the site contains large infestations of Serrated Tussock and smaller infestations of Cane Needle Grass. Some of the areas of Serrated Tussock and Chilean Needle Grass have recently been successfully replaced with native Kangaroo Grass. These trials are not the subject of the evaluations reported here, and will be reported on separately.

At the site, a small infestation of Chilean Needle Grass was the subject of small replicated patch burning or mowing in the early (October 11th) and late (December 2nd) Spring of 2002 From predictions of El Nino, it was considered likely that the growing season was going to be one of low rainfall. The purpose of the burning and mowing was to investigate the effects of fire and slashing on the survival, growth and reproduction of Chilean Needle Grass under high water stress in the field, as well as the type an extent of recovery of CNG from burning under these conditions. It was hoped from this that some vulnerability of CNG under these conditions might be detected.

Late Spring burning was found to result in lower densities of mature CNG tussocks resprouting after the Autumn break, than any of the other treatments - less than 10% of those in untreated plots. However the number of small tussocks and very immature tussocks increased (these are likely to have resulted from the fragmentation of some of the remaining mature tussocks), so that the total number of tussocks on the plots did not vary greatly between treatments. Early Spring burns also resulted in a major reduction in mature tussocks - to less that a quarter of control plots As for late burn treatments, the total number of tussocks on the early Spring burn sites was similar to that for other treatments, and most of the surviving tussocks were very small in size.

Mowing, by comparison, did not have a major effect in reducing the number of mature tussocks, when applied either in early or late Spring. Neither did mowing reduce the size of tussocks in a major way.

Interpreting the outcomes of these burn and mow treatments, in terms of tussock mortality, became more complicated as time went on. What is clear is that the total area occupied by CNG tussocks decreased to less that 25% of control plots as a result of burning, even though the total number of identifiable tussocks was not markedly different between treatments. What is likely to have happened is that the burning reduced the number of tussocks through mortality, but those that did survive fragmented into several sub-tussocks, resulting in no overall decline in tussock density. CNG is able to hold its density across extreme conditions of burning or slashing in a drought, which suggests that these treatments alone will not quickly remove CNG from a site. However, it is also likely that CNG is weakened in a major way by these treatments during drought, and is likely to be susceptible to follow- up treatments of burning, mowing, spraying with herbicide, or physical removal.

The effects of burning or mowing in a drought on production of seed was dramatic. Late Spring burning in particular removed all viable seed from the site, and prevented CNG from seeding by around 50%. By comparison, early Spring burning and each of the mowing treatments did not reduce seed production in the following year, and in some cases may have slightly stimulated seed production.

Neither did their appear to be there any major recruitment of seedlings (i.e. growth of new plants) from the seedbank in the late Spring burns, either in the Autumn growing season following burning or mowing or in the following Spring.

The combined effects of burning , while not reducing CNG in density across the treatments, did weaken CNG in major ways, in terms of the size of tussocks remaining on the treatment sites after burning. These treatments also prevented CNG from gaining ground in the years following treatment, by preventing establishment of new plants from the seedbank, and even by reducing in major ways the capacity of CNG from adding new seed to the seedbank.

Toolleen — Mt Camel Road near Bendigo. The Bendigo road site is located on Mt Camel to Toolleen Road, on the Eastern side of the Mt Camel ranges. The site is approximately 120 km north of Melbourne, in the Southern foothills of the Great Dividing Range. In 1997 Chilean Needle Grass was dominant in large patches along sections of the road. One of these patches was used to investigate the feasibility and effectiveness of replacing CNG with native Kangaroo Grass (Mason, 1998). The 'spray and hay' method, previously used successfully to replace Serrated Tussock with Kangaroo Grass, as reported in Phillips & Hocking (1996), was followed. In brief, this method entailed reducing the biomass of CNG by mowing in late spring, spraying out the CNG with glyphosate (as Roundup) in autumn, laying down seed-bearing Kangaroo Grass hay of known seed content in winter, allowing the awned Kangaroo Grass seeds to bury in the ground, and then removing the hay thatch, either by burning or by physical removal, in early spring. For some treatments (not described in detail here due to lack of space) the outcome of the 'spray and hay' process resulted in high densities of Kangaroo Grass and minimal re-establishment of CNG. The purpose of the study reported here was to re-assess the Kangaroo Grass - Chilean Needle Grass mix to determine the extent to which Kangaroo Grass, established over plots previously dominated by CNG, could resist re-invasion.

In the most successful Kangaroo Grass (KG) replacement plots, KG had established at an average of 17 plants m^{-2} when assessed six months after establishment (Mason, 1998). CNG had re-established in these treatments at an average of 6 plants m^{-2}. The ratio of KG to CNG in the autumn of 1998 was therefore approximately 3:1. When these treatments were re-assessed in spring 2003, the average density of KG was found to be 18 plants m^{-2} and the average density of CNG plants in the same plots was 6 plants m^{-2}. The ratio of KG to CNG after five years was therefore 3:1. Both the KG and CNG were sufficiently mature to be flowering, and estimates of the seed production per plant of CNG were similar to those on the control plots at Iramoo, St Albans. The seed rain of CNG onto these KG dominated plots was therefore high. Nevertheless, CNG had not been able to increase in proportion with time in the treatments. A decrease in both KG and CNG densities over time has also been reported elsewhere (Phillips & Hocking, 1996, Mason & Hocking, 2002), and has been attributed to the progressive increase in competitiveness between individual tussocks, as these grow and require more light and access to below ground resources, especially nutrients and water, leading to a 'thinning out' to densities that are able to be supported by the existing resources.

In other treatments also, where KG establishment had occurred but had not been as successful, and CNG had re-established at higher levels, the ratio of KG plants to CNG plants after five years had remained close to the initial establishment ratio. These results together suggest that Kangaroo Grass is able to compete successfully with Chilean Needle Grass, at least over the first five years of growth, and resist progressive invasion by CNG. Comparative survey results by Lunt and Morgan (1998) similarly suggest that, provided Kangaroo Grass is kept in a healthy state, and does not enter a state of senescence due to a lack of biomass reduction, it is resistant to invasion by Chilean Needle Grass.

Seedbank sampling at other sites with a range of treatments. In addition to the detailed studied above, the following sites have been sampled for the levels of filled and unfilled CNG seed: Indigo Shire (north-central Victoria) at two sites, Meredith in the Brisbane Ranges to the west of Melbourne, Sunbury to the north-west of Melbourne, and the single know population of CNG in Hobart in Tasmania. Each of these sites has been treated more than once for removal of CNG, mostly by the repeated application of glyphosate (eg Roundup) herbicide on several occasions. At each of the Victorian sites, the levels of filled

CNG seed constituted less than 10 seeds per square metre, and the vast majority of the seed (over 80%) was unfilled or dead seed. In Tasmania, no filled CNG seeds were detected in any of the soil cores taken from the site. Each of these sites will be monitored in the spring of 2005 to determine the extent of new seedling establishment. Predictions are that, at each site, establishment of new seedlings will be low, and close to a level consistent with eventual eradication.

DISCUSSION & CONCLUSIONS

Control of CNG by repeated spraying. In each of the sites where there has been repeated, ongoing spray out over several years of mature Chilean Needle Grass plants and of newly establishing seedlings, the density of new CNG seedlings has been reduced to a low level. Likewise, the associated seedbank of filled CNG seed has been reduced to low levels.

It would appear that repeated spraying out of CNG by trained ground staff over a number of years, within acceptable maintenance budgets typical for shires, local councils and land managers, can reduce the CNG seedbank and rate of recruitment to levels which constitute a very low level presence. The results obtained also suggest that CNG might be able to be removed from an area, given sufficient time and persistence, and possibly with appropriate competitive replacement (see section below). These results are in contrast to the pessimistic warnings about the difficulties of controlling CNG reported from elsewhere (Gardener & Sindel, 1998)

Nevertheless, the possible capacity of the CNG seedbank and recruitment rate to recover quickly from this low level cannot be ignored. Results of the seed production rate of the younger control stand of CNG at Laverton, and the high level of seed production after only five years at Bendigo, indirectly suggest that CNG may be able to rapidly reverse the spray-induced decline in CNG. There needs to be additional investigations to determine the rapidity with which CNG is able to recover from this level of control, and what window of time is available to keep CNG under control, if there is an absence of spraying after several years.

How much viable seed is there in the CNG seedbank?. At each of the sites sampled for seedbank under mature stands of CNG, the density of filled CNG seed was much lower than expected, compared with previous reports of the CNG seedbank. These results lead to a set of suggestions which need urgent investigation; namely that:

- the CNG viable seedbank may not be the same order of magnitude at all sites
- there may be differences in the CNG viable seedbank between sites (for example, between Victoria and NSW - the seedbank results reported here are the first comprehensive figures for Victoria)
- there may be differences in the CNG viable seedbank between sites managed for conservation and sites managed for agricultural production
- there may be agents at work in the soil of some sites that reduce the viability of CNG seed - as suggested by the high ration of empty seed to filled seed at Laverton and Melbourne Airport

The possibility likelihood that, at some sites at least, the viable seedbank of CNG is lower than assumed earlier by land managers, leads to the possibility that CNG at these sites may be more easy to bring under control, and perhaps even eradicate, than previously suggested.

Effectiveness of Kangaroo grass in controlling re-establishment by CNG. It would appear that Kangaroo Grass is effective as a competitive replacement for CNG, and may be useful across conservation and agricultural contexts as a component of a diverse set of strategies for control of CNG. Competitive replacement of CNG by Kangaroo Grass at Laverton Grassland and at Bendigo were both carried out early in the process of removing CNG from each site. Based on the figures obtained for reduction in CNG seedbank and recruitment after several years of spray-out at Laverton and Melbourne Airport, it is likely that a two or three year spray program over CNG, followed by re-vegetation with Kangaroo Grass, and follow-up spot spraying of any subsequent residual CNG recruitment, may be an effective way of limiting the presence and spread of CNG in contexts where Kangaroo Grass replacement is the most useful competitor. It is notable that the Kangaroo Grass established as a replacement on the sites evaluated was able to survive and re-sprout after the heavy drought of 2002-2003, as one would expect from a summer-growing deep rooted native perennial tussock grass. The impact of replacing CNG with KG on the seedbank of CNG under re-vegetation plots over time, is in urgent need of investigation. This may be a way of reducing to insignificant levels the presence of CNG on previously infested sites, by providing replacement cover of Kangaroo Grass, which is likely to prevent CNG seed from re-entering the seedbank, allow competitive in-fill by Kangaroo Grass in any gaps incidentally created (e.g. by scratching or burrowing animals) and perhaps promoting the rate of decline of the CNG viable seedbank, by some as-yet unexplained mechanism.

Effects of burning and mowing in a drought year on CNG survival, growth and re-establishment. While the burning and mowing treatments during the drought did not completely, or even largely, remove Chilean Needle Grass, it is clear that these treatments, and the late spring burn in particular, were able to weaken the growth and prevent the reproduction of CNG. Late Spring burning, and to a lesser extent mowing, especially in dry conditions, is likely to be a useful contribution to an integrated approach to management of CNG. The high reproductive effort of CNG will not only be curtailed by late Spring burning in the year of the burn, but also in subsequent years. The major reduction in tussock size is also likely to allow easy removal of remaining tussocks, either by herbicide spray or by physical removal. This type of integrated approach to CNG management should be the subject of further investigation.

A simple model for control of CNG. It is clear that the seedbank, and emergent seedlings of CNG can be reduced to low levels by repeated removal using selective spraying with herbicides. The high levels of seedbanking of CNG reported elsewhere do not appear to translate into filled seed at the sites investigated here. It may be that at some sites at least, the relatively low levels of filled seed in the seedbank will allow CNG to be brought under longer term control, within the budgetary constraints of most land owners and managers. There is an urgent need to determine the range of values for filled seed in the seedbank of CNG infestations across a range of land management contexts, to determine the potential for long term control of CNG, and whether there are some categories of CNG infestation are more amenable to this type of control than others.

Concluding remarks: implications for control of CNG and related species in Tasmania. The impacts of Chilean Needle Grass on agricultural and biodiverse systems in mainland Australia form a compelling case for minimising opportunities for CNG and related species from arriving in Tasmania, and for developing early detection and eradication protocols for Tasmania. Weeds officers in Tasmania are well aware of the potential problems and have the first stage of protocols in place (see www. dpiwe.tas.gov.au). Cooperation at the national level for appropriate research and on-ground management approaches will be needed to head of these weeds in future. For Serrated Tussock and Chilean Needle Grass, access to Weeds of National Significance resources and funding will be needed to minimise the threats to agriculture and biodiversity. Recent mainland-based research suggests that if CNG (and by implication other related South American Stipoid grass weeds) are detected early enough, in Tasmania and other outlying areas, including Queensland and South Australia, and acted upon over several years, there is a high likelihood that they can be effectively controlled and possibly eradicated. Lessons from the mainland suggest that postponing action on these weeds until they become problems of large-scale concern is not an option, or at best will be a hugely expensive one.

ACKNOWLEDGEMENTS

Thanks for research input and technical assistance to: Louise Beames (some results are part of her Louise's Honours Thesis), Megan O'Shea, David Steart, Davide Coppolino, Matt Hatton & Claire Rawlinson.

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Prospects for biological control of serrated tussock

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Summary. Various potential agents for biological control have been investigated in Australia, the country of origin of serrated tussock (*Nassella trichotoma*). Three proven or potential pathogenic fungi found on serrated tussock (*Arthrinium, Dinemasporium* and *Fusarium*) were tested in an inundative trial in pots with serrated tussock and 31 species of other grasses. The fungi infected serrated tussock and 2-18 other grasses, but were not highly virulent on serrated tussock, and *Fusarium* killed four other grasses, suggesting that none of these has immediate biocontrol potential. A buried seed trial at six sites in Victoria for up to 7 months in Victoria showed decreases in seed viability associated with infection by the fungi *Alternaria* (78% infection), *Bipolaris* (16%), *Trichoderma* (4%) and *Fusarium, Coniochaeta, Penicillium* and *Gloeosporium* (all <1%). These seem to have effects on seed destruction in seedbanks and may have potential for biological control.
Keywords: serrated tussock, fungus, seed burial, pathogen

INTRODUCTION

Nassella trichotoma (Nees) Arech. (serrated tussock), is a major and problematic noxious weed in Australia (Campbell 1998). Serrated tussock is mainly controlled by traditional means, such as manual weed removal and herbicides. The recent report of resistance to flupropanate, the only selective herbicide, will impose limitations on its use in the future. Biological control (classical, inundative or augmentative) is potentially an alternative means of weed control. However, a program investigating potential classical biological control agents using fungal pathogen sources in Argentina (Anderson *et al.* 2002) has encountered problems in that the fungal pathogens found have been difficult to culture and infect and have not had high virulence.

In Australia five fungi have previously been observed infecting serrated tussock in Victoria in 1996-1997 (Hussaini *et al.* 1998, Hussaini *et al.* 2000): species of *Ascochyta, Dinemasporium, Pleospora, Zinzipegasa* and *Fusarium,* with the first four fungi observed in leaf spots and the last in crown rot. *Ascochyta, Fusarium* and *Dinemasporium* reduced seed germination in serrated tussock by 7-100% (Hussaini *et al.* 2000), suggesting their possible use in inundative or augmentative biological control. Further development of these previously identified fungi requires their pathogenicity to be tested on older plants, and their host specificity to be tested against endemic Australian grasses and important pasture species. One aim of this study was to investigate two of the fungi previously isolated: species of *Dinemasporium* and *Fusarium* and a third fungus (*Arthrinium* sp.) common on seeds, on older serrated tussock and grass species important within Australia. This would indicate if these fungi could potentially be used as biological control agents against serrated tussock in the field.

Serrated tussock mainly spreads by seed, with the seed bank in the soil being a constant source of inoculum. The lifetime of seed in the soil is unknown. Some microorganisms in soil may attack seeds and reduce the seed bank over time, but this has not been investigated so far, and is a potential means of biological control. The research presented here investigated the endemic soil-borne microorganisms infecting buried seeds and with potential to be used in a biological control program for serrated tussock in Australia.

MATERIALS AND METHODS

Plant infection trial. A total of 134 plants was treated, including 19 species of *Austrostipa*, 12 other grass species of importance to Australia and two provenances of serrated tussock, both collected from Victoria (Table 1). The emphasis in the trial was on the diversity of grasses tested, and replication of the plants in the trial was limited by growth of the plants from the original germination. All plants were grown to approximately the same size and 5-6 months old in a glasshouse with a controlled temperature of 15-25°C and natural lighting during spring.

Plants were inoculated with spore suspensions of *Fusarium* sp. and *Dinemasporium* sp. Léveillé isolated from serrated tussock in Victoria (Hussaini *et al.* 1998; Hussaini *et al*. 2000). The *Fusarium* sp. was identified as *Fusarium oxysporum* Schltdl. An isolate of *Arthrinium* sp. G. Kunze ex E. M. Fries observed on seeds of serrated tussock in the field was also used. For spore production, cultures of *F. oxysporum*, *Dinemasporium* sp. and *Arthrinium* sp. were grown on 90 mm Petri dishes containing 1/5 strength each of potato dextrose agar (PDA; Oxoid) and malt extract agar (MEA; Oxoid) at 25°C and 25 µE m^{-2} s^{-1} from 36 W Osram 'Warm White' lights in a 12 h photoperiod for 21 days. Plates were flooded with approximately 10 mL of 0.5% Tween 20 (v/v) (Labchem, Auburn, Australia) in Milli-Q water and were scraped with a sterile glass rod. Spore suspensions were 1 x 10^6 spores mL^{-1} in 0.5% Tween 20 in Milli-Q water. Fungi grown on both media were included in the fungal suspension. Suspensions were placed in a sterilised10 L plastic bucket, the pot was inverted and the plant foliage was submerged in the inoculum. Control plants were dipped in 0.5% Tween in Milli-Q water only.

Plants were covered with polythene bags for 48 hours before the bags were removed. Plants were placed in the same glasshouse as before, randomly allocated on a bench with a capillary matting system. The symptoms and plants affected were recorded weekly for . At 2 months, plant material was removed, inspected with a dissecting microscope, and a microscope slide prepared of any visible fungal growth for examination with a compound microscope and identification.

Seed burial trial. Surface-sterilised seeds of *N. trichotoma* from two provenances (Victoria and New South Wales) were buried with or without monthly fungicide (Benlate) at two depths at six sites in Victoria for up to 7 months during 2001 (Casonato 2003). Recovered seeds were surface-sterilised, plated out on 1.5% water agar in 150 mm Petri dishes and incubated for 14 days on benches at 24°C in a 12 h photoperiod provided by a combination of 3 Philips White (30 W) and 4 Sylvania Grolux (30 W) fluorescent lights. Microorganisms infecting the seeds were isolated and identified.

RESULTS

Plant infection trial. The three fungal species, *Arthrinium* sp.*, Dinemasporium* sp. and *F. oxysporum,* infected *N. trichotoma* plants and 2, 2 and 18 respectively of the other 30 grass species tested (Table 1). The amount of damage caused to the inoculated plants of *N. trichotoma* by the fungi was minimal and none was killed. The damage to the other grass species varied from no or little visible infection in plants inoculated with *Arthrinium* sp. and *Dinemasporium* sp. to basal rotting and death in six plants of four other grass species inoculated with *F. oxysporum*. None of the untreated, control plants had visible infection from any of the fungi used as inoculum, although one plant, of *A. nullanulla,* died without visible foliar infection (Table 1).

Table 1. Fungal infection of *Nassella trichotoma*, endemic Australian grasses and grasses of importance in Australia inoculated with fungi isolated from *N. trichotoma*: *Dinemasporium* sp., *Fusarium oxysporum* and *Arthrinium* sp. Infection noted in parentheses; if no infection was evident, no value is given. ? possibly infected by *F. oxysporum*, with basal infection noted (other *Fusarium* spp. may have caused infection on the leaves).

Species	Authority	No. of plants treated (no. infected)(no. dead)			
		Dinemasporium	*Fusarium*	*Arthrinium*	Control
Aristida sp.	L.	2	2(1?)	0	0
Austrodanthonia duttoniana	(Cashmore) H.P. Linder	1	1	1	2
Au. Geniculata	(J.M. Black) H.P. Linder	2	2(2?)(2)	2	1
Au. Setacea	(R. Br.) H.P. Linder	2	2	2	1
Austrostipa aristiglumis	(F. Muell.) S.W.L. Jacobs & J. Everett	3	3(3?)(1)	3	3
A. breviglumis	(J.M. Black) S.W.L. Jacobs & J. Everett	1	1(1)?	1	1
A. blackii	(C.E. Hubbard) S.W.L. Jacobs & J. Everett	1	1(1?)(1)	1	1
A. curticoma	(Vickery) S.W.L. Jacobs & J. Everett	1	1(1)?	1	2
A. drummondii	(Steud.) S.W.L. Jacobs & J. Everett	1	0	0	0
A. elegantissima	(Labill.) S.W.L. Jacobs & J. Everett	3	3(2?)	3	3
A. exilis	(Vickery) S.W.L. Jacobs & J. Everett	2 (1)	2(2)?	2	0
A. flavescens	(Labill.) S.W.L. Jacobs & J. Everett	1	1(1)?	1	3
A. gibbosa	(Vickery) S.W.L. Jacobs & J. Everett	1	0	0	0
A. mollis	(R. Brown) S.W.L. Jacobs & J. Everett	3 (1)	3(2?)	3	2
A. mundula	(J.M. Black) S.W.L. Jacobs & J. Everett	2	2(2?)	2	1
A. nullanulla	(S.W.L. Jacobs & J. Everett) S.W.L. Jacobs & J. Everett	1	1(1?)	1	1(0)(1)
A. platycheata	(Hughes) S.W.L. Jacobs & J. Everett	1	1(1?)	1	1
A. pubinodis	(Trin. & Rupr.) S.W.L. Jacobs & J. Everett	2	2(2?)(1)	2	1
A. rudis	(Spreng.) S.W.L. Jacobs & J. Everett	3	3(2?)	3	3
A. scabra	(Lindl.) S.W.L. Jacobs & J. Everett	2	2 (2?)(1)	2	2
A. setacea	(R. Brown) S.W.L. Jacobs & J. Everett	1	1(1?)	0	0
A. stipoides	(Hook. f.) S.W.L. Jacobs & J. Everett	2	2(2?)	2	2
A. trichophylla	(Bentham) S.W.L. Jacobs & J. Everett	1	0	0	0
Dichanthium sericeum	(R. Br.) A. Camus	1	1	1	0
Dichelachne crinite	(L. F.) Hook.f.	2	2	2(1)	1
Diplachne fusca	(L.) Beauv.	1	1	1	1
Elymus scabrous	(R. Br.) A. Love	3	3	3	3
Enneapogon sp.	Desv. ex. Beauv.	2	2	2	1
Enteropogon sp.	Nees.	2	2(2?)	2	0
Nassella trichotoma (V8)	(Nees) Arech	3(3)	3(3?)	3(3)	3
N. trichotoma (V10)	(Nees) Arech	3(3)	3(3?)	3(3)	3
Poa poiformis	(Labill.) Druce	3	3	3(1)	3

Arthrinium sp. infected all serrated tussock plants, with the development of dark-brown to black fruiting bodies on the surface of the foliage. The fruiting body was often associated with a small necrotic ring. *Dichelachne crinita* and *Poa poiformis* were infected with *Arthrinium* (Table 1) but no death occurred in any inoculated plant. Infection was confirmed by the observation of fruiting bodies; however there appeared to be no internal penetration of the leaves on microscopic investigation.

Dinemasporium sp. infected all *N. trichotoma* plants, with only two out of 28 other genera and species infected, one plant each of *A. exilis* and one *A. mollis* (Table 1). Fruiting bodies developed on the plants; however, no necrotic areas developed in association with these and no plant died. The greatest development of infection occurred on *N. trichotoma* plants, in which leaf blades died from the tip when fruiting bodies were present on the same blade.

F. oxysporum infected *N. trichotoma* and other grass genera. Twenty-six out of 29 plants from 16 *Austrostipa* spp. became infected with *F. oxysporum,* with four species having a plant die. Five out of 21 plants from 11 species of other grass species were infected and both *Austrodanthonia genticulata* plants died (Table 1). Plants inoculated with *F. oxysporum* had visible rotting at the base, where white hyphal masses, some with a salmon-pink tinge, were observed. Many of the leaves of these plants were chlorotic. Due to the hyphal masses not sporulating, the fungus was not identified. Inoculated plants appeared, on inspection, to have a smaller root biomass than uninfected plants. Serrated tussock appeared to have the least visible effects. Inoculated plants also had secondary infection, with serrated tussock having the least. Secondary infection by fungi such as *Alternaria* sp. and *Penicillium* sp. was confirmed microscopically on some serrated tussock plants, but was greatest on six plants of other species that died. On *N. trichotoma* and six plants of other grass species, *F. roseum* Link. was present on necrotic areas of leaves. Control plants did not develop this secondary infection.

Seed burial trial. Average seed infection varied from about 6-26% depending on site and treatment. There were significant ($P<0.05$) effects of burial-dependent factors (burial site, burial duration and fungicide) and the seed-dependent factor, provenance, but not of burial depth or seed age (Table 1). Fungi were the most common microorganisms infecting the seeds (Table 2). *Alternaria* spp. were by far the most common (55-93%), but there was also significant infection by species of *Bipolaris* and *Trichoderma*, with <1% of total infection each by species of *Fusarium*, *Coniochaeta*, *Penicillium* and *Gloeosporium*, and by actinomycetes.

Table 2. Effects of main factors and significant interactions on infection (proportion) of *Nassella trichotoma* seed after recovery from burial at six sites for three burial durations.

Factor	P value
Burial site	0.042
Burial duration	0.000012
Burial depth	0.094
Fungicide	0.028
Provenance	0.0054

Table 3. Infection (%) of retained *Nassella trichotoma* seed buried in soil for 7 months by the major types of microorganisms.

Genus or group	Range (%)	Mean (%)
Alternaria spp.	55.3-92.6	77.5
Bipolaris spp.	2.4-33.1	16.3
Trichoderma spp.	0-23.9	3.6
Fusarium spp.	0-3.8	0.7
Actinomycetes	0-2.7	0.6
Coniochaeta spp.	0-4.5	0.4
Penicillium spp.	0-1.2	0.2
Gloeosporium spp.	0-0.8	0.1
Others	0-1.9	0.3

DISCUSSION

Plant infection trial. The three fungi used in this trial, *Arthrinium* sp., *Dinemasporium* sp. and *F. oxysporum,* were neither host-specific nor highly virulent to serrated tussock, as other grass species became infected but no serrated tussock plant died.

Dinemasporium sp. was largely found on senescent leaves and may either follow or cause tip death in serrated tussock. *Dinemasporium* is found all year round on dead stems, sheaths and leaves of many grasses including *Agrostis, Bromus, Festuca, Phalaris* and *Poa* (Ellis and Ellis 1985). As this fungus stopped serrated tussock seed germination (Hussaini *et al.* 2000), further research is required to investigate its life cycle and potential as an inundative agent for younger serrated tussock plants. No plant death occurred in any plant inoculated with *Arthrinium* species, which are saprophytic and are found on numerous other plant species (Barnett and Hunter 1998).

The plants inoculated by *F. oxysporum* were visibly rotting at the base, with many leaves being chlorotic; these symptoms agree with those in the literature, with *F. oxysporum* causing root rots in many plant species. *F. oxysporum* has been used in biological control programs in the past (Caesar 1996; Caesar *et al.* 1998), with a formulated *forma specialis* of *F. oxysporum* reducing stand density of leafy spurge (*Euphoria escula)* by 30% over a single season (Caesar *et al.* 1999). However, inoculation with *F. oxysporum* was associated in this study with the death of a number of other grass species. Secondary fungal infections such as *Penicillium* and *Alternaria,* also identified, may have also contributed to plant death. The high humidity and limited air movement in the glasshouse probably heightened the infection by these fungi, which are common and widespread. Plants that died were from the genera *Austrostipa* and *Austrodanthonia*, which predominantly require well drained soils and open plains (Australian Plants Society Maroondah 2001) and may not have been suited to the capillary matting system used, making the endemic plants vulnerable to fungal attack in conditions that were optimal for fungal growth. *F. oxysporum* could exhibit greater virulence on *N. trichotoma* by manipulating the infection window and the pathogen population (Charudattan and Dinoor 2000). Further investigation into the use of this fungus could only be warranted for consideration as an inundative application on dense stands of serrated tussock.

Serious consideration would need to be undertaken before initiating an inundative biological control program with any of these fungi investigated. There is the possibility, in certain circumstances, that these fungi could be used on a small local scale in cases where alternative control measures have not been satisfactory. Any control being initiated with these fungi would need to be undertaken only in areas where serrated tussock has blanket coverage and where none of the surrounding vegetation is a grass species of importance, particularly an Australian endemic grass species.

Seed burial trial. Endemic soil-borne fungal pathogens isolated from Victorian trials with buried seed were associated with poor germination of buried serrated tussock seed, suggesting they could be developed for use on a local scale in inundative or augmentative biological control.

The fungi isolated were ubiquitous and weak pathogens or saprobes (Barnett & Hunter 1998) and found at all sites. *Alternaria* species are widespread and are mostly pathogens, weak facultative pathogens or saprobes, but can kill environmental weeds (Lawrie *et al.* 2002). *Bipolaris (Drechslera)* species are typically saprobic but some cause severe disease in weedy grasses (Lawrie *et al*. 1998; Chandramohan & Charudattan 2001). *Fusarium* species also have known pathogenic species, e.g. *F. oxysporum* reduced leafy spurge (*Euphorbia esula* L.) by 30% (Caeser *et al.* 1999). *Trichoderma viride* has antagonistic properties and is often found in soil. Broad-spectrum fungi such as these could be developed as mycoherbicides for weed control, as they have rapid conidial production if exposure to other plants and fungi is minimised (Bruckart *et al.* 1996).

An inoculation trial with *Alternaria, Gloeosporium, Trichoderma, Fusarium* and *Penicillium* reduced seed germination by up to 50% (Casonato *et al.* 2004), suggesting a biocontrol role in soil reducing seed banks. The similarity in effects of the five fungi on germination suggests that all may contribute to seed death in soil, but research is needed on which endemic soil-borne fungi have most potential to inhibit germination, especially in trials in soil and with less inoculum. The interaction of the fungi used in this study with other microorganisms present within the rhizosphere may reduce their effectiveness.

Propagules of soil-borne pathogens are protected from environmental extremes. As a result, inoculum based on such pathogens may persist and give residual control (Auld and Morin 1995). These pathogens have not been widely investigated because they are usually highly virulent on a wide range of plant species. However, the bioherbicide DeVine® is based on the soil pathogen *Phytophthora palmivora,* which has a wide host range (Auld and Morin 1995). Also, the plurivorous and widely occurring fungus *Sclerotinia sclerotiorum* has potential for biocontrol of Canada thistle (*Cirsium arvense* (L.) Scop.) and dandelion (*Taraxacum officinale* (L.) Weber) (Auld and Morin 1995; Bourdôt *et al.* 2000).

The ability of fungal biocontrol agents to infect other hosts is one of the most important issues when dealing with pathogens as biological control agents (Cook *et al.* 1996). Microorganisms applied as bioherbicides may have the potential to establish and spread. However, populations of microorganisms generally decline to a density naturally sustainable within that environment, often to undetectable levels (Cook *et al.* 1996). Augmentative inoculum would need to be applied periodically. Further investigation and development of these fungi is warranted.

ACKNOWLEDGMENTS

SC received an APA scholarship and a partial scholarship from CRC for Weed Management Systems to undertake this work. Thanks to Jane Barton for reviewing drafts. Thanks to all landholders involved in the project.

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Spraytopping as a management tool to reduce seed production in Chilean needle grass infestations

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Summary. Two field and one glasshouse trial were established at Inverleigh and DPI, Frankston, Victoria, respectively to evaluate the effect of sub-lethal rates of glyphosate and 2,2-DPA on panicle and cleistogene seeds production of Chilean needle grass. One field trial was conducted during each spring of 2003 and 2004 on established tussocks and the glasshouse trial was done in spring 2004 using young tussocks raised from seedlings. Results in the first field experiment indicated that application of glyphosate at 0.510 kg ha^{-1} from 3 September to 13 October prevented panicle seed development and produced the minimum number of filled and germinable panicle seeds. 2,2-DPA proved to be ineffective. The second field experiment showed that application of glyphosate at ≥ 135 g ha^{-1} on 18 and 27 October prevented production of filled and germinable panicle seeds. However, this level of control could be achieved at 1 October only with glyphosate at ≥ 270 g ha^{-1}. The glasshouse trial showed that glyphosate at 216 and 270 g ha^{-1} applied in October prevented the production of filled and germinable panicle seeds. Increasing glyphosate rates decreased stem and panicle seed germination linearly but did not influence basal seed germination. Glyphosate at ≥ 270 g ha^{-1} during November proved to be most effective in controlling stem seeds.

INTRODUCTION

Chilean needle grass (*Nassella neesiana* (Trin. & Rupr.) Barkworth) is a perennial exogenous stipoid grass that produces both panicle and cleistogene seeds. *N. neesiana* is widespread in pastures and natural ecosystems on the Northern Tablelands of New South Wales and in southern Victoria. It grows through the winter but provides a lower feed value than *Dactylis glomerata* (L.), which is considered as a moderate pasture grass when compared for protein, energy and digestibility (C. Grech personal communication). Under heavy infestations, pasture productivity decreases as much as 60% and causes significant reduction in stock-carrying capacity during the summer season (Anon. 2001, Gardener *et al*. 2003).

Chilean needle grass has very versatile reproductive system. Beside aerial inflorescences, it also produces cleistogenes on the stem nodes (Connor *et al.* 1993). Panicle seeds mature and fall off in mid to late summer followed by stem seeds and these then form the bulk of the soil seedbank. The stem seeds are concealed under leaf sheaths and each stem node has the potential to produce a few seeds on and above the ground nodes. Basal cleistogenes come up in singles seeds at the very base of the stem on the first node beneath the soil surface. The newly formed basal seeds are light dull yellow colour and are still held under the leaf sheath. As they mature, they become brown and thin and are released in the soil as the leaf sheath ruptures.

Gardener *et al.* (2003) observed potential panicle seed production of 22203 seed m^{-2} depending upon the number of flowering heads per unit area. This dual mode of seed production diminishes the prospect of quick success of control/eradication measures. Spraytopping (sub-lethal herbicide application) has been widely employed as a tool in different cropping systems to reduce infestations of grasses, for the prevention of diseases and to enhance feed quality (Leys *et al*. 1991, Hill *et al.* 1996, Gatford *et al.* 1999).

This study was undertaken to evaluate optimum time of application during spring season for different glyphosate and 2,2-DPA rates that may preclude panicle and cleistogene seed development.

MATERIALS AND METHODS

Three experiments were conducted, two in the field and one in a glasshouse. The field trial sites were in *Phalaris* based pasture that was heavily infested with Chilean needle grass. The glasshouse trial was done on tussocks raised from panicle seeds. The field soil was loamy, whereas, in the glasshouse steam-sterilized potting mix (1:1 sand:pine bark) in 15 cm pots was used. In field trials no fertilizer was added, however, in the glasshouse trial Nutricote Black (16N, 1.4P, 8.3K) was applied at 6 g/pot in the beginning of the spring season. Herbicides in field trials were applied to 6 x 3 m plots with a hand held Azo-Dutch sprayer with spray volume 176 L ha^{-1}. In the glasshouse trial, application was done using a track-spray-unit with a spray volume 100 L ha^{-1}. Germination tests for cleistogene and panicle seeds were done for 50 seeds from each plot/pot (or maximum available if less than 50 seeds) in a germination cabinet at 25/15^{0}C (alternating 12-hr light/dark). Panicle seeds germination was tested four months while cleistogene seed germination was tested five months after panicle seed harvest. A random 100-panicle seeds/plot or pot were examined for filled seeds (squeezing the seeds with tweezers) and expressed as filled seeds ha^{-1}. The germinable seeds ha^{-1} was computed by multiplying the percent seed germination and filled seeds ha^{-1} data for each plot.

Treatments in each experiment were set in a randomised block design with four replications except the first field experiment (3 replications). Except the glasshouse trial (from mid December to end January) the panicles were harvested in mid December. Stem and basal cleistogenes for the pot trial were assessed in April.

First field experiment. A field trial was established in spring 2003 at the Hamilton Highway, Inverleigh, Victoria. The site was selected in July 2003 and grazing was excluded until the end of the trial. The treatments comprised a six herbicide (glyphosate at 0.1275, 0.255 and 0.510 kg ha^{-1}; 2,2-DPA at 2.22 and 3.7 kg ha^{-1}; no herbicide placebo) by five times of application (3 September, 22 September, 3 October, 13 October and 27 October) factorial.. Chilean needle grass tussocks were vegetative at the first two dates (3 September and October) and reproductive on 13 October (flag-leaf swelling) and 27 October (panicle emergence).

In each plot panicles were harvested from a centrally placed quadrat (50 x 50 cm). The panicle seeds were cleaned, sorted and weighed. A sub-sample of one hundred panicle seeds was drawn from each plot, weighed and results scaled to total number of seeds ha^{-1}. Appropriately transformed data was analysed as a six herbicide by four times of application (excluding 22 September as rain fell just after application) factorial, but with a residual error constructed from a randomised block analysis with all $6 \times 5 = 30$ treatments.

Second field experiment. This experiment was designed as a five herbicide treatment (glyphosate at 0, 135, 270, 405, 540 g ha^{-1}) by three application time (1, 18, and 28 October 2004) factorial, at the Roxby Estate, Inverleigh, Victoria. The tussocks were vegetative at 1 October, spiky stems at 18 October and full panicle emergence at 28 October. The experimental site had old Chilean needle grass tussocks. The mature plants had 25-40 cm high tussocks with dead centres and green leaves growing from the margin. To get uniform growth in early spring, the tussocks were slashed in the winter season. The slashing and prolonged dry weather promoted young tillers with thin stems.

One hundred panicles (or maximum available if less than 100 panicles) were harvested separately from the experimental area (excluding 50 and 100 cm width and length, respectively, on both sides of the plot). The panicle seeds were cleaned, and sorted for each plot to estimate the ancillary characters *viz*. filled seeds, germinable seeds, seed germinations etc.

Measurements were analysed using general linear model analysis with effects for blocks and five specific combinations of treatment (Table 3). There was no evidence of effects between individual treatment combinations within these groupings (P > 0.1). Analyses were restricted to treatment combinations that had variable data (not all zeros), and the residual error was constructed from deviations from all treatments present in the analysis (GenStat Committee 2005).

Glasshouse experiment. This was a five-glyphosate rate (0, 135, 216, 270, and 405 g ha^{-1}) by five times of application (first week of July, August, September, October, and November 2004) factorial, within a glasshouse at Frankston, Victoria. Chilean needle grass seedlings were raised from previous season's panicle seeds. Four-week-old seedlings were placed in jiffy pots and transplanted into 15 cm pots in April 2004. The tussocks were vegetative till October but were producing full panicles seeds in November. The mature panicles were harvested regularly from mid December to end of January and the seeds were cleaned and sorted for assessment. Watering was withdrawn at the end of February to terminate the experiment.

All the mature stems in each treatment were chopped off 1-2 cm above the soil surface and dissected for stem cleistogene. The total number of stem seeds was scaled to 100 stems/pot. The clumps were dug out from the pots and assessed for basal seeds. In each pot, 20 mature stems bases were searched for basal seeds and scaled to 100 stems/pot.

For each measurement, response curves to glyphosate application rate were constructed for different application dates using generalised linear models, and then back transforming to the original scale (GenStat Committee, 2005). Brief details are presented in Figures 1 to 6.

RESULTS

Effect of herbicides. Glyphosate was the more effective herbicide in reducing the germinable and filled seeds and percent seed germination. The highest rate of glyphosate (0.510 kg ha^{-1}) had the maximum impact, resulting in the minimum number of germinable, filled seeds and percent seed germination (Table 1). 2,2-DPA was much less effective even at high rate. There was no evidence (P > 0.1) that these herbicide effects differed with application time.

In the glasshouse trial, all the herbicide rates (135, 216, 270 and 405 g ha^{-1}) killed the plants during the July application; but did not prevent panicle seeds developing during the November application (Figure 1). In August, September and October applications, the number of plants producing panicle seeds decreased with increasing glyphosate rates. For those plants producing panicle seeds, the response of both germinable and total panicle seeds to glyphosate treatments was similar, and at all the application times these seeds decreased with increased rates (Figure 2 and 3).

Cleistogene development and germination. Basal seeds exhibited a higher percent germination compared to panicle and stem seeds and they were unaffected by glyphosate treatment at any rate. However, panicle and stem seeds decreased with increasing glyphosate rates (Figure 4). Lower rates of glyphosate (135 and 216 g ha^{-1}) had less impact on stem cleistogene development during the August and September applications compared to higher rates (270 and 405 g ha^{-1}). During the October application all glyphosate rates except 135 g ha^{-1} gave same level of control. However, in the November application glyphosate at ≥ 135 g ha^{-1} stopped stem seed development (Figure 5). The lowest rate of glyphosate (135 g ha^{-1}) was found to be ineffective in preventing basal seed development but higher rates (≥ 216 g ha^{-1}) showed similar levels of basal seed control (Figure 6).

Herbicides and application time interactions. Medium and high rates of glyphosate (0.255 and 0.510 kg ha^{-1}) produced the minimum number of panicle seeds at all times of application (from 3 September to 27 October) along with the high rate of 2,2-DPA (3.7 kg ha^{-1}) at 3 September. The highest rate of glyphosate proved to be most effective in preventing the panicle seeds when applied any time from 3 September to 13 October (Table 2).

Glyphosate at the lowest rate (135 g ha^{-1}) at 1 October was less effective compared to higher rates (270, 405, 540 g ha^{-1}). Effects of the different glyphosate rates varied with time of application; on 18 and 28 October the lowest rate was sufficient to prevent the occurrence of filled and germinable seeds (Table 3), however, this level of control was observed on 1 October only with higher rates (≥ 270 g ha^{-1}).

Table 1. Effect of herbicides applied at four times in spring on panicle germinable seed, filled seed and seed germination.

Herbicide	Rate (kg ha^{-1})	Germinable Seed ha^{-1} (x10^6)	Filled seed ha^{-1} (x10^6)	Seed Germination (%)
Glyphosate	0.1275	1.3(0.80)*	4.0(1.28)	23(29)
Glyphosate	0.255	0.1(0.71)	0.4(1.19)	7(16)
Glyphosate	0.510	0.0(0.70)	0.0(1.18)	0.4(4)
2,2-DPA	2.22	8.8(1.14)	19.0(1.53)	47(43)
2,2-DPA	3.70	5.5(1.12)	4.0(1.44)	27(31)
Untreated	-	11.7(1.22)	35.0(1.70)	39(39)
LSD (P=0.05)		(0.16)	(0.12)	(12.0)

* Transformed data in parenthesis: $\log_{10}$ (Germinable seed + 5), $\log_{10}$ (Filled seed + 15), and % seed germination (angular)

Table 2. Effect of herbicides and application times on total panicle seed production ha^{-1} (x 10^6).

Herbicide/Date	Rate (kg ha^{-1})	Times of application			
		3 Sep.	3 Oct.	13 Oct.	27 Oct.
Glyphosate	0.1275	21(1.4)*	9(1.1)	13(1.2)	6(1.0)
Glyphosate	0.255	2(0.8)	1(0.7)	2(0.7)	4(0.9)
Glyphosate	0.510	0(0.6)	0(0.6)	0(0.6)	2(0.8)
2,2-DPA	2.22	42(1.7)	18(1.3)	14(1.3)	29(1.5)
2,2-DPA	3.7	2(0.8)	41(1.7)	15(1.3)	21(1.4)
Untreated	-	39(1.6)	50(1.7)	41(1.7)	66(1.8)
LSD (P=0.05)		(0.38)			

* Transformed data in parenthesis: $\log_{10}$ (Panicle seed + 4)

Table 3. Glyphosate rates and time of application effect on Chilean needle grass panicle seed production.

Variates	Mean					Sed	
	Untreated [A]	Oct 1 at 135 g/ha [B]	Oct 1 at ≥ 270 g ha^{-1} [A]	Oct 18 at ≥ 135 g ha^{-1} [A]	Oct 28 at ≥ 135 g ha^{-1} [A]	A v/s A Column	A v/s B Column
Germinable seeds/100 panicles (1)	913	124	0	0	0	-	129.3*
Seeds/100 panicles (2)	1572	1015	1104	332	750	79.1 - 111.5	122.9 – 143.2
% Filled seeds (3)	81	24	0	0	0	-	6.5*
Germination % (4)	70	46	-	-	-	-	6.4*

* Only applicable for treatments with a value greater than 0
In rows (1), (3) and (4) LSDs are obtained by multiplying sed by 2.262. In row (2) LSD is obtained by multiplying sed by 2.030

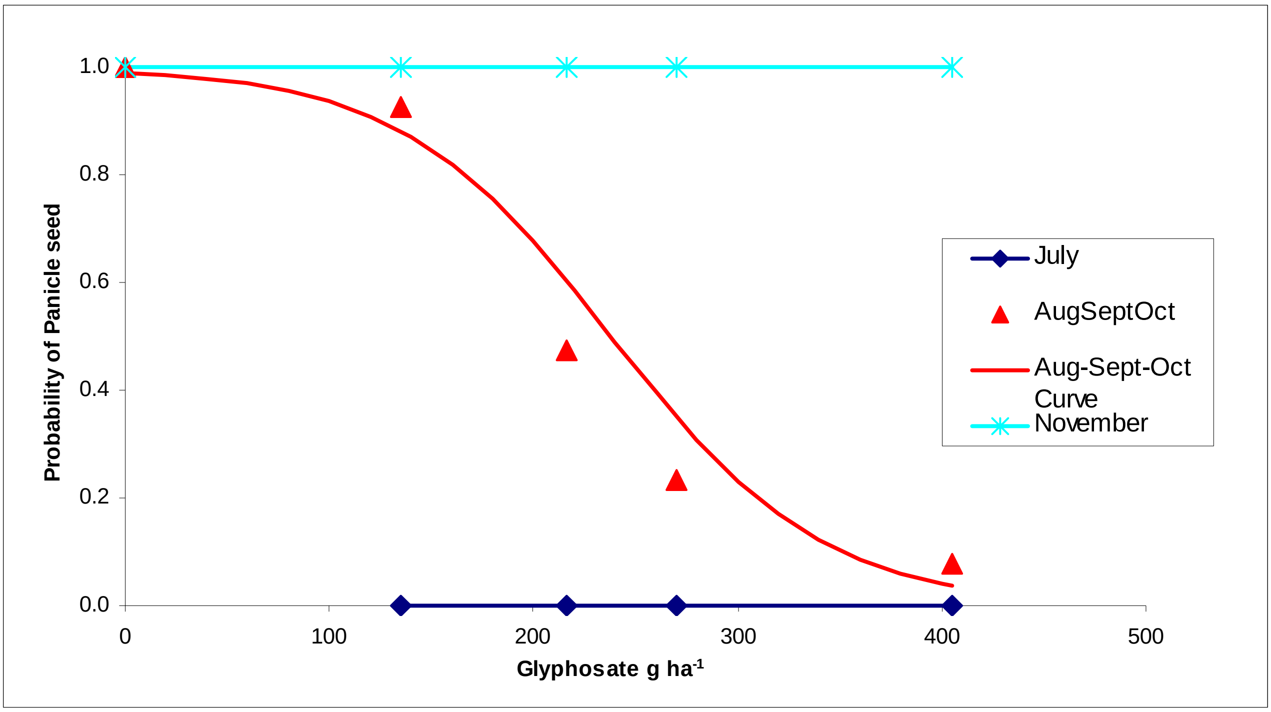

Figure 1. The effect of glyphosate rates and time of application on panicle seeds occurrence. The probability of panicle seed occurrence is adjusted for block and date on logistic transformed scale. Responses fitted using logistic regression with Bernoulli errors.

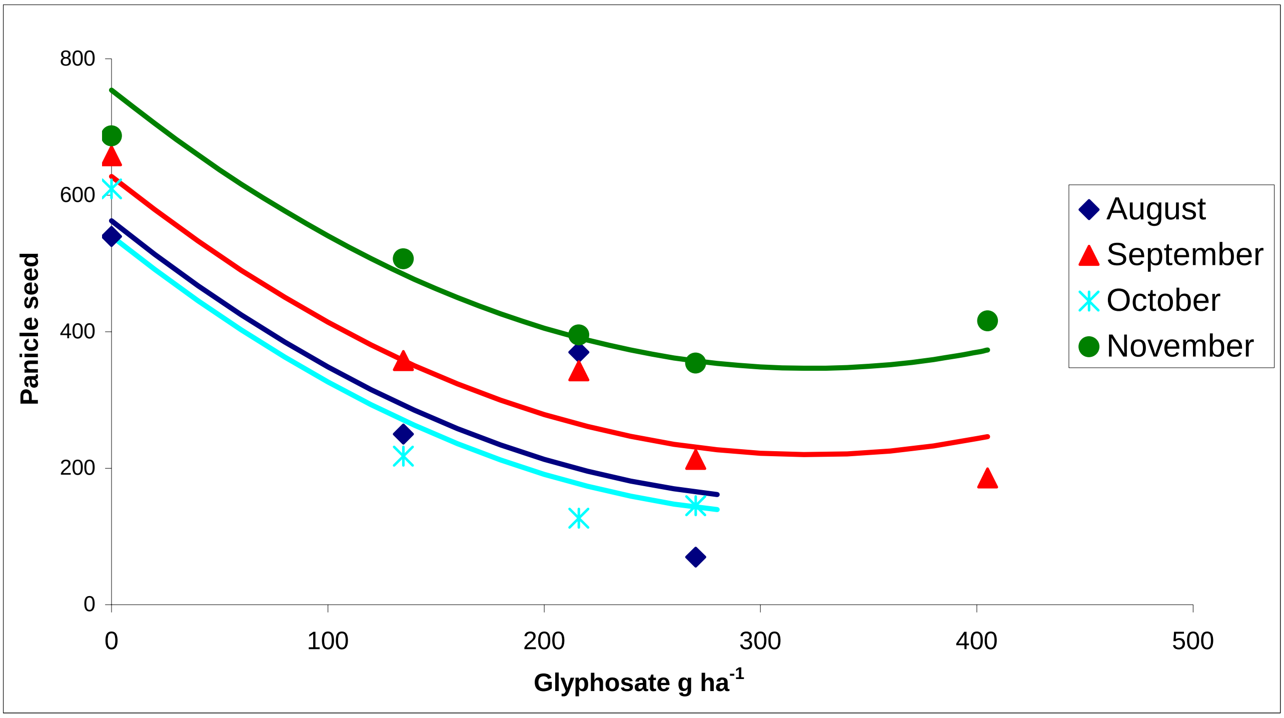

Figure 2. The effect of glyphosate rates and time of application on number of panicle seeds/pot, for those pots where panicle seeds were present. The number of panicle seeds is adjusted for block. Responses fitted using general linear regression.

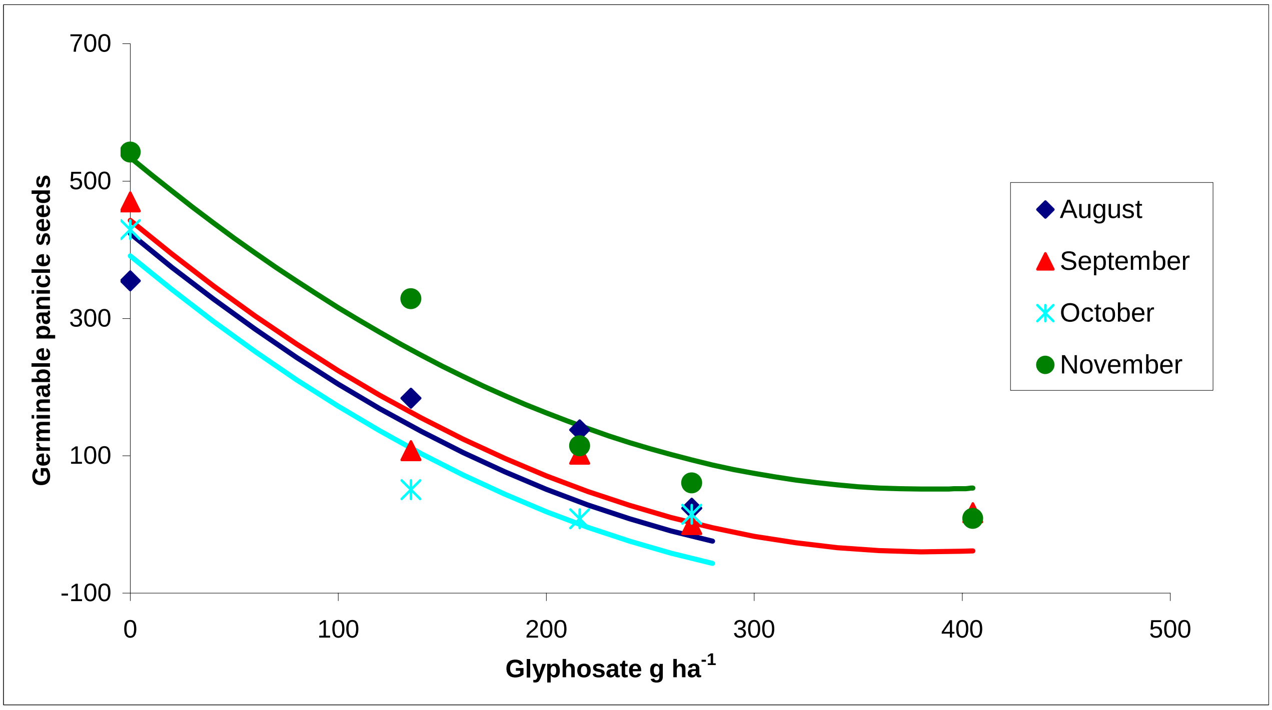

Figure 3. The effect of glyphosate rates and time of application on number of germinable panicle seeds/pot adjusted for block. The analysis is restricted to those pots where panicle seeds were present. Responses fitted using general linear regression.

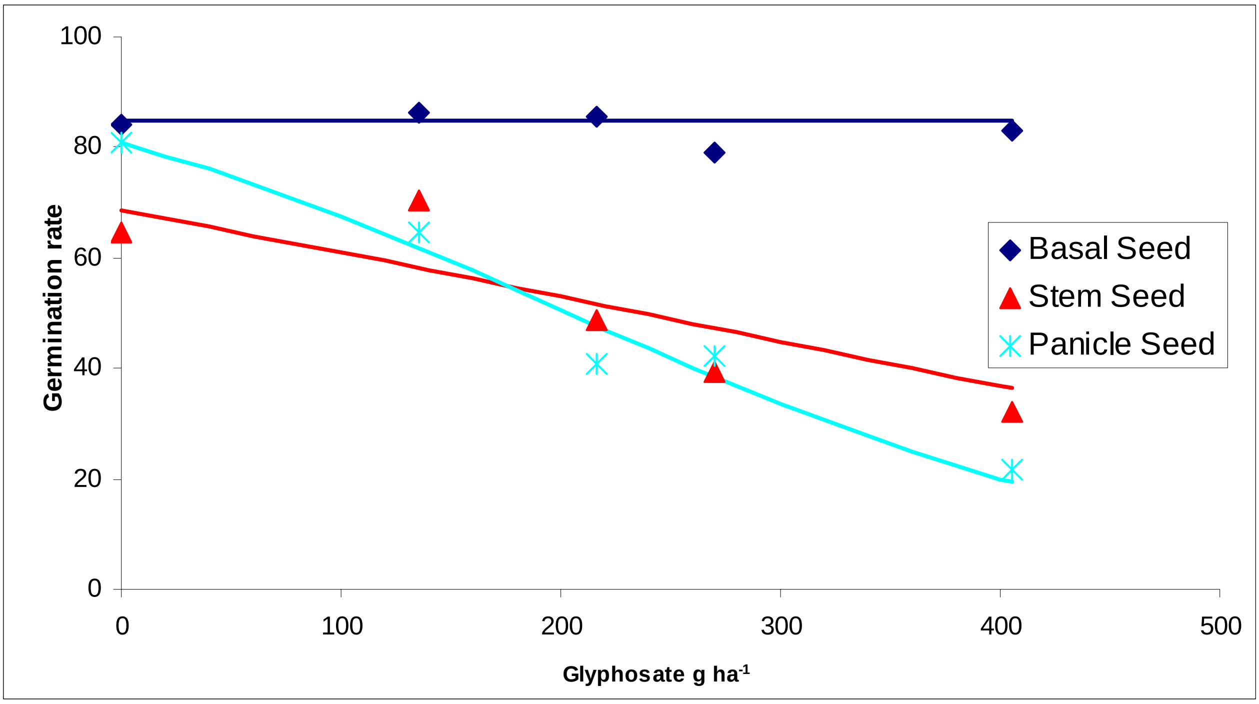

Figure 4. The effect of glyphosate rates on panicle, stem and basal seed germination. The germination rate is adjusted for block and date on logistic transformed scale. Responses fitted using logistic regression with overdispersed binomial errors.

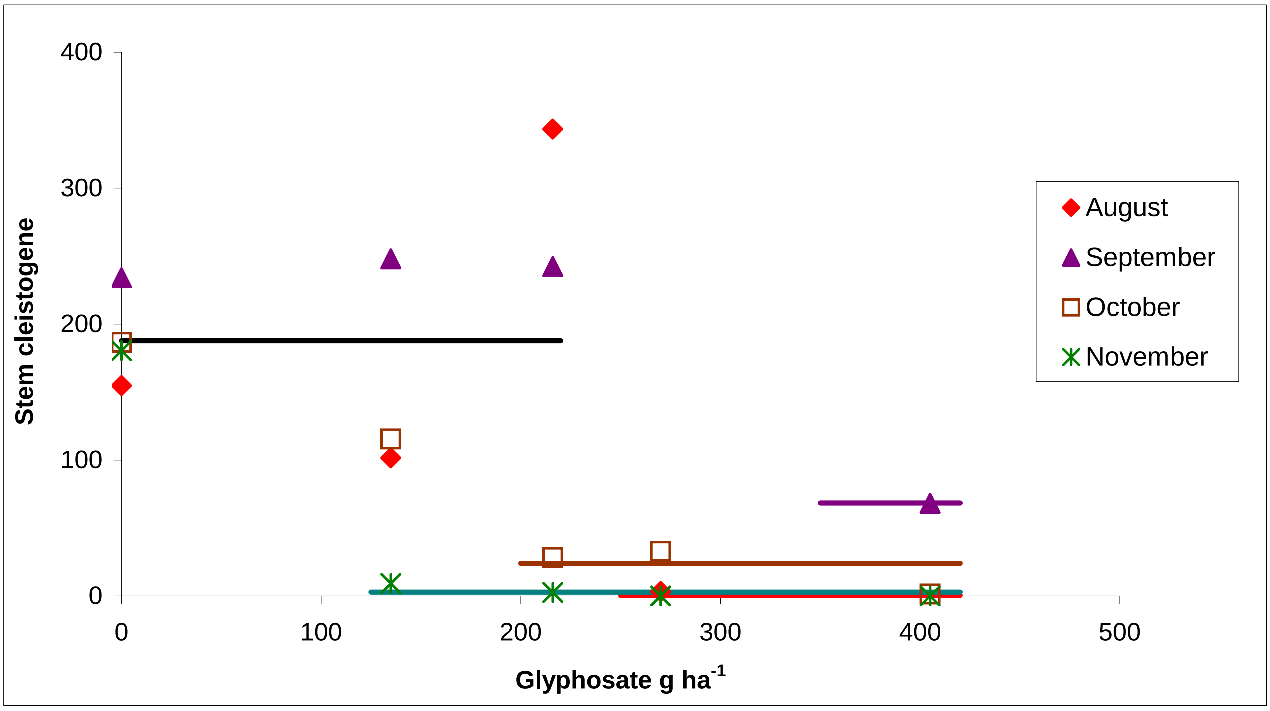

Figure 5. The effect of glyphosate rates and time of application on stem cleistogene. The number of stem cleistogene adjusted for block and date on transformed scale. Responses using general linear regression after log(y+50) transformation.

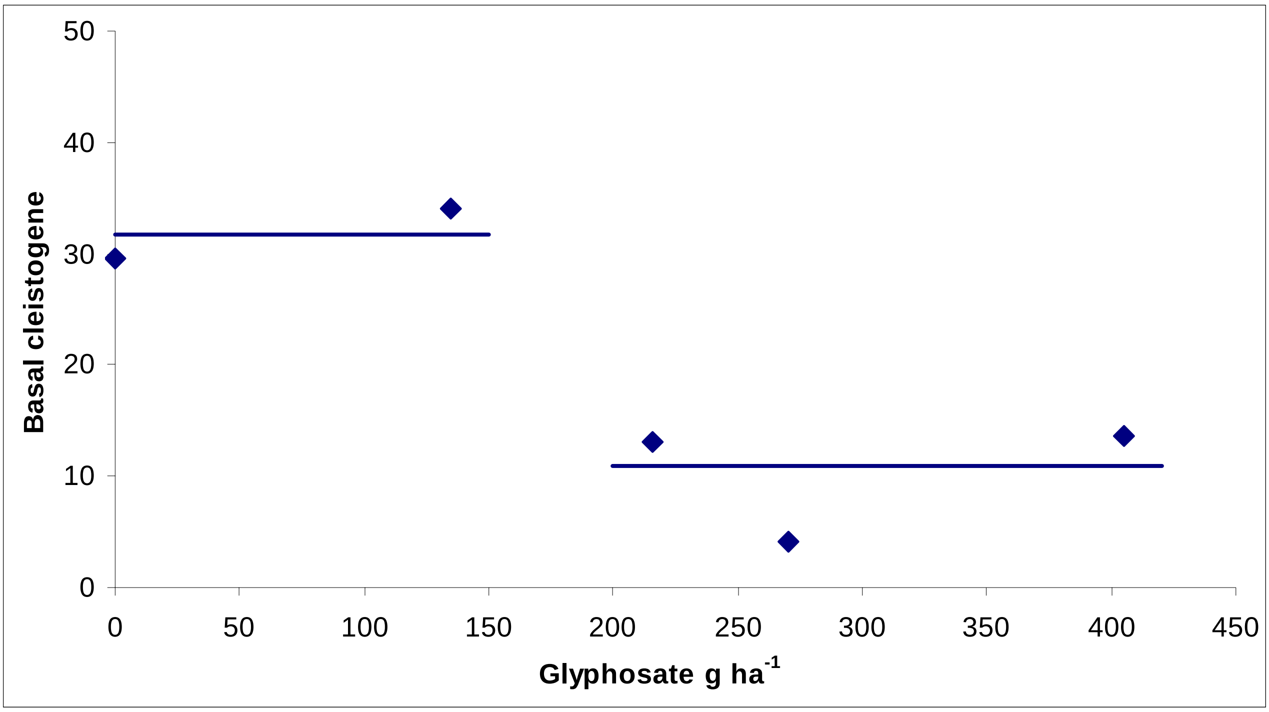

Figure 6. The effect of glyphosate rates on basal cleistogene development. The umber of basal cleistogene adjusted for block and date on transformed scale. Responses fitted using general linear regression after log(y+10) transformation.

DISCUSSION

In this investigation glyphosate at higher rates (0.510 kg ha^{-1}) was a more effective herbicide for preventing Chilean needle grass panicle seed production than 2,2-DPA, particularly when applied from 3 Sept to 13 October. This effectiveness of glyphosate may be attributed to the non-selective and translocated action, which quickly disables the plant from performing physiological processes needed for seed development and results in unfilled seeds or complete loss of panicles. However, 2,2-DPA even at higher rates (3.7 kg ha^{-1}) did not match the lowest rate of glyphosate (0.1275 kg ha^{-1}). The poor performance of 2,2-DPA may be attributed to slow action as it is absorbed through the roots and Chilean needle grass plants have a very short window of activity to complete seed formation and maturation. This explanation of the effect of 2,2-DPA is supported by early September application at 3.7 kg ha^{-1}, where it was comparable in effect to medium glyphosate rates (0.255 kg ha^{-1}).

In the second field experiment, a lower rate of glyphosate was not effective in preventing the production of germinable seeds when applied in early October, but was comparable to medium and high rates in mid and late October applications. To deal with anticipated poor tiller establishment, the old tussocks were slashed in August to ensure new growth in the early spring. Though slashing promoted new tillers, dry weather conditions in spring lead to thin stems. This may be the reason that weak stems did not withstand non-selective and knock down action of glyphosate and gave good performance at lower rates in mid and late applications.

On seedling-raised tussocks in the glasshouse, it was observed that increasing rates of glyphosate decreased the occurrence of panicle seeds during August, September and October applications (vegetative stage) but after the panicle emergence, glyphosate cannot prevent the production of panicle seeds. High rate of glyphosate (405 g ha^{-1}) in the first week of October and November could prevent the production of germinable seeds, as these application times coincide with late vegetative and panicle emergence stages, respectively. This reflects that the rate was enough to arrest the physiological activity of the plant. Since the basal seeds are at an advanced stage in the spring they escape the deleterious effect of glyphosate but panicle and stem seeds are developing during this period thus their production and germinability is influenced by glyphosate. The reason for basal seeds reduction by medium and high rates of glyphosate to a certain degree may be attributed to killing of some of the young stems in tussocks before they became reproductive. However, once the stem becomes reproductive, it is likely to produce basal seed (Gardener, *et al*. 2003). The reason for reduction of stem seeds in November applications in all the glyphosate rates might be stems' death or very restricted stem growth because stem seeds mature mid summer when panicle seeds mature and fall off.

The overall conclusion from these experiments is that application of glyphosate at rates of 250 g ha^{-1} between August and October are likely to very substantially reduce production of viable Chilean needle grass seeds and may be a useful contribution to Chilean needle grass management. However 2,2-DPA is ineffective for this purpose unless applied early and at high rates. For glyphosate application as a spraytopping the timing is critical.

ACKNOWLEDGEMENTS

The assistance of Julio Bonilla in establishing the trials and final assessments is greatly acknowledged. The authors are grateful to Nigel Ainsworth for his valuable comments on earlier version of this article.

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Weedy Sporobolus Grasses Herbicide Screening: Preliminary Results

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Summary. Twenty four herbicides including the current registered herbicides were screened for activity on pre-emergence, juvenile and mature plants of the weedy Sporobolus grass species *Sporobolus pyramidalis* and *Sporobolus fertilis*. No new herbicides trialed -effectively controlled mature plants. Several herbicides showed good activity on juvenile plants and as pre-emergence herbicides. Further work needs to be done to define the recommended application rates for juvenile and pre-emergence plant stages and to also determine the selectivity of these herbicides on native and exotic pasture grasses.
Keywords. Weedy Sporobolus, herbicide screening.

INTRODUCTION

Weedy Sporobolus grasses (WSGs) (*Sporobolus fertilis, S. africanus, S. pyramidalis, S. natalensis* and *S. jacquemontii*) are serious introduced weeds for the beef and dairy industries of Australia. The economic cost of WSGs is high because they reduce animal production and are relatively expensive to control. They are also significant environmental weeds, which destroy habitat and alter biodiversity particularly where monocultures form. Current registered herbicides for WSG control are restricted to flupropanate (Taskforce) and glyphosate, with each having limitations.

Previous herbicide screening work conducted by Loch and Harvey (1999) trialled 15 herbicides on *S. pyramidalis* and *S. fertilis* and sown pasture species. They identified several herbicides that effectively controlled these species as seedlings and as a pre-emergence in a glasshouse situation. However, only atrazine provided some useful selectivity with certain grasses when applied in a field situation during pasture establishment. Current research conducted by the Queensland Department of Natural Resources & Mines and the CRC for Australian Weed Management is being undertaken to identify and register more herbicides for WSG control using *S. pyramidalis* and *S. fertilis* as the test species. The objective is to improve herbicide control technologies, thereby enabling more effective control of WSGs in grass pastures and reducing the risk of herbicide resistance.

MATERIALS AND METHODS

For all herbicide screenings, a randomized complete block design with three replicates was used. Each experimental unit consisted of 20 WSG plants for the juvenile and mature plant life stages, while 50 seeds (viability > 90%) were planted < 1cm deep in dry soil prior to herbicide application for the pre-emergence study. For the mature plant life stage, two 400 mm pots containing 10 plants and four 250 mm pots with five plants in each were used for the first and second screening, respectively. Increased numbers of smaller pots were used for the second trial to facilitate easier handling for staff, whilst still allowing sufficient space for plants to grow. For all other plant life stages 200 mm pots were used.

A sandy loam soil was used for all treatments with the mature and juvenile plants fertilized at the time of planting at a rate of four, five and 10 grams (10.5% N, 3.3% P, 10.0% K, 12.3% S, 3.2% Ca, 1.13% Mg, 0.09% Mn, 0.05% Cu, 0.07% B, 0.07% Zn) per 200, 250 and 400 mm pot, respectively. Pre-emergent treatments were not fertilized. Herbicides were applied using overhead fan sprays at a spray volume of 200 L ha^{-1} for all plant growth stages. Watering ceased for one day following foliar herbicide application, but was then resumed using overhead sprinklers at a rate sufficient to maintain pots near field capacity.

Twenty-four herbicides were tested based on their ability to kill grasses. Most of these herbicides are used in agriculture for in crop grass weed control in either broad leaf crops such as legumes or grass crops such as wheat. Some are non selective and used for knockdown and/or residual weed control in situations where total weed control is required, while others are selective and will not damage broad leaf crops or pasture species. Anecdotal evidence also suggested that some desirable grass species may have a degree of tolerance to some of the chosen herbicides.

The herbicides tested included the current registered herbicides Taskforce (745 g L^{-1} flupropanate sodium) and Roundup Biactive (360 g L^{-1} glyphosate-ipa) as well as Arsenal® (250 g L^{-1} imazapyr), Nu-trazine (500 g L^{-1} atrazine), Balance® 750 WG (750 g Kg^{-1} isoxaflutole), Basta® (200 g L^{-1} glufosinate-ammonium), Brushoff® (600 g Kg^{-1} metsulfuron-methyl), Correct 100 EC (100 g L^{-1} propaquizafop), Diuron (900 g Kg^{-1} diuron), DSMA (220 g L^{-1} DSMA), Flame® (240 g L^{-1} imazapic-ammonium), Fusilade® (212 g L^{-1} fluazifop-P), Graslan* (tebuthiuron 10%), Hero 600 WG (600 g Kg^{-1} ethoxysulfuron), Hussar® (50 g/kg iodosulfuron-methyl-sodium), MKH 3586 (experimental) (900 g Kg^{-1} amicarbazone), MSMA* 800 (800 g L^{-1} MSMA), Dimension* (200 g L^{-1} dithiopyr), Oust® (750 g Kg^{-1} sulfometuron-methyl), Puma® Progress (69 g L^{-1} fenoxaprop-p-ethyl), Select® (240 g L^{-1} clethodim), Sertin® Plus (120 g L^{-1} sethoxydim), Spinnaker* (240 g L^{-1} imazethapyr) and Verdict* 520 (520 g L^{-1} haloxyfop-R methyl ester). Initial screening of these herbicides involved high single herbicide rates to assess pre-emergent and post-emergent activity on *S. pyramidalis* and *S. fertilis*. The herbicides that showed activity in one or more of these categories after the initial screening were then selected for a second screening using two herbicide rates in the plant life stage where activity was evident. Juvenile plants were approximately 100 to 150 mm high with several tillers and mature plants had at least one inflorescence at the time of herbicide application respectively. In all cases apart from with Taskforce plant mortality was assessed by visual inspection for any live shoots 12 weeks after herbicide application. Plant mortality for Taskforce was assessed six months after herbicide application due to its slow acting nature.

RESULTS

The herbicides that were retained for further screening after the initial screening for each growth stage are shown in Table 1. The herbicides Balance, Brushoff, Diuron, DSMA, Flame, Graslan, Hero, Hussar, Oust and Spinnaker were excluded from further screening due to low or no activity in any growth stage.

Mortality of mature plants of *S. fertilis* was generally higher than that of *S. pyramidalis* for all herbicides except for Roundup Biactive where the result was reversed (Table 1). Where reasonable mortality of mature plants did occur after the second screening it was at rates that made selectivity from those herbicides highly improbable (Table 1). Consequently, for the purposes of this study research on mature plants was discontinued. There does however appear to be opportunities for further investigation of the efficacy and grass selectivity of several herbicides including Arsenal, Correct, Fusilade and Verdict which showed high mortality particularly when used on mature plants of *S. fertilis* (Table 1).

Eight herbicides (Arsenal, Correct, Fusilade, Puma Progress, Roundup Biactive, Select, Taskforce and Verdict) and five herbicides (Arsenal, Nu-trazine, MKH 3586, Dimension and Taskforce) were identified for further investigation on juvenile WSG plants and as pre emergent herbicides, respectively, due to high WSG mortality rates.

Although Basta and Sertin Plus showed high mortality on juvenile plants, work on these herbicides was discontinued due to the unlikelihood of grass selectivity at the proposed rates.

Table 1. Mean plant mortality (%) of mature, juvenile and pre-emergent plants of *S. pyramidalis* and *S. fertilis* 12 weeks after herbicide application for the second screening. Values within columns followed by the same letter are not significantly different ($P<0.05$). (- indicates herbicide not applied to plant life stage).

Herbicide	S. pyramidalis			S. fertilis		
	Mature	Juvenile	Pre-emerge	Mature	Juvenile	Pre-emerge
Arsenal 2 L ha^{-1}	-	100 a	100 a	-	93 a	100 a
Arsenal 4 L ha^{-1}	0 e	100 a	100 a	0 g	100 a	100 a
Arsenal 8 L ha^{-1}	8 bcd	-	-	97 a	-	-
Basta 3 L ha^{-1}	-	95 ab	-	-	27 b	-
Basta 6 L ha^{-1}	-	100 a	-	-	100 a	-
Correct 1 L ha^{-1}	-	100 a	-	-	100 a	-
Correct 2 L ha^{-1}	15 bc	100 a	-	93 ab	100 a	-
Correct 4 L ha^{-1}	50 a	-	-	97 a	-	-
Dimension 2 L ha^{-1}	-	0 e	100 a	-	0 d	100 a
Dimension 4 L ha^{-1}	-	0 e	100 a	-	0 d	100 a
Fusilade 1 L ha^{-1}	-	100 a	-	-	100 a	-
Fusilade 2 L ha^{-1}	3 cde	100 a	-	47 de	100 a	-
Fusilade 4 L ha^{-1}	62 a	-	-	93 ab	-	-
MKH 3586 1 kg ha^{-1}	-	-	100 a	-	-	100 a
MKH 3586 2 kg ha^{-1}	-	-	100 a	-	-	100 a
MSMA 800 6 L ha^{-1}	0 e	0 e	-	0 g	0 d	-
MSMA 800 12 L ha^{-1}	0 e	10 e	-	0 g	12 c	-
Nu-trazine 4 L ha^{-1}	-	85 b	100 a	-	95 a	100 a
Nu-trazine 8 L ha^{-1}	-	100 a	100 a	-	98 a	100 a
Puma Progress 0.6 L ha^{-1}	-	100 a	-	-	98 a	-
Puma Progress 1.2 L ha^{-1}	-	100 a	-	-	95 a	-
Roundup Biactive 2 L ha^{-1}	0 e	100 a	-	0 g	100 a	-
Roundup Biactive 4 L ha^{-1}	60 a	100 a	-	18 f	100 a	-
Select 0.2 L ha^{-1}	-	61 c	-	-	97 a	-
Select 0.4 L ha^{-1}	-	94 ab	-	-	95 a	-
Select 0.8 L ha^{-1}	0 e	-	-	2 g	-	-
Select 1.6 L ha^{-1}	0 e	-	-	63 cd	-	-
Sertin Plus 1 L ha^{-1}	-	80 b	-	-	95 a	-
Sertin Plus 2 L ha^{-1}	0 e	100 a	-	22 ef	98 a	-
Sertin Plus 4 L ha^{-1}	0 e	-	-	47 d	-	-
Taskforce 2 L ha^{-1}	3 cde	41 d	83 ab	95 ab	100 a	100 a
Taskforce 4 L ha^{-1}	5 cde	100 a	100 a	100 a	100 a	100 a
Verdict 520 0.4 L ha^{-1}	-	100 a	-	-	100 a	-
Verdict 520 0.8 L ha^{-1}	-	100 a	-	-	100 a	-
Verdict 520 1 L ha^{-1}	7 bcd	-	-	82 bc	-	-
Verdict 520 2 L ha^{-1}	13 bc	-	-	90 ab	-	-
Control	1 e	0 e	71 b	1 g	0 d	31 b

DISCUSSION

There seems to be little problem controlling juvenile WSGs in legume crops and pastures given that Fusilade and Verdict are currently used for grass control in these situations. What remains to be done with these herbicides is to further define the application rate necessary for effective control. Finding similar selectivity in grass crops and pastures that is cost effective is where the real challenge lies.

Taskforce is registered for the control of WSGs at all growth stages. It offers some selectivity with grasses but anecdotal evidence suggests that there are several issues to be worked through with its use, such as soil type effects, tolerance of native grasses (particularly in the tropics), withholding periods, residue levels in agricultural products and herbicide resistance. Another issue of concern is the apparent low efficacy of Taskforce on juvenile and mature *S. pyramidalis* plants compared to efficacy on *S. fertilis* plants when applied at registered rates. This suggests further work is needed to refine the application rates of Taskforce for effective control of *S. pyramidalis*. The absence of any potential grass selective herbicide for mature WSG control among those screened leaves WSG control with the current registered herbicides albeit with apparent low efficacy when used on *S. pyramidalis*. The likelihood of advances in the near future is low unless new active ingredients are developed.

From the current study and the work of Hawton (1976, 1980) and Loch and Harvey (1999) it appears that atrazine with its pre-emergence and post emergence activity on seedlings may offer some opportunities for control of WSGs in established grass pastures. However there are issues with this herbicide such as residual effects on broad leave herbaceous plants (legumes and forbs), particularly in lower rainfall native pasture systems where opportunities for pasture regeneration and replacement are somewhat limited. Dimension and MKH3586 may offer opportunities as a pre-emergence herbicide in established pastures as they appear to have no post emergence activity. However these herbicides would need further evaluation before any recommendations could be made. Their use on large areas or low input grazing systems may also be cost prohibitive.

Future work will focus on detailed herbicide rate pot trials using the herbicides selected above, to identify the most effective rates for the control of juvenile and pre-emergent *S. pyramidalis* and *S. fertilis*. This may be followed by field trials on all WSGs as well as other native and introduced pasture grasses to determine grass selectivity if resources and work priorities allow.

ACKNOWLEDGMENTS

The advice and assistance of Joe Vitelli, Barbara Madigan and Shane Campbell in the conduct of this study and preparation of this paper is gratefully acknowledged.

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The National Serrated Tussock Survey – Impacts and Implications of its resistance to the herbicide, flupropanate in Australia.

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Abstract. A population of serrated tussock at Diggers Rest just north-west of Melbourne has been identified as being resistant to the herbicide flupropanate. This has prompted a national mail survey of 5000 land managers impacted by serrated tussock across Australia. Survey results have shown that serrated tussock has spread widely throughout Victoria, NSW, ACT and Tasmania with 15 out of 399 respondents reporting resistance and requiring further investigation. The survey has also shown that serrated tussock is costing each land manager between $15,000 and $20,000 annually in control and lost production costs. This emphasises the importance of promoting integrated management of serrated tussock.

Keywords. survey, serrated tussock, *Nassella trichotoma*, economic impact, herbicide resistance, flupropanate

INTRODUCTION

Serrated tussock (*Nassella trichotoma* Trin. & Rupr Barkworth) is a perennial, drought resistant tussock grass species that is native to the pampas grasslands of Argentina, Uruguay, Chile and Peru (Parodi 1930, Rosengurtt *et al.* 1970) and Bolivia (Walsh and Entwisle 1994). Serrated tussock is a proclaimed noxious weed in the Australian Capital Territory, New South Wales, Victoria, South Australia and Tasmania. It has been described as causing a greater reduction in pasture carrying capacity than any other weed in Australia with heavily infested paddocks in NSW carrying only 0.5 dry sheep equivalent (d.s.e.) per hectare compared to 7 to 15 d.s.e. on improved pasture without the weed (Parsons and Cuthbertson 1992). Serrated tussock is a Weed of National Significance (Thorp and Lynch, 2000) that has been estimated to conservatively cost Victoria $5 million per year (Nicholson *et al.* 1997) and the economy of New South Wales $40.3 million per year (Jones and Vere 1998). In 1977 it occupied 680,000 ha (Campbell 1977) and now occupies more than 870,000 ha in New South Wales with an estimated 2,000,000 ha at risk of infestation (Ian McGowan, NSW Department of Primary Industries, *Personal communication*)). In Victoria, serrated tussock was first collected at Broadmeadows (15 km NNW of Melbourne) in 1954 where it occupied 4 ha (Parsons, 1973). By 1979 it had spread to occupy approximately 30,000 ha (Lane *et al.* 1980) and by 1998 it occupied in excess of 130,000 ha (McLaren *et al.* 1998). Serrated tussock is also found in Tasmania where it is currently spread in scattered populations over an area of approximately 1000 ha (Christian Gonninon, Tasmanian Department of Primary Industries Water and Environment *personal communication*). The potential distribution of serrated tussock based on its current infestations in Australia has been estimated at 32 million ha with substantial areas of New South Wales, Victoria and Tasmania at risk of invasion (McLaren *et al.* 1998). Serrated tussock is being increasingly recognised as a serious environmental weed and the associated native vegetation being invaded by serrated tussock is described in McLaren *et al.* 1998.

Despite years of research, there are still limited control options for managing serrated tussock in Australia (Michalk *et al.* 1999). The only registered herbicides for control of serrated tussock in pastures are flupropanate, glyphosate, and 2,2-DPA. Flupropanate is widely regarded as the most selective and effective herbicide for controlling serrated tussock (Campbell and Vere 1995). Species such as phalaris, cocksfoot and kangaroo grass have some tolerance to flupropanate (Campbell 1979; Campbell *et el.* 1979; Campbell and Ridings 1988) while its residual action in the soil can prevent serrated tussock regrowing for three to five years (Campbell and Vere 1995). Flupropanate resistance has been identified in a population of serrated tussock in Victoria (Noble 2002). Serrated tussock plants suspected of being resistant to flupropanate were grown in a pot trial and treated with a range of flupropanate rates. The resistant serrated tussock survived application rates as high as 8L/ha which is four times the recommended rate used for controlling this species (Noble 2002). Similarly, petri dish dose response trials undertaken on serrated tussock seeds have shown that the flupropanate dose required to reduce the germination of seeds from resistant plants by 50% was approximately 10 times higher than for susceptible seeds (Graeme Pritchard, Victorian Department of Primary Industries, *Personal communication*) This has prompted a national survey to try and determine whether serrated tussock resistance to flupropanate is wide spread and to raise resistance awareness and promote integrated management of serrated tussock.

MATERIALS AND METHODS

In November 2004, a tick-box questionnaire was sent out to land managers in Victoria, NSW, ACT and Tasmania. In Victoria and Tasmania, questionnaires were sent out directly to landholders that had been recorded with serrated tussock on the land they managed. This also included a mailing list of 1130 within the Melton Shire in VictoriaThe Melton Shire was targeted because the property identified with serrated tussock resistant to flupropanate was located within this Shire. A further 931 surveys were mailed directly to land managers recorded with serrated tussock on the Victorian Department of Sustainability and Environment's Integrated Pest Management System (IPMS). Twenty questionnaires were sent out to Victorian park rangers, 10 to Vic Roads and 30 directly to Victorian spray contractors. In Tasmania 275 questionnaires were mailed out directly to land managers recorded with serrated tussock. In NSW 338 surveys were sent directly to NSW Landcare groups within serrated tussock infested locations while the remaining 2,265 surveys were sent to NSW and ACT Weeds Inspectors for distribution to land managers in their districts. The surveys were targeted to regions thought likely to be infested by serrated tussock. A total of 5000 surveys were sent (2125 to Victoria, 2450 to NSW, 150 to ACT and 275 to TAS). A colour CRC for Australian Weed Management Fact sheet entitled "Understanding the mechanisms behind herbicide resistance" was also sent out with the surveys to help land managers understand what herbicide resistance is and how it can be prevented. Each survey included a prepaid return envelope to aid land managers returning the survey.

Respondents were requested to provide information on the extent of land they manage and the coverage of serrated tussock infestation on their land. The infestations were categorized either as '**Dense** – monoculture or close to monoculture – very few native/other species present', '**Medium** – roughly equal proportions of serrated tussock to other native/pasture/crop species present', '**Scattered** - Native/pasture/crop species in much greater abundance than serrated tussock', '**Rare** – Single or very few serrated tussock plants present' or '**Absent**'. They were also asked to classify what proportion of these infestations occurred on pasture land, native vegetation or other (roadside, cropping, forestry etc). Respondents were also asked to indicate the costs as "material costs," "labour costs" "Time (days/year) cost" and "other costs" to control serrated tussock infestations in "pasture", "native vegetation" and "other" land classes. Questions were asked about chemical control including what herbicides they used for serrated tussock, the number of times they used these herbicides and the year they first used these herbicides. They were also asked whether they had noticed serrated tussock on the land they managed that had not died after two or more applications of a serrated tussock herbicide and whether they thought this could have been due to resistance.

RESULTS

Distribution and type of infestation. A response rate of approximately 8% (399) was obtained while approximately 250 surveys were returned address unknown. The respondents reported on a total area of approximately 0.42 million ha consisting of pasture, native vegetation and other (roadsides, cropping, etc) across Australia. The respondents reported serrated tussock infestations totalling approximately 102,048 ha comprising 48,747 ha on pasture, 43,019 ha in native vegetation and 10,281 ha on other areas (roadsides, cropping etc). Of this total, some 82,094 ha was in NSW, 8,113 ha in Victoria, 11,520 ha in the ACT and 321 ha in Tasmania (Table 1).

The most significant serrated tussock infestations reported occur in NSW where the majority of dense and medium infestations were reported on native vegetation with more scattered and rare infestations reported on pasture land (Table 1). Similarly, in the ACT respondents reported greater areas of dense, medium and scattered serrated tussock infestations in native vegetation than pasture. However, in Victoria and Tasmania more serrated tussock was reported in pasture than in native vegetation. These results may also reflect that all the Victorian and Tasmanian land managers received surveys through direct mail. However, in NSW and the ACT, surveys were sent via weeds officers, environmental officers and agronomists for distribution to land managers. In some cases these professionals reported on an entire district or region. In Victoria, the "Other" category recorded the largest area of dense serrated tussock. However, this was reported by a single landowner who did not provide contact details.

Economic impact. Table 2 lists the annual costs of serrated tussock control expressed as materials, labour and other (other costs of serrated tussock not included in materials and labour) listed for land use and State affected. As expected, NSW, the state with the most significant serrated tussock infestations are spending the most money on serrated tussock control ($691,759/year and $7,745/respondent). However, land managers from the ACT are spending on average $9,405/repondent/year on serrated tussock control which is more than double that reported for Victoria ($3,862/respondent/year) and Tasmania ($2,130/repondent/year). Labour was recorded as the greatest cost component in all land use types except in native vegetation in the ACT where $43,450 was spent on materials compared to $13,640 estimated for labour. The annual total production losses caused by serrated tussock is listed in Table 3. In total, production losses were estimated at $662,820 while the average losses per respondent was approximately $13,000/year. In total, serrated tussock was estimated to be costing the respondents approximately $1.8 million in management costs and lost production or about $15-20,000/year/respondent.

Table 1. Serrated tussock infestations categorised by State, land use and density reported from survey.

STATE	Land use types	Serrated tussock infestation density (ha)				
		Dense	Medium	Scattered	Rare	Total
NSW	Pasture	878	1078	17909	19735	**39,600**
	Native	1,099	4,303	16,798	10,855	**33,055**
	Other	143	12	3,910	5,375	**9,439**
	Total	2,120	5,393	38,617	35,965	**82,094**
VIC	Pasture	37	371	2,353	2,754	**5,515**
	Native	6	195	939	816	**1,956**
	Other	99	70	225	247	**642**
	Total	142	636	3,517	3,817	**8,113**
TAS	Pasture	30	31	121	39	**221**
	Native	1	2	64	28	**95**
	Other	0	0	5	0	**5**
	Total	31	33	190	67	**321**
ACT	Pasture	190	25	2,130	1,067	**3,412**
	Native	370	1,030	5,976	537	**7,913**
	Other	0	0	45	150	**195**
	Total	560	1,055	8,151	1,754	**11,520**
Total Australia		**2,853**	**7,117**	**50,475**	**41,603**	**102,048**

Table 2. The annual costs of serrated tussock control reported from survey.

STATE	Land use types	Annual total cost to control serrated tussock by State ($/yr).				Average per respon-dent ($/yr)
		Materials	Labour	Other	Total	
NSW	Pasture	165,714	177,110	23,970	**366,794**	**2,134**
	Native	50,180	116,172	87,570	**253,922**	**3,199**
	Other	15,347	41,286	14,410	**71,043**	**2,412**
	Total	**231,241**	**334,568**	**125,950**	**691,759**	**7,745**
VIC	Pasture	53,609	76,478	26,460	**156,547**	**1,010**
	Native	16,142	50,898	17,600	**84,640**	**918**
	Other	9,275	43,800	8,425	**61,500**	**1,934**
	Total	**79,026**	**171,176**	**52,485**	**302,687**	**3,862**
TAS	Pasture	2,050	5,390	3,350	**10,790**	**715**
	Native	2,325	4,650	2,500	**9,475**	**1,415**
	Other	0	0	0	**0**	-
	Total	**4,375**	**10,040**	**5,850**	**20,265**	**2,130**
ACT	Pasture	21,550	30,760	40,300	**92,610**	**5,438**
	Native	43,450	13,640	17,800	**74,890**	**3,755**
	Other	110	500	100	**710**	**212**
	Total	**65,110**	**44,900**	**58,200**	**168,210**	**9,405**
AUST	**Total**	**379,752**	**560,684**	**242,485**	**1,182,921**	

Table 3. Annual total production loss by State ($/yr)

State	No. of Replies	Total, $	Average per respondent $
NSW	31	478,600	15,439
VIC	15	91,740	6,116
TAS	1	1,000	1,000
ACT	4	91,480	22,870
AUST	**51**	**662,820**	**12,996**

Herbicide Resistance. Table 4 shows the number of respondents using flupropanate and glyphosate and average years/times used for control of serrated tussock compared by State. Almost twice as many respondents were reported using flupropanate to glyphosate in NSW and vice versa for Victoria. Flupropanate has been used on average more than ten years/times by respondents from NSW and the ACT. Glyphosate has been used more frequently than flupropanate in Victoria and Tasmania (Table 4.). The number of respondents reporting herbicide resistance is shown in Table 5. Serrated tussock resistance to flupropanate was identified by 9 land managers and resistance to glyphosate by 6 land managers (Figure 1.). All the Victorian flupropanate resistance reports were from properties in the Diggers Rest, Sydenham, Bulla locality just north of Melbourne.

Table 4. Herbicides used to control serrated tussock (Number of respondents) and average years/times used.

State	Flupropanate No. reporting – Ave years/times used	Glyphosate No. reporting – Ave years/times used	Total No. reporting
NSW	96 – 10.7	68 – 7.6	164
VIC	57 – 5.1	120 – 5.6	177
TAS	7 – 1.4	4 – 6.0	11
ACT	10 – 10.9	11 – 3.8	21
AUST	**168 – 8.0**	**203 – 6.3**	**373**

Table 5. Survey respondents reporting resistance.

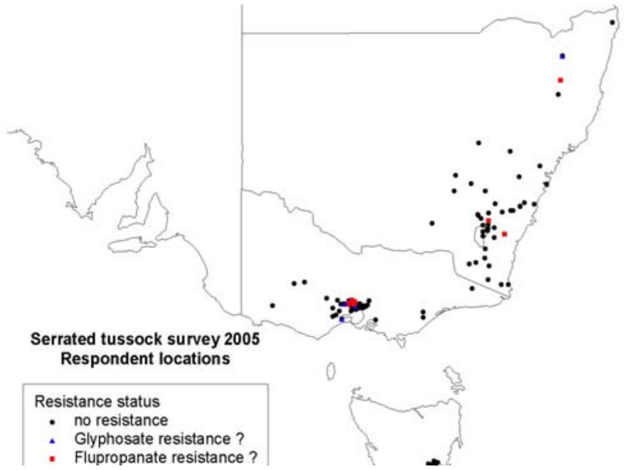
State	Flupropanate Resistance ?	Glyphosate Resistance ?
NSW	2	1
VIC	6 *	5
TAS	0	0
ACT	1	0
AUST	**9**	**6**

* Includes 1 property confirmed with resistance.

DISCUSSION

This survey has confirmed the massive impacts this weed is having on Australian agriculture with average annual serrated tussock costs ranging from $15,000 to $20,000 per year per respondent. This survey has also identified 9 (2%) properties reporting serrated tussock suspected of being resistant to flupropanate. A process of contacting these land managers and obtaining serrated tussock samples for testing resistance is underway. Similarly, six land managers have also expressed concern that glyphosate is not killing serrated tussock and that this could be due to resistance. The Victorian Department of Primary Industries has been working in collaboration with the Melton Shire Council to ensure that all serrated tussock on and surrounding the property confirmed with resistant serrated tussock is controlled. In addition, RMIT University in collaboration with the Victorian Department of Primary Industries have commenced a PhD project investigating the heritability and mechanisms causing resistance to flupropanate by serrated tussock. It is critical that land managers don't rely solely on one herbicide type to control serrated tussock. Land managers need to consider mechanical control, cropping, pasture rehabilitation, grazing management and a strategic use of herbicides to try and reduce the likelihood of resistance. This survey reinforces the need to practice integrated weed management to control serrated tussock.

Figure 1. Distribution of survey respondents reporting resistance.



ACKNOWLEDGMENTS

The authors would also like to acknowledge the support provided by the Commonwealth Government through the Natural Heritage Trust for this manuscript. The Authors would also like to thank Michael Michelmore from NSW Agriculture for providing names and addresses of NSW Weeds inspectors in serrated tussock localities in NSW. We would also like to thank Christian Gonninon from the Tasmanian Department of Primary Industries, Water and Environment and Alan Brennan from the Shire of Melton in Victoria for supplying databases of land managers in serrated tussock localities. We would also like to thank the NSW and ACT Weeds inspectors who delivered the surveys to farmers and land managers.

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Machinery Hygiene — What is on our vehicles?.

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Summary. Recent assessment of material for weed contamination, manually removed from vehicles during training in weed movement, machinery inspection and cleaning workshops has identified over 130 contaminant species. Fourteen species were declared noxious weeds in Victoria and six have regionally prohibited status. One weed of national significance was identified on two separate vehicles. Of the 18 utilities/4wd vehicles assessed an average of 617g of dry material was removed and 44% were carrying noxious weeds or Weeds of National Significance. Two vehicles were carrying multiple noxious species .

INTRODUCTION

The Victorian pest management framework identifies that risk of introduction and spread of pests needs to be communicated to the community so attitudes and behaviour are modified. (DNRE 2002). It is well known amongst weed professionals that vehicles can disperse an array of weed species. Wace, (1977) in his survey of car wash facilities in Canberra identified over 259 species or taxonomic entities that are potentially dispersed by vehicles. Gathering some hard data on the actual contaminants on each vehicle and comparing between vehicle types can be an expensive and time-consuming activity.

Workshops have been developed, that are aimed at increasing participants awareness of their obligations under the Victorian Catchment and Land Protection Act 1994 in particular to the movement and dispersal of noxious weeds and how they can implement practices to help them meet their obligations (Lardner et al 2004). These workshops have been conducted for 12 local or state government organisations both within Victoria and South Australia since July 2004.

These workshops provided a unique opportunity to assess contaminants cleaned from a variety of equipment for weed contamination. Assessment of much of the material is still on-going.

MATERIALS AND METHODS

An opportunity existed for assessing material carried on vehicles and equipment used as part of training courses in weed movement, machinery inspection and cleaning run by DPI over the last 12 months. A manual clean down and collection of samples from vehicles was required to be performed by participants as part of their assessment against national competencies. This generated over 100 individual samples from 35 items of machinery or passenger vehicles. Samples were collected and stored in zip-lock plastic bags.

Visual assessment was made on all samples for seed contamination and where possible seeds were identified to species. All samples were tested for germinants. Many of the samples, due to their volume, required sub sampling for economical germination assessment. Approximately 380 ml (1 punnet 12.1*6.7*4.7mm) of loose sample was spread thinly over half of a 30*27 cm trays containing three Litres of commercial sterile, potting mix. Two samples were placed on each tray and were separated by a ridge of potting mix to stop seed/soil movement from one sample to the adjoining sample. Trays were watered overhead and placed in an un-heated glasshouse and watered as required.

Germinated plants were assessed approximately fortnightly and identified as early as possible in their lifecycle. Due to time constraints species emerging were recorded but numbers of individuals of each species were not. Germination assessments continued for at least 12 weeks and for some samples up to 26 weeks. At the time of writing this paper samples collected after March 2005 were still being assessed.

Results have been recorded for the location of the sample on each vehicle, weight of sample taken and sub-sample assessed. Samples were not necessarily taken from all locations on all vehicles and total weights of samples are not necessarily all the material that could be removed off the vehicle. Hence results are likely to be an underestimate of the species present as germination conditions generally favoured winter germinators and not species likely to germinate in the summer. As a result of the sub sampling some species may have been missed in the assessment.

RESULTS

Results presented in this paper are a summary of the samples taken from each vehicle. A total of 35 items of vehicles and machinery have been cleaned and assessed for weed contamination. This consisted of; 18 utilities and 4wd vehicles, 5 tractors and slasher units, 3 out-front mowers, 3 graders, 3 backhoes and 3 trucks and trailers. The utilities are mainly from local government and state government organisations with three vehicles belonging to private contractors. All the vehicles are exposed in their daily business to weed propagules, some of them are put into high-risk situations on a frequent basis (ie. Spray units and, slashers for CNG control). Details for of material collected from each vehicle or machine, weights of material collected and assessed and the number of species identified for each vehicle are listed in Table 1. The noxious weeds and weeds of national significance are also listed.

Over 130 species have been identified from the samples assessed. The highest number of species on one vehicle was 38. No vehicles were contaminant and species free. Almost 40 families are represented in the flora observed on the vehicles and Table 2 lists the families represented. The most frequent family observed was Poaceae followed by Asteraceae and Fabiaceae.

The top 15 weed species identified on vehicles and machinery are presented in Table 3 along with the noxious weeds detected. 39% of passenger vehicles and 29% of machinery carried noxious weeds, while 11% of all vehicles carried multiple noxious weed species. The sample size is possibly too small to draw any conclusions regarding the type of propagule that is likely to be carried on particular vehicles or plant and machinery. It is more likely that the situation the vehicles are exposed to determines the species they will pick up

CONCLUSION

Vehicles play an important role in the potential spread of weeds. Passenger fourwheel drive vehicles used by local government and government business that are exposed to weed propagules pose a significant risk in spreading weed species of concern. The movement of plant and machinery will also spread weeds. Thorough cleaning of vehicles will significantly reduce this weed spread risk.

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Table 1. Weeds species identified from vehicle inspections.

Vehicle type	Date collected	Location	Weight (g) or volume (L) of material removed	Weight (g) or volume (L) of material assessed	Number of species detected	Noxious weeds species identified
Passenger Vehicles						
4wd wagon*	23/5/05	Koroit	67	53	8	
4wd tray*	11/5/05	Horsham	448	220	10	
4wd ute*	19/4/05	Naracoorte	942	204	13	
4wd ute*	10/5/05	Horsham	160	74	5	Pennisetum macrourum African feather grass
4wd ute*	20/4/05	Roseworthy	768	160	5	
4wd ute*	4/5/05	Bendigo	59	59	13	
4wd wagon*	4/5/05	Bendigo	2698	304	13	
4wd tray slip-on*	19/4/05	Naracoorte	556	98	17	
4wd ute*	20/4/05	Roseworthy	206	90	5	*Cenchrus longispinus* spiny burr grass
4wd spray unit*	21/4/05	Pt Augusta	824	236	36	*Xanthium spinosum* Bathurst burr *Tribulus terrestris* caltrop, *Marribum vulgare* horehound, *Cirsium vulgare* spear thistle, *Centaurea calcitrapa* star thistle, *Dittrichia graveolens* stink wort
4wd ute spray*	23/5/05	Koroit	902	134	15	*Ulex europaeus* Gorse, *C. vulgare* spear thistle, *Silybum marianum* variegated thistle
4wd ute*	21/4/05	Pt Augusta	746	100	4	*D. graveolens* Stink wort
2wd ute*	20/4/05	Roseworthy	2	2	3	*T. terrestris* Caltrop
4wd ute*	10/5/05	Horsham	382	172	15	
4wd ute	20/7/04	Bacchus Marsh	0.2 L	0.2 L	11	
4wd ute	21/7/04	Bacchus Marsh	0.2 L	0.2 L	10	
4wd ute*	21/4/05	Pt Augusta	42	42	4	
4wd ute*	9/6/05	Hume	810	188	24	*Nassellea neesiana* Chilean needle grass
Machinery (Plant)						
Backhoe	21/7/04	Bacchus Marsh	57.6 L	1.5 L	38	*Juncus acutus* Spiny rush,
Backhoe*	3/5/05	Bendigo	129 L	413	17	
Backhoe*	4/5/05	Bendigo	40	40	5	
Wing mower*	8/6/05	Hume	1066	118	7	
Tractor and slasher*	8/6/05	Hume	1116	340	19	*Foeniculum vulgare* Fennel, *Oxalis pes-caprae* oxalis,
Tractor and slasher*	8/6/05	Hume	178	48	26	*N. neesiana* Chilean needle grass
Tractor and slasher*	4/5/05	Bendigo	182	48	21	*T. terrestris* Caltrop
Tractor and slasher*	23/5/05	Koroit	222	86	13	
Out front mower	20/7/04	Bacchus Marsh	12 L	0.4 L	17	
Out front mower	21/7/04	Bacchus Marsh	5.7 L	0.4 L	20	
Out front mower*	8/6/05	Hume	652	80	10	
Grader*	23/5/05	Koroit	494	262	14	
Grader	20/7/04	Bacchus Marsh	11.9 L	3.8 L	32	*O. pes-caprae* oxalis *Conium maculatum* Hemlock
Grader*	9/6/05	Hume	2086	790	0	
Truck semi*	11/5/05	Horsham	2713	296	6	
Truck tipper*	4/5/05	Bendigo	1980	86	6	
Trailer*	4/5/05	Bendigo	52	26	13	

*Samples still under assessment at time of writing this paper

Table 2. Families and number of species identified in samples from vehicles and machinery.

Family	Species identified	Family	
Amaranthaceae	2	Aizoaceae	1
Apiaceae	3	Anacardiaceae	1
Asteraceae	14	Boraginaceae	1
Brassicaceae	9	Cucurbiteae	1
Carophyallaceae	5	Euphorbiaea	1
Chenopodiaceae	3	Gentinaceae	1
Crassulaceae	2	Gerinaceae	1
Cyperaceae	3	Liliaceae	1
Fabaceae	11	Lythraceae	1
Juncaceae	3	Meliaceae	1
Lamiaceae	3	Mimozaceae	1
Malvaceae	2	Oleaceae	1
Myrtaceae	3	Onogaraceae	1
Oxalidaceae	2	Pinaceae	1
Plantaginaceae	2	Primulaceae	1
Poaceae	38	Ranunculaceae	1
Polygoaceae	3	Thymelaceae	1
Rosaceae	2	Verbenaceae	1
Rubiaceae	2	Zygophyllaceae	1
Solanaceae	2		

Table 3. Number of vehicles and machines contaminated by species.

Species Noxious weed or WON*	**Number of contaminated vehicles**			**Species**	**Number of contaminated vehicles**		
Number of units	**Total (35)**	**Passenger (18)**	**Plant (17)**		**Total**	**Passenger (18)**	**Plant (17)**
Tribulus terrestris caltrop,	3	2	1	*Vulpia sp* Silver grass	16	7	9
Dittrichia graveolens stink wort	2	2	0	*Phalaris sp*	15	7	8
Cirsium vulgare spear thistle	2	2	0	*Lolium sp* Ryegrass	15	7	8
Oxalis pes-capre soursob	2	0	2	*Juncus bufonius* Toad rush	15	7	8
Nassella nessiana Chilean needle grass*	2	1	1	*Plantago coronopus* Bucks horn plantain	14	4	10
Pennisetum macrourum African feather grass	1	1		*Polygonum sp* Wire weed	14	4	10
Xanthium spinosum Bathurst burr	1	1		*Rumex sp* Docks	13	4	9
Foeniculum vulgare Fennel	1	0	1	*Crassula sp*	12	6	6
Cenchrus spp Spiny burr grass	1	1		*Medicago sp*	12	5	7
Centaurea calcitrapa star thistle	1	1		*Poa annua* Winter grass	12	4	8
Juncus acutus Spiny rush	1	0	1	*Trifolium sp* Clover	11	6	5
Silybum marianum Variegated thistle	1	1		*Bromus catharticus* Prairie grass	10	4	6
Conium maculatum Hemlock	1	0	1	*Plantago lanceolata* Ribwort	10	2	8
Ulex europaeus Gorse	1	1	0	*Sonchus oleraceous* Sow thistle	10	5	5
Marribum vulgare Horehound	1	1	0	*Hordeum spp* Barley grass	10	6	3

Producer perceptions of changing occurrence and successful control methods for *Nassella trichotoma* and *N. neesiana*

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Summary. A postal survey targeting sheep graziers across southern Australia was undertaken in January 2004. A total of 937 landholders responded to the questionnaire. Among other things, the survey gleaned information on producer perceptions of changing occurrence of pasture weeds and successful control methods. *Nassella trichotoma* (serrated tussock) and *N. neesiana* (Chilean needle grass) were reported as weeds by 14.5% and 2.2% of respondents, respectively.

Maps showing the distribution of the reported occurrences of both species are given. Serrated tussock showed significant variation between regions in the level of occurrence and the degree to which the perceived problems had changed. Chilean needle grass was reported as an increasing problem by the majority of respondents who had the weed on their properties. Some 92.9% of respondents who had serrated tussock and 81.3% who had Chilean needle grass had attempted to control these weeds.

For full time graziers, the most commonly reported control methods for Chilean needle grass were spot spraying (84.6%), cultivation (46.2%) and chipping (38.5%). Of the respondents using these techniques, 54.5% reported success with spot spraying, 33.3% with cultivation and 40% with chipping. Many of the respondents appear to be failing in their attempts to manage this weed.

On the other hand, the most commonly reported control methods being used by graziers for serrated tussock were spot spraying (79.0%), chipping (67.6%), sowing pastures (30.5%), fertilizer application (26.7%) and boom spraying (25.7%). Of the respondents using these techniques, 100% reported success with the use of boom spraying, 98.8% with spot spraying, 93.8% with sowing pastures, 87.3% with chipping and 78.6% with fertilizer application. Slashing and burning proved to be ineffective control methods. Many respondents reported that their success in serrated tussock control came with the integration of various strategies such as grazing management, pasture improvement and forage rotations. Producers also stressed the need for persistence in surveillance and control if favourable results were to be achieved.

Keywords. *Nassella trichotoma*, *Nassella neesiana*, survey.

Using Glyphosate for Serrated Tussock (*Nassella trichotoma*) Management in Southern Tablelands of New South Wales

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INTRODUCTION

Since its introduction in 1978 flupropanate (Frenock®) has been the major herbicide used in the fight against serrated tussock. When it was removed from sale in Australia in October 1998 land managers were left with no viable herbicide option to manage serrated tussock. In response research efforts were renewed to find a replacement herbicide. While glyphosate products have been shown to be effective, results were often variable, with effective rates of application ranging from 2 to 15 L/ha (360g a.i.) (Campbell, Miller & Michalk 1999).

In October 2000 flupropanate became available again under a number of registered names. Monsanto have registered Roundup Max® and Roundup Biactive® for serrated tussock control. Also since 1998 extensive experiments have been conducted on a range of glyphosate products, rates and spray adjuvants in order to gain more data on the efficacy of glyphosate on serrated tussock. These experiments were conducted over a number of seasons and sites on the Monaro and Southern tablelands of New South Wales. This paper summarises this study and highlights the situations in which glyphosate can be used most effectively for serrated tussock management.

MATERIAL AND METHODS

Herbicides were applied with a 2 or 3 metre hand held boom. Water volume per hectare ranged from 100–180 L/ha. Plots were 10 metres long, arranged in randomised complete blocks of 3 replicates. An unsprayed control and Frenock® (2 L/ha) treatments were included in all experiments. Efficacy of treatments was assessed 12 months after herbicide application. Percent control for each treatment is the average across three replications at each site. The effect of herbicide on background pasture was also assessed. This was achieved by recording every species within a $0.1m^2$ quadrant at twenty random locations in each plot in the spring following herbicide application. Results are expressed as number of quadrants with species present out of the total 20 quadrants (% occurrence).

Apart from the burnt experimental site at Michelago, herbicide was applied to heavy infestations (>50% ground cover) of mature serrated tussock.

Experiment 1. Spring 1998 — Sites at Bredbo, Yass and Michelago. At Michelago treatments were imposed on a) serrated tussock that was burnt approximately eight weeks prior to spraying, and b) where the serrated tussock was not burnt.

Aim. To evaluate a number of rates and glyphosate formulations for serrated tussock control (Roundup Biactive® @ 4, 6, 8, 10, 15 L/ha, Touch Broadacre Herbicide® @ 3.5, 5.2, 7, 8.7, 13.5 L/ha and Roundup CT Xtra® + 0.2%v/v Wetter TX® @ 2.9, 4.4, 5.8, 7.3 & 11 L/ha).

Experiment 2. Spring 1998 — Sites at Bredbo, Yass and Michelago. At Michelago treatments were imposed on a) serrated tussock that was burnt approximately eight weeks prior to spraying and b) where the serrated tussock was not burnt.

Aim. To evaluate addition of a number of spray adjuvants to Roundup CT Xtra® for serrated tussock control. (Roundup CT Extra® @ 2, 3, 4 & 5 L/ha with addition of 0.2% v/v Wetter TX®, 1% v/v Hasten® or 1% v/v SprayPlus® at each rate. One rate of Roundup Biactive® at 6 L/ha).

Experiment 3. Autumn 1999 — Sites at Bredbo, Yass, Maffra and Michelago. At Michelago treatments were imposed on a) serrated tussock that was burnt approximately eight weeks prior to spraying and b) where the serrated tussock was not burnt.

Aim. To evaluate the addition of a number of spray adjuvants to the low rates and autumn application timing of Roundup CT Xtra® for serrated tussock control (Roundup CT Xtra® @ 1, 1.5, 2, 3, 4, 5 & 10 L/ha with addition of 0.2% v/v Wetter TX®, 1% v/v Hasten® or 1% v/v SprayPlus® at rates of 1, 1.5 and 2 L/ha; 3, 4, 5 & 10 L/ha applied with 0.2% v/v Wetter TX® only).

RESULTS

Experiment 1. All treatments gave excellent control (>98%) where serrated tussock had not been burnt prior to herbicide application, except at Bredbo where 4 and 6 L/ha Roundup Biactive® gave 92% and 96% control respectively. Regardless of herbicide rate or formulation there were a few plants with regrowth after 12 months. Generally these were smaller plants that were shielded by larger plants at the time of herbicide application. Where serrated tussock had been burnt prior to herbicide application control was still very good for all treatments (>90%), however here there were a number of plants in each plot that were regrowing after twelve months, irrespective of the glyphosate formulation or rate of application. The probable conclusion being that the serrated tussock did not have sufficient time to recover after the burning to fully translocate the herbicide. At this site there was no advantage to burning the serrated tussock prior to herbicide application.

Experiment 2. All treatment gave 100% control where serrated tussock had not been burnt prior to herbicide application. However, where serrated tussock had been burnt prior to herbicide application, all treatments gave over 95% control except for Roundup Biactive® at 6 L/ha which gave 92% control. Reduced control on the burnt serrated tussock was similar to results for experiment one and, as stated above, there was no advantage to burning the serrated tussock prior to spraying.

Experiment 3. As application rates dropped below 2 L/ha of Roundup Ct Extra® regardless of spray adjuvant added, control of serrated tussock declined. At 1 and 1.5 L/ha, with all additive combinations, an average of 73% and 89% control respectively was achieved over all sites. At 2 L/ha control improved to give comparable results to the spring application (Experiment 1) at Yass (97%), Bredbo (99%), and Michelago sites (97% unburnt and 94% burnt). However at Maffra 2 L/ha only achieved 80% control, at 3 L/ha control increased to 97%. A possible explanation for this decline in efficacy could be attributed to the highly fertile basalt soil at the Maffra site. Campbell (2001) also found that serrated tussock was more difficult to kill on fertile soils. At all experimental sites the lower rates of Roundup CT Xtra® prevented the serrated tussock from seeding the following spring.

Time of application and its effect on pasture composition. The results of this study have shown that glyphosate was very effective at killing heavy infestations of serrated tussock at relatively low rates in both spring and autumn. The most striking difference between autumn and spring application and even the timing of each of these applications, was the effect glyphosate had on background pasture species. The non-selective nature of glyphosate presents limitations on its use in managing serrated tussock, being best suited for total vegetation control pre-sowing or for spot spraying isolated plants. However, this study has shown that many useful pasture species can be retained when using glyphosate for serrated tussock control, by carefully timing glyphosate application. Glyphosate applied in an annual pasture situation after the annual species have set seed in late spring and before they emerge in autumn, will have no effect on these species. Likewise, damage to perennial species such as phalaris may be minimised by applying glyphosate when they are dormant in summer or with some native species, when they are frosted in winter.

For example at the Yass site, pasture species were not disadvantaged by using glyphosate when compared to the then standard treatment of Frenock® (Figure 1). Note the equivalent levels of serrated tussock control with both treatments. Subterranean clover had already germinated at the time of spraying whcih accounts for its reduced occurrence in the sprayed plots. If spraying had occurred earlier, this damage may have been avoided. At the rates used at this site, a saving of approximately $56.00/ha in herbicide cost could be achieved by using glyphosate instead of flupropanate. It should be noted that neither herbicide would be adequate in preventing considerable reinfestation of serrated tussock because of the low occurrence of competitive perennial species at this site.

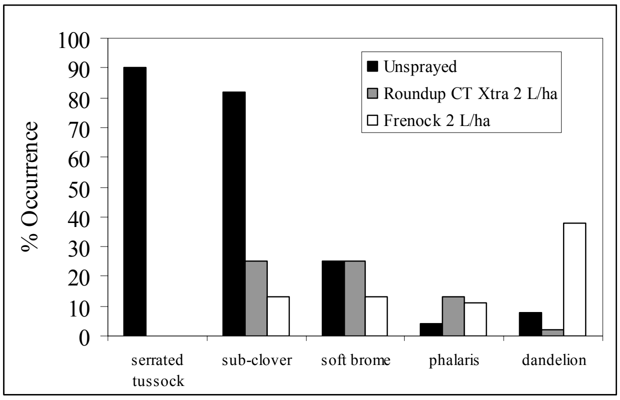

Figure 1. Percent occurrence of pasture species at Yass 6 months after herbicide application (April 1999).

Glyphosate is becoming more and more popular as an alternative herbicide for spot spraying or as a total knockdown herbicide in preparation for winter cereals or pasture. On the Monaro some landholders that have previously used recommended flupropanate rates broadacre in the spring, have found the residual is detrimental to the establishment and growth of winter cereals sown in February and March. Pasture legumes and grasses are also effected by the flupropanate residual if inadequate rainfall has fallen between the time of spraying and the time of sowing. Producers are encouraged to plan ahead and select the most appropriate herbicide for the situation. They are also being encouraged to use all weed management tools available and not to rely on a herbicide only option.

The use of a herbicide only strategy for serrated tussock control will in the long term be unsuccessful, since without competition from pasture, serrated tussock will reinfest. It is preferable that herbicides are used in conjunction with establishing and maintaining a perennial grass based pasture to prevent reinvasion of serrated tussock.

However, where the cost of establishing a pasture is beyond economic reach, a well timed application of glyphosate may enable some level of pasture production as well as controlling serrated tussock in the short term. The authors are currently conducting further experiments to evaluate these options. Campbell and Nicol (2001) provide further information regarding the use of glyphosate for serrated tussock control.

Take home messages.

- Glyphosate is effective at killing serrated tussock in spotting and boom spray situations.
- Associated useful pasture species can be retained when using glyphosate for serrated tussock control. However, landholders considering this option need to develop a good understanding of the growth cycles of the species present including both target and background plants to time the glyphosate application for maximum efficacy while minimising the effect on desirable species.
- Glyphosate will be most effective when applied to serrated tussock plants that are actively growing and only when weather conditions are conducive to spraying. Higher rates are required to kill tussock on high fertility soils such as basalt.
- In grazing country replacing serrated tussock with competitive species, conservative grazing and ongoing pasture management is the long-term answer to serrated tussock management.

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Flupropanate resistance mechanisms and heritability in serrated tussock

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Summary. The mechanism of flupropanate action was investigated in resistant and susceptible potted plants of serrated tussock (*Nassella trichotoma*) treated with flupropanate at up to 6 kg a.i./ha, as Taskforce® (75% a.i.). Fresh sections of leaves and roots were examined using energy dispersive X-ray analysis (EDAX) coupled with an environmental scanning electron microscope (ESEM). Flupropanate-treated susceptible plants accumulated the multivalent cations of Al, Cr, Fe, Mg, Mo, Ni and Si in their roots at normal rates of application, whereas resistant plants depleted them. These results suggest that flupropanate interferes with membrane structure and that resistance negates the effect. Controlled pollination experiments between resistant and susceptible plants showed that resistant plants produced only resistant seeds, no matter what the pollinating parent was. The cross susceptible x susceptible produced only susceptible seed, but the cross susceptible plant x pollen from resistant plant produced a mixture of susceptible and resistant seed. These results are consistent with resistance being genetically determined and being carried as a nuclear gene in pollen.
Keywords. flupropanate, *Nassella trichotoma*

INTRODUCTION

Serrated tussock is a Weed of National Significance in Australia. It is a highly invasive aggressive perennial grass indigenous to the pampas grasslands of Argentina, Chile, Peru and Uruguay (Parsons and Cuthbertson 1992; McLaren *et al.* 1998). For farmers, it significantly increases costs and decreases returns (McLaren *et al.* 2005). Landholders in Victoria have a legal responsibility to prevent the growth and spread of serrated tussock from their properties, as it is a State Priority Weed (Miller and Wilsher 1999). In heavy infestations, control is difficult to achieve, especially on non-arable land, and relies heavily on the appropriate use of herbicides.

The herbicide flupropanate (sodium 2,2,3,3 tetrafluoropropanate) is preferred because of its selective action and the need to minimise soil disturbance. Flupropanate is available in Australia as several proprietary formulated products (http://services.apvma.gov.au/PubcrisWebApp/ProductList) and can be applied at any time of year, as it is effective at all stages of growth (Parsons and Cuthbertson 1992). As the plant decays, the residual flupropanate is released into the soil and is claimed to kill seedlings for the next 3-5 years (Vee Dri (Aust.) Pty Ltd undated b). Flupropanate is therefore the herbicide of choice and has been the most effective herbicide for the control of serrated tussock over the last 20 years. Flupropanate is mainly taken up by the roots, where it is translocated to other parts of the plant (Vee Dri (Aust.) Pty Ltd undated a). The first signs of the weed dying are after 3-4 months, when the foliage begins to turn brown, but it can take up to 16 months to kill mature plants, depending on factors such as rainfall and soil characteristics (Vee Dri (Aust.) Pty Ltd undated b). The recommended rates are 2 L/ha (1.49 kg a.i./ha) for boom spraying and 200 mL per 100 L (= 1490 ppm a.i. (w/v)) for spot spraying (Taskforce® - (Vee Dri Aust.) Pty Ltd undated a).

Serrated tussock plants suspected to be field-resistant to flupropanate were found on a farm at Diggers Rest, Victoria in 2001. The owner of the farm reported that an area of serrated tussock had not responded to treatments of flupropanate, while others around it did. Noble *et al.* (2005) showed that the field-collected plants and seeds derived from them were resistant to flupropanate (Noble 2002). The development and spread of herbicide-resistant serrated tussock threatens the sustainability of the pastoral industry in south-eastern Australia, especially if resistance is pollen-borne, because of the speed and distance of transmission.

The aims of this study were to investigate the effects of flupropanate on serrated tussock and the heritability of resistance.

MATERIALS AND METHODS

Mechanism of action. The mechanism of flupropanate action was investigated in plants grown from tillers of resistant and susceptible potted plants of serrated tussock (*Nassella trichotoma*) collected at Diggers Rest, near Melbourne, in August-September 2002. Plants had been treated by spraying with flupropanate at up to 6 kg a.i./ha, as Taskforce® (75% a.i.) ? weeks previously. Fresh pieces of young leaves and roots were examined using a Phillips Fei Quanta 200 ESEM with the Gaseous Electron Detector (GSED) in the ESEM mode with the thermoelectric stage set at 6°C. Elemental analysis was by an energy dispersive analysis of X-rays (EDAX). A magnification of 800-12000 times was used with a live detector time of 100 s per analysis to quantify the samples. The individual elements were expressed as weight percentage of the sum of the total elements, which were calculated using EDAX ZAF Quantification.

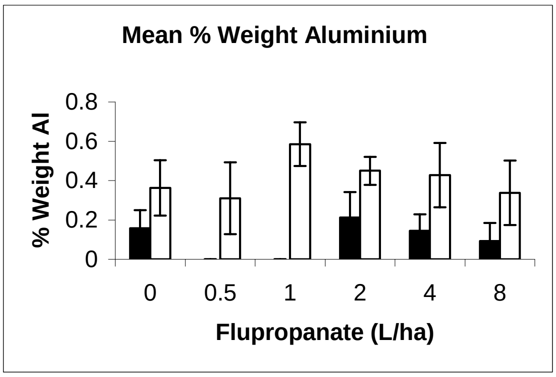
Heritability. Controlled crosses were made between and within serrated tussock plants (resistant and susceptible) from Diggers Rest and St Albans respectively in three separate glasshouses during Oct – Dec 2004. Anthesis in chasmogamous florets was between 7 a.m. and 11 p.m. Panicles were supported by bamboo sticks and covered by brown paper bags to avoid contamination by foreign pollen on evening prior to anthesis. Florets were very small (1-2mm) with a fine bifid feathery stigma and so crosses were made using an Optical Glass Binocular Magnifier (Donegan Optical Company, Kansas, USA). Florets were emasculated at 7-9 a.m., during which time the anthers extruded, but did not dehisce. When receptive, the stigmatic surface of the emasculated floret was dusted with pollen grains collected from a donor plant and the panicle was protected with a paper bag. Plants were selfed by covering the entire panicle with a paper bag prior to anthesis and keeping it undisturbed. The mature seeds of both crossed and selfed plants were harvested and stored in paper bags for 3-4 months to overcome dormancy before testing for resistance to flupropanate.

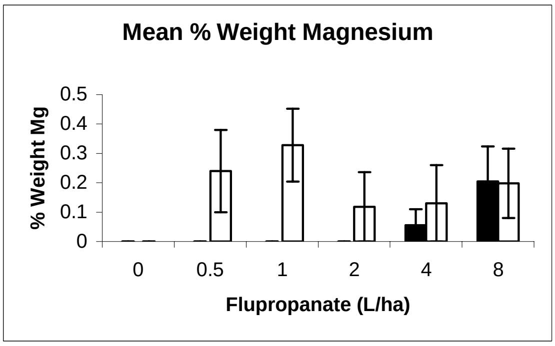
Screening F1 seedlings for resistance. Seeds were tested for resistance to flupropanate (Noble 1999) by placing firm, well formed seeds on Whatman 182 seed test paper in 9 cm diameter glass Petri dishes, moistening with 5 mL of 40 mg L^{-1} flupropanate as Taskforce® (75% a.i.) and incubating for 14 days at 25°C with a 12 h photoperiod supplied by two 'Fluora' tubes 15 cm from the seeds. Three randomised replicate Petri dishes, each containing 10 seeds, were used for each treatment. Control treatments had seeds wetted with distilled water. Standards of known resistant and susceptible seeds were included. Lost water was replaced three times a week. Petri dishes were re-randomised weekly. Shoot length was measured at 14 days.

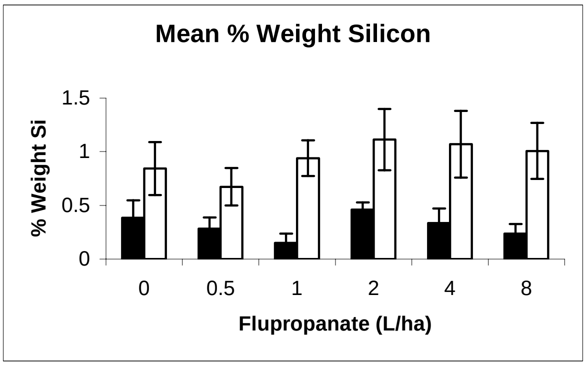
RESULTS

Mechanism of action. Root pieces of flupropanate-treated susceptible plants had greater concentrations of Al, Cr, Fe, Mg, Mo, Ni and Si at normal rates of application (≤2 L ha^{-1} Taskforce, 75% a.i.), than did resistant plants (Fig. 1). At >2 L ha^{-1}, both types of plant began to exhibit the same concentrations for some, e.g. Mg, but not others, e.g. Al, Si.. Concentrations of O were greater in resistant plants. Concentrations of C, Ca, Cl, Mn, P and K did not change between resistant and susceptible plants or with dose of flupropanate. There was no difference in the abundance of any element between resistant and susceptible leaf pieces.

Heritability. Three classes of resistance were detected: susceptible seedlings grew to 3- 4mm in 15 days, whereas fully resistant seedlings grew to 30-35mm and partially resistant seedlings grew to 12-15 mm (Fig. 2). Susceptible plants with pollen from susceptible plants produced only susceptible seeds (Table 1). Resistant plants with pollen from resistant plants produced a 1:1 ratio of fully:partially resistant seeds. The cross susceptible female x pollen from resistant plants produced a 1:9 ratio of resistant:susceptible seeds, whereas the cross resistant female x pollen from susceptible plants produced a 9:1 ratio of fully:partially resistant seeds and no susceptible seeds.







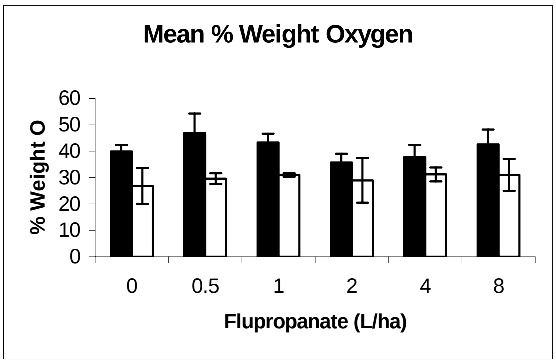


Figure 1. Effect of biotype and flupropanate concentration on content of Al, Mg, Si and O in serrated tussock roots. Black=resistant, white=susceptible plants. Bars=2 x SE.

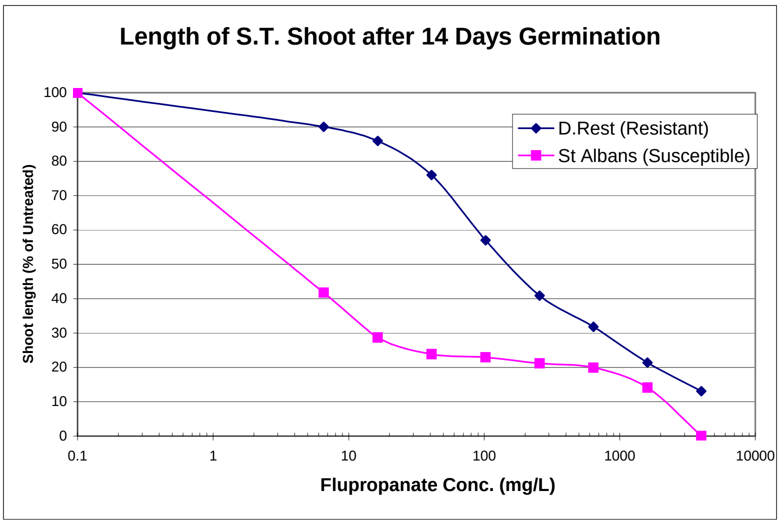


Figure 2. Effect of flupropanate concentration on shoot length of seedlings of two collections of serrated tussock seed. Values graphed are means of 4 replications, each of 50 seeds (McLaren *et al*. 2005).

Table 1. Resistance to flupropanate in progeny from controlled crosses of field-collected serrated tussock plants grown in a glasshouse, tested by Petri dish assay method with 40 ppm flupropanate. R=resistant, P=partially resistant, S=susceptible

Female parent	Male parent	Progeny (R:P:S)
S	S	0:0:30
R	R	16:14:0
S	R	1:2:27
R	S	27:3:0

DISCUSSION

Mechanism of action. The differences in content of some elements but not others suggests that flupropanate interferes with membrane structure and that resistance negates the effect. No chemical substance is able to free fluorine from any of its compounds (Gagnon Undated). This suggests that if the plant has taken up the herbicide, then fluorine will still exist as part of the flupropanate molecule somewhere in the plant. Otherwise the herbicide must still be in the soil environment. Flupropanate may affect the plant's ability to immobilise toxic ions, e.g. Al, or to clear excess minerals, e.g. Mg,. The lower concentration of O found in the susceptible plants may also indicate that flupropanate affects the plant's oxidative metabolism. Si in plants is associated with resistance to drought, salt and heavy metals (Kidd *et al.* 2001; Lux *et al.* 2002; Neumann and Nieden 2001) and Si also decreases the toxicity of Al in maize (Kidd *et al.* 2001) and of Fe and Mn in rice (Okuda *et al.* 1965). It is not clear why contents of Si are greater in susceptible than resistant plants at all flupropanate concentrations.

Future studies need to focus on X-ray analysis of mature plants at different times and concentrations after the application of flupropanate to see if the effects and trends change over time. An investigation into the rate of uptake of elements by both resistant and susceptible roots is suggested as it may indicate the effect of flupropanate on the plants or highlight an important physiological difference between the biotypes. Elemental mapping should also be employed to detect exactly where elements are accumulating in the cell and if the elements are immobilised into the cell walls or vacuoles.

Information on the transport and mode of action of flupropanate could also be derived from radioactively labelling the herbicide. It is possible to label the F or C in the flupropanate molecule, apply the herbicide to the plant and trace its path through the plant with the use of autoradiography. This would allow the metabolism to be followed and possibly the resistance mechanism to be found.

Heritability. These results are consistent with resistance being genetically determined, as phenotypes in progeny vary with parental phenotype. The 1:1 ratio of fully:partially resistant phenotypes in the F1 cross from resistant plants suggests that both homozygotes and homozygotes were involved (Table. 2).. The presence of fully and partially resistant plants from susceptible female parents suggests that resistance can be transferred by pollen. This is consistent with the recent finding (McLaren *et al*. 2005) that some seeds from plants collected on the roadsides surrounding the original property were resistant to flupropanate. This, in turn, suggests that resistance has spread from the site originally recorded to a distance of up to 4 km away, either by pollen or by seed in detached inflorescences. The lack of similarity in the ratios from reciprocal crosses suggests that both cleistogamous and chasmogamous seed were assayed, the resistant plants are a mixture of homozygotes and heterozygotes, or that there is a maternal component that affects the phenotype.

It is likely, however, that the number of seed assayed was too small to give accurate ratios. Greater numbers of plants need to be crossed to give accurate ratios and this is in progress. Also, raising the F1 plants to give an F2 generation will elucidate the nature of inheritance of the resistance and plants are currently being raised for this purpose from seeds that survived the seedling screening.

Table 2. Putative single gene mutation as genetic basis of resistance to flupropanate in progeny, assuming that RR=resistant, Rr=partially resistant, rr=susceptible

Female parent	Male parent	Expected ratio (RR:Rr:rr)	Actual phenotypes (R:P:S) (closest match)
RR	RR	all:0:0	-
RR	Rr	1:1:0	16:14:0 (good)
Rr	Rr	1:2:1	
RR	rr	0:all:0	27:3:0 (poor)
Rr	rr	0:1:3	
rr	RR	0:all:0	
rr	Rr	0:1:3	1:2:27 (poor)
rr	rr	0:0:all	0:0:30 (good)

ACKNOWLEDGMENTS

The authors wish to thank the property owner at Diggers Rest for his initial report of suspected resistance and for generously providing access and information for the collection of plants from his property and surrounding areas.

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GLOSSARY OF TERMS

- biomass – mass of dead and living plant material
- carrying capacity – a paddock's or farm's capacity to carry livestock, usually measured in Dry Sheep Equivalent (DSE) per hectare.
- chipping – use of a hoe to remove weeds
- cleistogene – seed that is self-pollinated and fertilised before the flower opens.
- DSE – annual energy requirements of an adult merino wether
- plant competition – competition to use available resources - light, water and nutrients
- exogenous - derived externally
- indigenous – of local origins
- inflorescence – cluster of flowers
- leaf sheath – tubular leaf base surrounding the stem at the node
- panicle – branched head of flowers
- perennial- surviving more than two growing seasons
- post-emergence – after seed germination
- pre-emergence – prior to seed germination
- quantitative – measuring by quantity
- regression – two variables that co-relate
- resistance – genetic mutation that no longer responds to herbicide
- rotation long/short – period of grazing followed by resting to allow regrowth
- spot spraying – single nozzle directed at individual plant
- stem nodes – growth node on the stem where leaves and flowers form
- stipoid – grasses of the family Poaceae: sub-family: Stipae
- unpalatable – not preferred by grazing animals, has either low nutritional value or digestibility or some physical barrier to grazing