Controlling variegated thistle in East Coast North Island hill-country

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Abstract

Variegated thistle can dominate north-facing slopes on North Island East Coast hill-country reducing pasture production and livestock carrying capacity. On a hill-country sheep and beef property near Gisborne, the herbicides 2,4-D + clopyralid were applied in early-May by knapsack in combination with a June aerial application of 2,4-D ester. This was more effective than a single June aerial application of 2,4-D ester in reducing the abundance of variegated thistle and enabling grasses from the seedbank to colonise the bare ground in the herbicide-treated patches. Mixtures of grasses, legumes and herbs, oversown onto bare patches previously occupied by thistle plants, did not establish on a north-facing slope. While they did establish on a south-facing slope, the sown species did not persist, most likely due to selective grazing. To establish competitive pasture, natural germination from the seedbank may be less risky than oversowing seed into thistle patches, if desirable species are present in the seedbank.

Keywords: *Silybum marianum*, weed control, herbicide, competition, competitive pasture species

Introduction

Variegated thistle (*Silybum marianum*) can severely reduce pasture productivity (Chambreau & MacLaren 2007). It is an annual that predominantly germinates throughout autumn (Khan *et al.* 2009) and flowers in late-spring producing over 6000 seeds/plant (Sindel 1991). The seeds are heavy (about 20 mg/seed), fall near the parent plant and can remain viable for at least 9 years in the soil (Roche 1991). The thistle can grow up to 2.5 m tall and form dense thickets on a range of aspects and slopes, suppressing the growth of desirable pasture species. The base of the flowers, stems and leaves have many sharp spines that promote livestock avoidance, affecting both production (lower utilisation of forage) and management (impeding livestock and vehicular movement) (Chambreau & MacLaren 2007).

In other situations, variegated thistle is considered highly productive and profitable. It is grown as a medicinal plant because it produces silymarin, which is extensively used in the pharmaceutical industry (Martin *et al.* 2006; Alemardan *et al.* 2013). As such, its potential use in New Zealand as a horticultural crop has

been explored. However, negative impacts of variegated thistle, as described above, have made it a declared pest plant in some regions such as the Gisborne District and, therefore, growing it for its medicinal properties is not an option.

Where variegated thistle plants form dense thickets and crowd out other pasture species in New Zealand East Coast hill-country, there may be little pasture cover remaining over summer after the thistle produces seeds and dies. This leads to conditions that favour thistle establishment in successive autumns; the bare ground can be easily recolonised from the seed in the localised soil seedbank. This cycle can lead to self-perpetuating thistle patches that gradually spread if control methods are not deployed (Roche 1991).

A range of control methods have been explored. Biocontrol has been largely unsuccessful (Bruzzese 1996). Goats have been successfully used in Australia and elsewhere (Davidson 1990; Stanley *et al.* 2000). Chemical herbicides can be effective (Glue & Matthews 1957; Dellow 1996), but are costly and can damage desirable pasture legumes or produce resistant populations of the thistle (Harrington *et al.* 2011). Further, chemical control alone without pasture improvement is of little use (Glue & Matthews 1957).

Control of variegated thistle using pasture management is a potential option, particularly during autumn when thistle seeds germinate, as they are particularly vulnerable to shading during establishment (Pook 1983). To develop a dense sward, it may be necessary to introduce seed of competitive pasture species into hill-country pastures where variegated thistle has become endemic, especially in old thistle patches where much bare ground is present over summer. A dense sward may be produced from species that are productive and grow vigorously, such as perennial ryegrass (*Lolium perenne*), plantain (*Plantago lanceolata*) and prairie grass (*Bromus willdenowii*) or that are considered to be less productive, but form a dense mat, such as browntop (*Agrostis capillaris*) or some fescue species (*Festuca* spp.). Whatever the choice, consideration must be given to their suitability for the environment in which they are to be grown. Additionally, the timing of herbicide application can be manipulated to increase desirable pasture cover and obtain greater control of variegated thistle (Robertson 1955; Duncan 1963). Spraying the thistle with herbicide

Figure 1 Rainfall (bars), average maximum and minimum temperature and 20-year average (1995-2015) rainfall for Tangihanga Station.

early in autumn should remove them from the sward when they are smaller and have had less opportunity to crowd out other pasture species. However, this may necessitate multiple herbicide applications if the germination period is prolonged; thistle that germinates and establishes after the first application may still pose a major threat to pasture productivity. Another potential benefit of earlier application is that a greater range of herbicides can be used on the smaller thistle plants, including ingredients which are less harmful to legumes.

To investigate control options for variegated thistle in East Coast hill-country, a range of treatments were compared from 2016 to 2018. This included different combinations of competitive or mat-forming pasture species and variation in the timing and type of herbicide application, aiming to increase pasture cover and reduce thistle populations. The hypothesis tested was that a greater cover of competitive pasture species in autumn (by either introduction of pasture species and/or earlier application of herbicide to manipulate the sward composition) will reduce thistle populations and thereby improve the pasture botanical composition.

Methods

Site

The study sites were on Tangihanga Station near Gisborne (38° 33' 25" S 177° 53' 17" E), a 2000 ha mixed sheep and cattle breeding and finishing hill-country unit. It is a summer-dry environment with a 20-year average summer rainfall (December to February) of 169 mm and average annual rainfall of 1166 mm (based on interpolation of the NIWA CliFlo database, Figure 1). Rainfall was below average in autumn 2016 (183 versus 240 mm long-term), below average in summer 2016-2017 (132 versus 169 mm long-term) and

above average in summer 2017-2018 (203 versus 169 long-term).

Soil test results were not available for the specific experimental sites, but the most recent farm soil test results (September 2014) were: pH = 5.6, Olsen P = 14 mg/kg, QT K = 7.2, QT Ca = 5.9, QT Mg = 17.2, Sulphate S = 2.6 mg/kg.

Thistle patch characterisation (2016) - Experiment 1

To determine to what extent variegated thistle could replace pasture species

and form dense patches, the botanical composition of three large (each >1.0 ha), randomly chosen, thistle patches on northerly aspects in each of six paddocks (3 patches/paddock), were assessed using a point quadrat method, on 20th December 2016. The northerly aspect was chosen as this was where the variegated thistle was most prevalent and formed the densest patches. In each patch, the identity of the plant species (at ground level) was recorded at 1 m intervals along a 10 m chain transect (Power 1991). This was done for 10 parallel transects separated by 1.5 m, giving a total of 100 points in each patch.

Productive pasture species establishment (2016-2017) - Experiment 2

The establishment success of three hand-broadcast multi-species mixes was determined on a moderately-sloped (15-25°) northerly aspect in one paddock and southerly aspect in another. Treatments comprised three mixes (legume only, and two combinations of grasses, legumes and herbs) and an unsown resident control (Table 1). The species included were subterranean clover (*Trifolium subterraneum*), white clover (*Trifolium repens*), balansa clover (*Trifolium michelianum*), grazing brome (*Bromus stamineus*), perennial ryegrass, cocksfoot (*Dactylis glomerata*), plantain and chicory (*Cichorium intybus*). The sown species were used at the same seed rate in all three treatments (Table 1). Treatments were established in 5×5 m plots in a randomised complete block with four replicate blocks positioned down the hillside.

Paddocks were grazed by Coopworth ewes to a residual of about 1500 kg DM/ha preceding aerial spraying with paraquat on 7th May (200 g/ha a.i. in 200 L water). This achieved sward suppression with grass browned-off and about 1000-1200 kg DM/ha of wilted

cover remaining at sowing.

Seed was hand-broadcast on 12th and 13th May 2016 on the southerly and northerly aspects, respectively. The southerly aspect site was trampled by 1300 ewes on 12th May, with the mob run 10 times across the paddock section in which the plots were located. The soil of the northerly aspect site was too dry for trampling so this was postponed until 30th May after 12 mm of rain using the same procedure as for the southerly aspect site. Slug bait was applied at the time of sowing and also on 19th July at a rate of about 20 kg/ha (18 g/kg metaldehyde).

Seedlings were counted on 18th July 2016, in ten random 15×10 cm quadrats in each plot. Herbage production was estimated using 20 rising plate meter readings per plot (Farmworks Plate Meter F200). The plate meter was calibrated using the industry recommended all-year calibration: Compressed pasture height × 140 + 500 (Thomson & Blackwell 1999; Lile *et al.* 2001; Anon 2008). The proportion of each sown species in total herbage dry matter was assessed on 17th October and 6th December 2016 and 22nd March 2017, in twenty 40×25 cm quadrats in each plot using the BOTANAL method, a dry weight ranking method involving visual estimation of the first, second and third most dominant species in the sward (Tothill *et al.* 1992). Pre-determined multipliers based on multiple pasture cuts were then used to estimate the contribution of each species to total herbage dry matter (Jones & Hargreaves 1979; Tothill *et al.* 1992).

Productive pasture species and thistle control (2016-2017) - Experiment 3

A site was established on the northerly aspect (in the same paddock as Experiment 2) to test whether the oversown mixes could suppress the establishment of variegated thistle. Old thistle patches (aerial sprayed with a helicopter in June-July 2015) were randomly

identified and seed mixes were hand-broadcast within these patches on 13th May 2016, after all live thistle plants were removed by hand roguing. Thistle patches were identified by the presence of pieces of old thistle stem lying on the ground.

Treatments, comprising the same four and seven-species mixes (Table 1) and resident pasture as a control, were established in a randomised complete block with seven replicate blocks positioned down the hillside within seven randomly selected old thistle patches. Plots were 5×5 m. The same establishment and measurement protocols (including the same dates) were followed as for the pasture establishment study.

Integrated control (2017-2018) - Experiment 4

Combinations of herbicide application and oversowing with competitive pasture species to control variegated thistle were compared. The three treatments were ‘early application’ (2,4-D + clopyralid applied by knapsack), ‘early application + oversowing’ (glyphosate by knapsack + oversowing a fescue-browntop mix) and ‘late application’ (2,4-D ester by aerial application, Table 2). The whole property (2000 ha) progressively received a late aerial application of 2,4-D ester (2 L/ha), from 29th June 2016 till the end of July 2017. Hence herbicide was applied twice in the early application treatments (May and July) but only once in the late application treatment (July). The oversown pasture mix was Duraturf Traditional™, comprising 5% by weight of browntop (*Agrostis capillaris*) and the remainder equal portions of creeping fescue (*Festuca rubra* subsp. *rubra*) and Chewings fescue (*Festuca rubra* subsp. *commutata*). This mix was chosen as it grows in low fertility conditions, is not highly palatable for livestock and thus less likely to be selectively grazed, and forms a thick mat of grass to help suppress thistle emergence. A germination test of the mix at 25°C yielded a germination percentage of 64% of seed after 19 days.

Treatments were applied in six of the paddocks used to characterise thistle patches (Experiment 1). Three large (>1.0 ha) thistle patches were randomly selected on northerly aspects in each paddock, and treatments applied in a 6×6 m plot in the centre of each patch. The design was a randomised complete block, with six replicate paddocks.

Herbicide was applied on 8th May 2017 (as per Table 2) and the Duraturf Traditional™ seed mix was oversown at a rate of 40 g/m² (400 kg/ha) 17 days later on 24th May, allowing a 2 week gap to ensure that sown grass seedlings were not affected by the herbicides. After hand-broadcasting, plots were trampled by foot and a heavy chain dragged multiple times (>10) across each plot to increase seed-soil contact.

On 8th May 2017 at the time of the early herbicide application, variegated thistle plants were counted

Table 1 Species sown on a northerly and southerly aspect in three hand-broadcast multi-species mixes on a hill-country property near Gisborne in Experiments 2 and 3.

Species	Sowing rate (kg/ha)	Control*	2 species	4 species	7 species
Subterranean or white clover **	9		X	X	X
Balansa clover	6		X	X	X
Grazing brome	20			X	X
Perennial ryegrass	16				X
Cocksfoot	4				X
Plantain	2			X	X
Chicory	2				X

*Control: resident pasture. **A late flowering subterranean cultivar was sown on the North aspect and white clover on the south aspect.

in sixteen 25×40 cm quadrats in each plot and ground cover of the thistle, grasses, legumes and broadleaf weeds visually assessed. On 28th June 2017 (51 days after herbicide was applied in the ‘early application’ treatments), three measurements of treatment effectiveness were made: variegated thistle plant population density, percentage control (a score estimating the percentage of thistle visually affected by the herbicide), and the percentage cover of bare ground. Further thistle population density and ground cover assessments were undertaken on 13th September 2017 and 20th March 2018.

Results

Thistle patch characterisation (2016) - Experiment 1

When assessed on 20th December 2016, thistle plants were senescent; thickets of stems were present with shrivelled leaves at the base of the dense thistle stands. Grasses other than perennial ryegrass (e.g., browntop and *Rytidosperma* spp.) were the most abundant component in thistle patches, averaging 51% of ground cover (range: 11-84%) then variegated thistle plants averaging 44% (range 11-77%). Perennial ryegrass averaged 4% (range 0-10%) and bare ground 1% (range 0-10%).

Productive pasture species establishment (2016-2017) - Experiment 2

Oversown forage grasses, legumes and herbs sown in late-autumn 2016 did not establish on the north-facing aspect; there was no difference ($P>0.05$, data not shown) in seedling densities of oversown pasture species between any of the treatments and the unsown control in July 2016 or in their ground cover in October 2016, after which time measurements were discontinued.

On the south aspect, seedling densities of perennial ryegrass, cocksfoot, plantain and chicory were higher in the seven-species mix than in the control in July

2016, with 55 total sown seedling/m² ($P<0.05$, Table 3). The percentage of white clover as a proportion of total dry matter was greater in the seven-species mix than in the control in October 2016, as was the percentage composition of plantain in December 2016 ($P<0.05$, Table 3). No other differences between sown treatments and the unsown control were detected in October 2016 or in March 2017. By March 2017, unsown low palatability grasses, predominantly browntop and *Rytidosperma* spp., comprised 61% of the total dry matter.

Available dry matter averaged 2400 and 1510 kg DM/ha in September 2016 and December 2016, respectively, and there was no difference in pasture production between any of the sown treatments and the unsown control ($P>0.05$). Cattle were in the paddock during the March 2017 assessment when the available pasture dry matter was lower in the seven-species mix than in the unsown control (1360 versus 1570 kg DM/ha, $P<0.05$).

Productive pasture species and thistle control (2016-2017) - Experiment 3

Oversown pasture species established in the thistle patches, but did not persist beyond the first year and were thus unable to suppress variegated thistle. Seedling densities of balansa clover, plantain and total sown species were greater in the four and seven-species mix than in the unsown control in July 2016 (Table 4). Total sown seedlings averaged 21 plants/m² in the oversown treatments, but only 2 plants/m² in the unsown control, where some ryegrass seedlings emerged from the seedbank (Table 4). By October 2016, the percentage of perennial ryegrass in total dry matter was over four-fold greater in the seven-species mix than in the unsown control, and the total percentage of sown species was over five-fold greater in the seven-species mix compared to the unsown control. However, by the following autumn (March 2017), there were

Table 2 Herbicides applied to control variegated thistle on a hill-country property near Gisborne in autumn and winter 2017 in Experiment 4. Pasture Guard herbicide was applied at a rate of 2 L/ha.

Product name (active ingredient)	Method	Water rate (L/ha)	Applied	Treatment		
				Early application	Early application + oversowing	Late application
Pasture Kleen 680 (2500 g 2,4-D ester/ha) + Versatill 300 (100 g clopyralid/ha)	Knapsack	150	8 May	X		
Weedmaster TS540 (200 g glyphosate/ha)	Knapsack	150	8 May		X	
Pasture Guard (680 g 2,4-D ester/L)	Aerial	100	July	X	X	X

no differences in species composition between the oversown treatments and the unsown control ($P>0.05$, data not shown).

Although all variegated thistle seedlings were removed from the plots at the time of sowing in March 2016, new thistle seedlings averaged 1% of total dry matter in July 2016, 5% in October 2016 and 3% in March 2017. There was no difference between the oversown treatments and the unsown control in the ground cover of variegated thistle.

Integrated control (2017-2018) - Experiment 4

In May 2017, before herbicide application, the plant density of variegated thistle seedlings was similar in all three treatments, averaging 27/m². On 28th June 2017 (51 days after herbicide was applied in both ‘early’ treatments), variegated thistle plants comprised <2% of total ground cover in the early application treatments, but 89% of total ground cover in the ‘late application’ treatment ($P<0.001$, Table 5). In contrast, bare ground was greater in the early application treatments (25 and 67%) than the late application treatment (2%) in which

thistle plants had not yet been sprayed ($P<0.001$, Table 5). The thistle control score also indicated that the early application had been effective, with an average of 98% of plants affected in the early treatments.

By September 2017, herbicide applications had reduced thistle densities to less than one plant/m² in both early application treatments and four plants/m² in the late application treatment. By the following autumn (2018), new variegated thistle plants had emerged and there was no difference between treatments in thistle population density, averaging six seedlings/m² and occupying 14% of total ground cover ($P>0.05$, Table 5).

There was no effect of oversowing the fescue-browntop seed mix on the botanical composition of the sward. There was no difference between the early-spray and early-spray + oversowing in fescue-browntop ground cover (data not shown) or total grass ground cover on any of the assessment dates ($P>0.05$, Table 5).

By September 2017, grass species that emerged from the seedbank had replaced the thistle in the early application treatments and occupied the bare ground, averaging 71% of total ground cover in the early

Table 3 Seedling establishment and percentage of total dry matter of individual and total sown species in swards oversown with two, four and seven-species mixes and in the unsown resident pasture (control) on a south aspect of the hill-country property near Gisborne in Experiment 2. Means in bold are greater than those in the control ($P<0.05$).

Measurement	Month	Species	Control	2-species	4-species	7-species	SED	F prob
Establishment (seedlings/m ²)	July 2016	White Clover	12	24	24	25	9.5	NS
		Plantain	0	0	0	12	2.3	0.002
		Chicory	0	0	0	4	0.2	<.001
		Cocksfoot	0	0	0	2	0.3	<.001
		Perennial ryegrass	0	0	0	13	2.3	0.001
		Total sown species	12	24	29	55	10.1	0.013
Composition (% of total DM)	October 2016	White clover	5	12	13	20	3.7	0.015
	December 2016	Plantain	0.1	0.5	1.3	3.2	0.86	0.024

NS = not significant

Table 4 Seedling establishment and percentage in total dry matter of oversown four and seven-species mixes in variegated thistle patches on the hill-country property near Gisborne on a southerly aspect in Experiment 3. The control was unsown pasture. Means in bold are greater than those in the unsown control ($P<0.05$).

Measurement	Date	Species	Control	4-species	7-species	SED	F prob
Establishment seedlings/m ²	July 2016	Balansa clover	0	6	5	2.1	0.027
		Plantain	0	8	8	2.8	0.024
		Total sown species	2	21	20	6.8	0.024
Composition (% of total DM)	October 2016	Perennial ryegrass	10	15	44	12.6	0.034
		Subterranean clover	0	3	1	0.6	<.001
		Unsown grasses	84	74	42	12.5	0.011
		Plantain	0	4	6	1.1	<.001
		Total sown species	10	22	51	12.8	0.017

application treatments and only 21% of total ground cover in the late application treatment ($P<0.001$, Table 5). Of the grasses, perennial ryegrass was the dominant species, and to a lesser extent browntop, sweet vernal (*Anthoxanthum odoratum*), *Microlaena* and *Rytidosperma* species. Grasses continued to dominate the swards, averaging 64% of total ground cover in the early application treatments, but only 31% of total ground cover in the late application treatment in March 2018 ($P<0.05$, Table 5). There was a trend towards greater broadleaf weed content and more bare ground in the late application than in the early application treatment, measured in March 2018. However, differences between treatments were not significant due to the high variability between the six replicate paddocks ($P>0.05$). Variability between paddocks was exacerbated by livestock impacts. For example, in two of the paddocks, livestock trampling and pugging of early application treatment plots were noted in June and September 2017.

Discussion

In the absence of effective management, variegated thistle formed dense patches by late autumn, after which other pasture species were crowded out until the thistle plants senesced in late summer. This was demonstrated in Table 5, which shows that thistle ground cover was 87% by May and 89% by June 2017, but only approximately 50% of ground cover in December when the plants were senescent and the grass cover had increased. Despite the strong competitive pressure from the variegated thistle population, some perennial ryegrass plants were able to grow and were present as thistle plants died. These grasses appear to be important as they were able to set seed while protected by the variegated thistle plants and this seed was observed to be critical to regenerating pasture. The severe impact of variegated thistle on pasture production emphasises the importance of preventing its establishment, whether through judicious use of herbicide or other means, such as maintaining a competitive pasture sward and dense cover to reduce thistle establishment.

Table 5 Variegated thistle density and ground cover of variegated thistle, grasses, broadleaved weeds and bare ground in three herbicide application treatments on the hill-country property near Gisborne in Experiment 4. Early application: knapsack applied 2,4-D + clopyralid in May 2017 and Early application + oversow knapsack applied glyphosate + oversowing (hand broad-casting) of a fescue-browntop mix on 8th May 2017. Late application: aerial application of herbicide to the whole property in July 2017. Means in bold are different to those in the unsown control ($P<0.05$).

Measurement	Date	Late application	Early application	Early application + Oversow	SED	F prob
Variegated thistle density						
Thistles/m ²	May 2017	34	20	28	5.7	NS
	Sept 2017	4	<1	<1	1.4	0.04
	March 2018	4	5	9	2.5	NS
Control score	June 2017	0	96	99	2.0	<0.001
Ground cover (%)						
Thistle	May 2017	87	79	70	7.1	NS
	June 2017	89	2	<1	3.3	<0.001
	Sept 2017	49	<1	<1	13.7	0.007
	March 2018	16	8	17	8.8	NS
Grasses	May 2017	13	21	30	7.1	NS
	Sept 2017	21	76	66	9.9	<0.001
	March 2018	31	66	62	11.9	0.031
Weeds	May 2017	0	0	0	-	-
	Sept 2017	<1	0	0	-	-
	March 2018	29	13	9	11.2	NS
Bare ground	May 2017	0	0	0	-	-
	June 2017	2	25	67	7.8	<0.001
	Sept 2017	29	24	34	9.6	NS
	March 2018	24	12	11	6.2	NS

NS = not significant

The studies undertaken provided limited evidence for the hypothesis that a greater cover of competitive pasture species in autumn will reduce thistle populations. Oversowing competitive pasture species was not successful. The poor persistence of the oversown mix on both north and south aspects where the oversown species established, was most likely due to selective grazing by sheep. The operator observed on several measurement dates that the sown species on the south aspect were defoliated by the livestock to a much greater extent than the unsown control and surrounding pasture, which is consistent with lower herbage production in the seven-species mix than the unsown control in March 2017. Productive pasture species such as perennial ryegrass, cocksfoot and legumes have a higher nutritive value and are more palatable than species such as browntop (Fulkerson *et al.* 2007; Lambert & Litherland 2000) that were present at the field site where it formed a thick mat with a high proportion of dead material of low nutritive value. Based on these results and the problem of selective grazing, oversowing desirable pasture species into larger patches (>1 ha) of variegated thistle after herbicide application is unlikely to succeed.

The approach of oversowing the fescue-browntop mix was also unsuccessful, since it did not establish. This may be due to other species in the seedbank being more competitive and being better able to establish at lower temperatures associated with a late autumn sowing date (e.g. perennial ryegrass, Wright *et al.* 1978). Earlier application of herbicide (i.e. in April) and oversowing of browntop when soil temperatures were higher may have been more successful; further studies on timing of herbicide application and oversowing are required.

Both the early and late herbicide application treatments successfully reduced the variegated thistle densities in the following autumn but did not eliminate them totally. This lack of difference between treatments in the low thistle densities emphasises the need for repeat treatment of infested areas over subsequent years given that variegated thistle seed can remain viable in the seedbank for many years. Some studies have found that seeds last for 10 years in the soil, although seed viability declines rapidly over the first few years (Bruzese 1996). This indicates that surveillance and removal of survivors in the first few years after a thistle control program is particularly important.

Although the integrated control study did not provide evidence for the hypothesis with respect to oversowing competitive pasture species and reducing thistle populations, some of the herbicide treatments applied successfully improved botanical composition. At the time of designing the study, the intent was to apply a control treatment of untreated variegated thistle

in addition to the two knapsack applied herbicide treatments. Variegated thistle infestations over the farm were particularly severe in autumn 2016 (covering up to an estimated 15% of individual paddocks) and it was concluded that the negative impact on the farm would be too great if the six paddocks in which the plots were established had to forgo an aerial application of herbicide. Thus the control became 'aerial herbicide application only', and it was the difference in timing between the aerial and knapsack applied treatments that had the greatest impact on botanical composition.

The major difference between the treatments was that grasses recolonised the sward to a greater extent in the patches after early applications of herbicide. So by September, the bare ground had been replaced by grasses which resulted in three times as much grass cover produced from an early than a late application. This is not surprising given that the thistle plants were a month younger and smaller and temperatures were warmer at the time of the early application treatment. This is in contrast to the late application of herbicide in June, when little grass was present in the sward and 89% of the ground cover comprised thistle and temperatures were cooler. Warmer temperatures would facilitate greater growth of grass from the seedbank (in the early application treatment receiving glyphosate) and from the seedbank and existing grass plants (in the early application + oversow treatment where selective herbicide was used). The principle of working with the desirable pasture species in the soil seedbank has also been investigated by Maxwell *et al.* (2014) in South Island hill-country. They demonstrated how adventive clovers contributed more than oversown clovers to the total pasture biomass. The species emerging from the seedbank are more likely to be adapted ecotypes than those of oversown species (Wedderburn *et al.* 1996), which will contribute to their establishment success and persistence. In a recent study located on the same property as reported here, James & Tozer (2018) found sufficient seed of perennial ryegrass and legumes in the soil seed bank to regenerate pasture after removal of variegated thistle.

There was large variability between replicate paddocks, which affected the statistical significance of the results. In a number of early application plots, livestock trampling and pugging could have impeded grass growth. It appears that the livestock (bull beef) were attracted by the thistle-free sprayed plot areas in the dense large patches and congregated there. By contrast, in the late application treatment, the entire thistle patch inside and outside the plot area was similarly affected by the herbicide, and there was no visual evidence of stock congregating in the late application treatment plot areas. This observation demonstrates how there can be unintended consequences of applying treatments at

a plot scale within a paddock, leading to interactions with livestock that can override the effect of the actual treatment. These interactions must be taken into account when interpreting results. Despite this difficulty, the impact of the herbicide on the pasture composition was statistically evident.

Conclusions

There are frequent summer droughts and variable autumn rains in North Island East Coast hill-country, which makes control of variegated thistle difficult. Given the failure of the oversowing treatments, but the significant herbicide effects, it is concluded that timing of application of herbicide to whole thistle patches should be prioritised and that oversowing of patches is risky due to establishment failure or selective grazing. A better strategy may simply be allowing the seedbank or existing grasses in the sward to fill the gaps by applying herbicide earlier when thistle rosettes are small. Further, repeat chemical application over several years, taking into account the need to avoid the evolution of herbicide resistance in the thistles, will likely be required given that the variegated thistle seedbank is persistent.

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