

The impact of cutting prior to goat grazing on variegated thistle (*Silybum marianum*)

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Abstract Variegated thistle (*Silybum marianum*) is a prevalent weed on the East Coast of the North Island of New Zealand. Goats may provide a novel management tool to control thistles, but little is known about how cutting thistles prior to grazing affects thistle consumption by goats. This study investigated the extent to which goats consume either uncut entire variegated thistle plants or cut thistles. Eight groups of three goats were presented with thistle vegetation in each of two replicate 1-hour feeding sessions on 2 consecutive days. Averaged over both days, in the cut treatment, goats consumed 99% of the leaves that had been removed from the thistles and reduced the ground cover of the thistle plants by 68%. In the uncut treatment, ground cover of the thistles was reduced by 46%. A combination of cutting and goat grazing is likely to be a useful tool for stopping variegated thistle debris from smothering pasture and for inhibiting seed setting. Further work is required to test this at paddock scale.

Keywords Variegated thistle, novel weed control, Saanen, thistle management, hill country, weed control

INTRODUCTION

With the expansion of dairy farming, as well as escalating costs of farming in general, sheep and beef farmers must obtain greater value from New Zealand hill country for their farms to remain viable. A major constraint is the prevalence of pernicious weeds that compromise pasture growth and increase herbicide costs. Thistles are perhaps the most significant weed of hill country, infesting millions of hectares of hill-country pastures throughout the North and South Islands (Bourdôt et al. 2007). In some areas, variegated thistles (*Silybum marianum*) are a particular problem. For example, in the East Coast of the North Island, variegated thistles are classified as a “progressive containment and a sustained control weed” (Gisborne District Council 2019). With increasing concern over environmental stewardship and consumer preference for non-chemical control methods, cost-effective and environmentally sustainable control methods are

required.

On less steep country, mowing has been shown to be effective (Bourdôt & Rural News Group 2015). Repeated mowing will reduce thistle populations but timing is important and the thistle clippings can smother the pasture. This approach is, however, not feasible for steeper country. In hill country, manual cutting and slashing have been the main alternatives to herbicide. Using browsing animals like goats, however, may be an effective and less labour-intensive option.

Some studies have shown that goats graze variegated thistles and can reduce their prevalence in pasture. In degraded pastures in Australia dominated by barley grass (*Critesion murinum*), brome grasses (*Bromus* spp.) and wild oats (*Avena fatua*), mixed grazing with two-thirds Cashmere goats and one-third sheep reduced thistle growth when compared to grazing with sheep alone. Compared to sheep-only grazing, mixed stocking

reduced the diameter and height of the thistles during the vegetative stage and the number of seed heads per plant from 27 to 3 during the reproductive stage (Holst & Allan 1996). Further, in swards grazed by sheep, variegated thistle ground cover increased from approximately 10% to 40% between July and December, while that in goat-grazed swards declined from 10% to near 0% over the same period (Holst & Allan 1996). Goats also had a strong effect on thistle stem density and flowering frequency in New Zealand pastures (Rolston et al. 1981). Defoliation of rosettes was limited but became intensive once the reproductive phase began for three species of thistles (Californian (*Cirsium arvense*), marsh (*C. palustre*) and Scotch thistle (*C. vulgare*)). Goats actively select seed heads (Stanley et al. 2000) and when the seed heads are ingested by goats only 0.5% of the thistle seeds that are excreted are viable (Harrington et al. 2011). Survival of seed in the soil seedbank is at least nine years (Bruzzese & Darby 2002), so sustained prevention of seeding is likely to be required over large areas to have significant impacts on thistle re-infestation of pastures. As variegated thistle mainly behaves as an annual (James & Tozer 2018), preventing flowering and seed dispersal is critical for the control of this weed. These results suggest that goats could be a useful tool to reduce variegated thistle populations in New Zealand hill country.

In principle, integration of grazing and cutting may provide even better control of variegated thistle in flatter country (mow+graze) as well as in steeper country (cut+graze). If thistles are cut late in the season, before reproductive development (i.e. before the flowering stems start to elongate), it may be possible to prevent flowering, since thistle plants may have insufficient time to regrow and produce as many viable seeds (Davidson 1990; Dodd 1989). Using goats to graze the thistle clippings would reduce the impact on pasture growth by limiting the shading of desirable pasture species. However, this integration of grazing and cutting has never been experimentally tested. Therefore, a proof-of-concept study was set up to investigate the relative

palatability of cut variegated thistle vegetation versus intact (uncut) thistle plants to goats.

METHODS

Trial site

The trial took place at Ruakura Research Centre near Hamilton. The site consisted of pastures >25 years old, comprising mainly of perennial ryegrass (*Lolium perenne*), paspalum (*Paspalum dilatatum*), browntop (*Agrostis capillaris*) and broad-leaved plantain (*Plantago major*). The soil type was a Hamilton clay loam with a pH of 5.7 and an Olsen P of 21 mg/L. Monthly rainfall in October, November, December, January, February and March was 53, 78, 186, 23, 14 and 29 mm, respectively (based on data from the Ruakura weather station). Rainfall was below the long-term average of 66 mm for February and above the long-term average of 102 mm for December. On average this period was 12-mm drier per month than the 25-year average (1991–2015).

The trial consisted of three phases:

1. Thistle Sourcing, Establishment and Management.
2. Goat Acclimatisation – the goats were fed leaves cut from transplanted plants to introduce them to thistle leaves wilted for various lengths of time.
3. Feeding Phase – the goats grazed plants established from seed to assess the relative palatability of attached leaves and cut wilted leaves, and to test the effect of grazing and mowing on the survival of the plants.

Thistle source, establishment and management

Live thistles and thistle seeds were collected from the same farm, ~20 km north of Gisborne.

For the Acclimatisation Phase, live variegated thistle plants (rosette diameter approx. 15 cm, root depth around 10 cm) were removed in October 2018, kept moist and transplanted into a paddock at Ruakura within 2 days.

For the Feeding Phase, variegated thistles were grown from seed collected in summer 2016. One hundred and twenty variegated thistle seeds were

sown on 20 September 2018 (one per pot 7 cm x 7 cm x 8 cm deep) in potting mix and watered daily to drip point. Plants were maintained in a glasshouse with ambient light conditions. The temperature in the glasshouse was maintained between a minimum of $15^{\circ}\text{C} \pm 1^{\circ}\text{C}$ and maximum of $25^{\circ}\text{C} \pm 1^{\circ}\text{C}$. The germination percentage was 96%, with 116 of the 120 thistle seeds germinating within a 48-hour period within 3 days of sowing. Thistle seedlings were planted into the field site on 24th October 2018 when they had two true leaves. A total of 64 seedlings were planted, eight in each of the eight replicates, with a survival rate of 97%. Pasture and the top 5 mm of soil was removed with a spade within a 30 cm² area and the soil cultivated to a depth of 30 cm. A thistle was planted into the centre of each prepared area and irrigated with 500 mL water.

All thistles had Thrive fertiliser (Yates, New Zealand) applied weekly until the beginning of November (at a rate of 90 g/L in 500 ml water, N: 25.0, P: 5.0, K: 8.8%w/w + trace elements). From November, Thrive for Flowering Plants fertiliser (N: 14, P: 2.6, K: 21%w/w) was applied weekly at the same rate until the Feeding Phase began in February. Slug bait (SlugOut, active ingredient 15 g/kg of metaldehyde; NuFarm NZ) was applied at the recommended rate. Feeding Phase thistles were on average 65 cm in width and 14 cm high at the beginning of the Feeding Phase and no thistles had bolted.

Goat acclimatisation

Female Saanen-cross, 4 to 6-year-old, non-lactating goats from the Ruakura herd were used as they were familiar with the paddocks and facilities in the trial. Acclimatisation of the goats to the thistle treatments was done in a pen (3.6 m W x 4.8 m L x 1.8 m H). Each group of three goats went into an indoor pen in the same order, beginning at 0830 each day. The goats were exposed over 4 consecutive days to each of the four thistle forage treatments (fresh-cut thistle, or Cut 1, 2 or 3 days before feeding). On the fifth day, the goats were offered all the thistle treatments simultaneously. For all thistle treatments, leaves

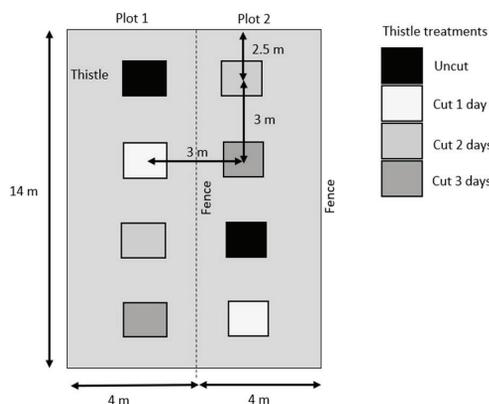


Figure 1 Replicate and paired plot design. Treatments were applied randomly in each of the 8 replicates. Goats had access to one plot on day 1 and the other plot on day 2. The remainder of the plot is mown pasture and the replicates were fenced using a 4-wire electric fence.

were chopped up and 2–3 pieces (approx. 6 g) were presented in identical containers. After each day of acclimatisation, the goats were given *ad libitum* access to pasture. At 1600, they were taken off the pasture and provided with a half bale of grass hay.

Feeding phase

The design was a randomised complete block design, with eight replicates each of two paired plots (Fig. 1). Goats were assigned randomly to the replicates as eight groups of three animals each – goats remained in their same group of three from the acclimatisation period. Each group had access to one of the plots of each pair on the first day (21 Feb) at 0900 for 1 hour, after which they were moved into a neighbouring paddock. The goats grazed the remaining plot of each pair on the second day (22 Feb).

There were four thistle treatments within each 14 m x 4 m plot: Uncut or Cut 1, 2 or 3 days before feeding. For the Cut treatments, approximately half of the leaves of each thistle (average 47 g) were excised at the junction between the leaf and stem and left on the ground where they “fell” next to the thistle from which they were cut. Thus, each ‘Cut’ treatment comprised a mixture

of excised and attached leaves, simulating a damaged thistle plant. Thistles were positioned along a longitudinal transect down the centre of each plot, with 3 m between each thistle base and a 2.5 m gap between the end of the transect and the fence (Fig. 1). The pasture in each plot was mown to 4 cm (~1100 kg of dry matter/ ha) and grass clippings removed the day before the beginning of the Feeding Phase, so that goats had negligible pasture available.

Three days after the end of the Feeding Phase, all thistles in the Cut treatments were cut off at ground level to simulate normal mowing techniques. Thus, the Cut-1 treatment was mown again five days after initial cutting, the Cut-2 treatment at 6 days and the Cut-3 treatment at 7 days.

Measurements

The height and diameter (widest point of rosette) of each thistle was measured before and after each Feeding Phase. Plant survival was recorded before the Feeding Phase began and periodically up to 4 weeks afterwards.

The percentage ground cover of each thistle plant in the plot was assessed using a 1 m² quadrat with 5 x 5 cm cells. The thistle herbage was photographed within a 1 m² quadrat and analysed in the program 'Image J' (National Institutes of Health, USA) to quantify the ground cover both before and after grazing, and to calculate the reduction in ground cover during grazing. Variegated thistle plants were scored for vigour before grazing: 1 = green; 2 ≤50% of the total number of leaves were yellowing; 3 >50% of total number of leaves were yellow or dead.

To assess the palatability of thistle leaves that were attached or had been cut and wilted, a 'typical' leaf was selected from each treatment, excised if necessary, weighed and the leaf photographed on a white background for measurement of leaf curvature before snap-freezing in liquid nitrogen. Samples were stored at -20°C prior to freeze drying. Each dried leaf was ground in a Cyclone Sample Mill (UDY Corp., USA) with a 1 mm sieve and bulked with the same treatment from another replicate (to give a total of four bulked

samples for each treatment for the first day of the Feeding Phase). Low and high molecular weight water soluble carbohydrate analyses were done using the anthrone method (Thomas 1977), which was modified to use a combined water and ethanol-based extraction procedure (Parsons et al. 2004). For leaf-curvature analyses, a line was drawn on each photo in the computer program 'R studio' (R studio Inc.) depicting the curvature of the central midrib of each thistle leaf in a two-dimensional (X-Y) plane. The X and Y coordinates at centimetre intervals along the curve were recorded for subsequent statistical analyses.

Statistical Analysis

Data were analysed by analysis of variance using Genstat (18th edition) with a split-plot design that fitted paddock, replicate within paddock and grazing plot within replicate as random variables, and thistle treatment as the fixed variable. There was no difference between the first and second day in any of the variables measured so data were averaged over both days and the averages analysed. Plant-survival data were analysed by a binomial regression with fixed dispersion of 1. A mixed model smoother function was used to estimate the influence of the number of days since the thistle was cut on the leaf curvature.

RESULTS

At the beginning of the study, all variegated thistle plants were vegetative with an average diameter of 65 cm and height of 14 cm. The proportions of green, senescing and dead leaves were similar in all treatments before grazing (averaging 63% green, 13% senescing and 24% dead, $P>0.05$).

Immediately after the Feeding Phase, 94% of Uncut thistles and 37% of Cut-1 thistles survived. No thistles in the Cut-1 treatment recovered from being cut off at ground level on day 5. Only 19% of Uncut thistles survived during the following 4-weeks, and no other thistles re-grew (Table 1).

Nearly all available thistle leaves from plants cut 1, 2 or 3 days prior to grazing were consumed (>98% of cut biomass, Table 1) and there was no difference between the three treatments in the amount consumed ($P>0.05$). The ground cover

Table 1 Effect of goat grazing on uncut variegated thistle and variegated thistle cut 1, 2 and 3 days before grazing. Measurements include the percentage survival of thistle plants from the day before the Feeding Phase (Day 0), on day 3 after the Feeding Phase ended, day 5 once plants were cut to ground level and at 4 weeks after the Feeding Phase. The percentage of thistle biomass consumed (leaf consumed %); the reduction in thistle ground cover during grazing (pre-grazing area – post-grazing area (area loss %)); %DM of the thistle leaves; and the concentration of low molecular weight (WSC low), high molecular weight (WSC high) and total water-soluble carbohydrate (WSC total) on the first day.

Variegated thistle measurement	Uncut	Cut 1	Cut 2	Cut 3	SED	P-value
<i>Survival of thistle plants (%)</i>						
Before	100	100	100	81	10.8	0.021
After 3 days	94	36	0	0	21.62	<0.001
After 5 days	94	0	0	0	6.25	<0.001
After 4 weeks	18.8	0	0	0	6.25	0.007
<i>Grazing impacts (%)</i>						
Leaf consumed	*	99	100	98	1.2	ns
Area loss	46	71	63	71	5.8	<0.001
<i>Pre-grazing leaf quality</i>						
Leaf DM (%)	9	36	51	60	5.3	<0.001
WSC low (mg/g)	7.4	14.9	14.4	20.8	2.70	<0.001
WSC high (mg/g)	0.7	1.5	2.2	2.6	0.65	0.033
WSC total (mg/g)	8.1	16.3	16.6	23.4	2.90	<0.001

*not measurable since no record of the quantity of leaf consumed was possible.

of the thistles declined in response to grazing. Overall, ground cover was reduced to a greater extent in the three Cut treatments than in the Uncut treatment (average of 68% reduction in ground cover in Cut treatments vs 46% in the Uncut, $P < 0.001$).

Leaf dry matter increased (i.e. the moisture content declined) as the days after cutting increased ($P < 0.001$). Leaf DM comprised approximately 9% in the Uncut and increased to up to 60%, when thistle leaves were cut 3 days before feeding (Table 1).

The concentrations of low molecular weight and total water-soluble carbohydrate were generally lowest in the Uncut, intermediate when cut 1 or 2 days prior to feeding and highest when cut 3 days prior to feeding ($P < 0.001$; Table 1). A similar pattern was observed in the high molecular weight water-soluble carbohydrates, although the effect was less pronounced ($P < 0.033$).

There was an effect of treatment on the curvature of the leaf, with the three cut treatments being similar and much more curved than the uncut control (Fig. 2).

DISCUSSION

Variegated thistle management plans typically do not focus on using grazing animals as a control method. This may be, in part, because thistles are toxic to sheep (Bruzzese & Darby 2002). However, variegated thistles are not toxic to goats and are therefore a potential control option (Arviv et al. 2016). Goats used in trials to graze thistles typically require pre-conditioning. For example, Arviv et al. (2016) found that goats pre-conditioned to eating variegated thistles indoors were 50% more likely to consume thistles outdoors than non-conditioned goats (30% vs. 21% thistles consumed respectively). The goats in our study were only briefly introduced to thistles for the 5 days prior to the trial, not intensively

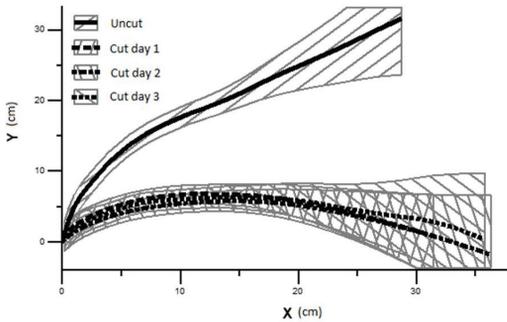


Figure 2 X and Y are measured in cm and indicate the shape of the thistle for the four treatments in a two-dimensional plane. Hatched bands are 95% Least Significant Difference intervals. Two curves are significantly different at the 5% level where the bands do not overlap.

pre-conditioned, but still ate nearly all of the thistle leaves available, especially those that had been previously excised. This finding suggested that cutting the variegated thistle plants combined with goat grazing could be an effective control mechanism. Most of the thistles in the Cut treatments died after the Feeding Phase and no regrowth occurred over the next 4 weeks. This was in contrast to the uncut plants, where most thistles survived the Feeding Phase.

Goats readily ate the leaves at 1, 2 or 3 days after cutting. This result implies there is flexibility in the post-cutting grazing management to remove the cut thistles and goats can be brought into a paddock several days after cutting. Removal of thistle debris in this manner may limit the covering and shading of the pasture and avoid the creation of bare patches (Dingwall 1950). This type of management is important, as bare patches can be colonised by other undesirable weedy species, remain bare (James & Tozer 2018), or be prone to re-infestation of variegated thistle the following autumn from seed in the seedbank (Pook 1983).

Excision of thistle leaves and up to 3 days of wilting had clear impacts on the physical and chemical attributes of the leaves. When handling the thistles, the research team noted that the cut

wilted leaves were softer and less prickly, which was consistent with their change in shape. The change in these physical attributes of the thistles after cutting may have made it easier for the goats to consume them compared to the leaves that were left on the uncut thistle.

While the concentration of water-soluble carbohydrate in the leaves increased with days since cutting, it was not likely to be a significant factor for the goats, since they consumed the majority of cut leaves provided.

Goats also consumed the uncut thistle during the Feeding Phase period although there was less reduction in leaf area than if the leaves had been cut prior to grazing. The goats tended to eat more excised leaves, regardless of whether or not the leaves had been wilted prior to grazing. It is important to note that this study was not designed to assess preference; we encourage future work that provides *ad libitum* access to the various treatments in order to assess goat preference.

Integrating this knowledge into new variegated-thistle management plans needs to include consideration of other livestock classes too. On sheep and beef hill-country farms where variegated thistles are a problem, the paddock could be grazed by sheep or cattle to make the most profitable use of the pasture, and then the thistles slashed before the goats are put into the paddock. This could make goat grazing more effective as other potential forage is removed and the main food source is cut thistles.

In steeper country where slashing is not a viable option, spray-grazing may be a useful tactic. In spray-grazing, a sub-lethal dose of herbicide is applied aerially to a thistle patch (Anon 2007) resulting in the thistles wilting. The introduction of goats after spraying to consume the wilted thistles could result in the death of the thistle plants. Pasture survival is increased due to the thistles being grazed before shading of the pastures can occur. A combination spray-grazing with goat grazing has been suggested as a successful thistle-control technique in Australia (Anon 2007). Less herbicide needs to be applied with spray-grazing which has environmental

and financial benefits. However, work is needed that evaluates the effect of herbicide use on consumption by the goats, as well as the effect on the goats themselves.

Fencing is a limiting factor with regards to goats, and the fencing infrastructure may need to be upgraded on typical sheep and beef farms. In the future, “virtual fencing” technologies may be able to contain the goats to the areas where they are needed.

For this knowledge to be confidently incorporated in to the farm weed-management toolbox, further study is required. In particular, the growth phases of the thistle plant used in this trial were somewhat different from that observed on the East Coast. Seeds were sown in early spring and the plants remained vegetative throughout the study period; this timeline differs from the East Coast season, where variegated thistle typically germinates in autumn and becomes reproductive in late spring. Timing of any control efforts are critical. Dodd (1989) found that immature variegated thistles with stems <20 cm were still able to produce viable seed after simulated mowing and slashing in Australia. This highlights the importance of identifying the best time to cut the thistles so that they do not have time to regrow and produce seed before senescence – information that must be incorporated into any weed-management plans developed for farmers.

CONCLUSIONS

This initial proof-of-concept study showed that goats consumed up to 99% of the cut variegated thistle foliage. There is clearly potential to include grazing by goats in an integrated weed management strategy. However, further work should be done at paddock scale over a longer period on the East Coast within the typical variegated thistle season. This would enable a robust test of the effectiveness of goats in controlling variegated thistle and limiting pasture shading on commercial hill-country properties.

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