Analysis of Canada thistle Biomass Reduction from NOP Approved Non-Tillage/Cultivation Control Methods

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Abstract

Canada thistle is a very problematic agricultural weed, particularly for organic farmers. This persistent invader quickly inhabits disturbed soils and aggressively competes with agricultural crops for resources such as water and nutrients. Deep roots and thick rhizomes (underground, horizontal stems of a plant that often sends out roots and shoots from nodes) allows Canada thistle to spread underneath the surface of the soil, putting up new shoots along the way. Large populations of Canada thistle can sequester carbohydrate reserves in the roots and rhizomes enabling plants to easily recover from aboveground vegetative damage. In an attempt to determine if and how an effective management plan could be constructed, experiments were performed on an organic farm in Central Colorado in order to compare ten different control methods that are available to organic farmers, and at three different frequencies of applications. The questions addressed were: how and to what extent will Canada thistle respond to various treatment methods, and how will the frequency of application affect the success of each method. Data gathered from May through October for two consecutive years indicates that great variations exist among treatment methods, and that the frequency of application is just as important as the method of treatment being applied. This suggests that in order to maintain effective thistle control in organic farming a treatment plan would require two considerations: 1) the frequency of application, and 2) the treatment method being used. A combination of treatment methods at various frequencies, timed over seasonal intervals, may provide the best approach from which a long-term strategy could emerge. Future research should be devoted to continued investigation of frequency and method strategies, as well as variations of timing and application of treatment strategies for optimal thistle control for organic farmers.

Nomenclature: AllDown®; Burn Out II®; Deadeye®; Matran 2®, Matran EC®; ThermX 70®; 30% Acetic Acid; Canada thistle, *Cirsium arvense*

Key Words: Rhizomes, carbohydrates

Introduction

Canada thistle (*Cirsium arvense)* is considered to be one of the most aggressive and difficult to manage agricultural weeds. Native to North Africa, Europe and Asia, this member of the Aster, or Sunflower family (*Asteraceae*), reproduces by seed, as well as through an extensive lateral root system that readily puts up new shoots, particularly in response to vegetative damage (Myers and Bazely, 2003, Anthony, et al. 2004). Large root systems store carbohydrate reserves deep underground, enabling them to quickly put up new shoots, creating patches of genetically identical plant populations capable of responding to disturbances with new and increased plant growth. This extensive root system, which are capable of reaching depths of up to fifteen feet (Myers and Bazely, 2003, Anthony, et al. 2004) enables Canada thistle to aggressively compete for water and other resources, and it is suggested that secondary compounds such as flavonoids, sterols, alkaloids and phenolic acids, as well as nitrogen containing compounds, may create resistance to herbivory or provide some allelopathic effects on surrounding vegetation (Mamolos and Kalburtji, 2001, Jordan-Thaden and Louda, 2003). Additionally, genetic diversity within the species creates slight variations in the anatomy and physiology of the plant, which could potentially modify the plants response to its environment (Myers and Bazely, 2003, Hettwer and Gerowitt, 2004). Infestations occur in cultivated fields, pastures and rangeland, along roadsides and ditches, as well as in forests and riparian areas. Canada thistle can out-compete native plants and agricultural crops by quickly inhabiting and dominating bare soils, forming dense populations in farmland, construction areas and any other site where soil is disturbed or aboveground vegetation is removed (Brant et al., 2004).

Development of an effective weed management program requires greater knowledge of the effectiveness, risks, costs and benefits of various weed control practices, as well as a more thorough investigation of the synergistic effects of combining various techniques. Some current methods for the control of Canada thistle include: mechanical methods – crop rotation, tilling, hoeing, cultivation, hand pulling, etc., synthetic herbicides (currently the most commonly used method of weed control), non-synthetic herbicides – acetic acid (vinegar) or clove oil based, etc., and bio-controls, which employ the use of insect herbivores to help control weed populations (Myers and Bazely, 2003)**.**

The goal of this experiment was to test a variety of treatments for controlling Canada thistle in organic agricultural settings, and to determine how the frequency of applications influenced control strategies. Investigating several treatment methods and frequencies of thistle control could potentially offer a reference point from which a Canada thistle management plan could be established. One of the main conclusions of this paper is that the frequency with which a control method is applied is equally or more important than the method itself. In this experiment, we tested the hypothesis that the frequency of application has as much or more effect on Canada thistle control than the specific type of treatment.

This work tested these questions with two null hypotheses: 1) the frequency by which a control method is applied is not significant and 2) differences among control procedures are not significant. If Canada thistle control is a function of frequency and method, we predicted that there would be significant variation among plots treated at different frequencies and there would be significant variation among plots treated with different control methods.

Materials and Methods

Field Experiments. Field experiments were conducted in a 15' X 300' section of farmland located at Pachamama Organic Farm in Hygiene Colorado. During the research period from May2005 through October 2006 the farm was not certified organic, but all practices there complied with the National Organic Program (NOP) Standards. The experimental plot was divided into three groups consisting of ten 10'x15' test plots as well as two control plots which were left untreated. Each of the 30 test plots were treated for thistle using one of ten different methods applied at three different frequencies: every two weeks, every four weeks, and every eight weeks. Assessments were performed on a weekly basis. Treatments included several commercial products, including clove oil-based herbicides, such as Burnout II®, clove oil 12%, sodium laurel sulphate 8% and acetic acid, lecithin water , citric acid and mineral oil 80%; Matran 2® and Matran EC®, clove oil 50% wintergreen oil, butyl lactate, and lecithin 50%; acetic acid based herbicides, including AllDown®, Citric acid 5.0%, Garlic 0.2%, acetic acid, yucca and water 94.8%; and Deadeye®, acetic acid herbicide with sodium chloride (exact specs unknown). We also experimented with homemade versions of 10%, 15% and 20% generic acetic acid solutions with ThermX 70, a yucca based surfactant (added to aid in breaking the surface tension of the solution, which reduces run-off and allows the treatment to penetrate the leaf cuticle). In addition to these treatments, we experimented with hand pulling, hoeing, and flame-weeding.

All non-synthetic herbicides had to be pre-mixed with water prior to each application, with the exception of AllDown®, which, at the time was sold pre-mixed. Burnout II® and Deadeye® are concentrates that needed to be mixed with water at a 1 to 2 product to water ratio. Matran2® and Matran EC® were the most concentrated of all the solutions that were tested, requiring seven parts water to each part product. Because Burnout II®, Matran2® and Matran EC® are clove oil-based they tend to separate easily from water and therefore require constant, vigorous shaking. Large-scale applications would require an agitator to keep the product from separating during applications. The generic 10%, 15% and 20% acetic acid solutions were used to test simple “homemade” solutions. An initial concentration of 30% acetic acid was diluted with water and combined with ThermX 70. The organic solutions were typically applied using a backpack sprayer equipped with a 2-nozzle spray boom, which applied an even cover over the plots. Treatments were performed on hot dry days, with the exception of hand pulling, which was usually performed after the fields were irrigated or after it had rained.

Assessments. The first treatment was conducted on May 15, 2005 and data was collected for each of the thirty plots twice per week throughout the months of May through October, 2005 and 2006. Each of the experimental plots was assessed for plant numbers and the percentage of biomass relative to the control plot, which was an untreated plot with approximately 200 well-established thistles. The numbers of thistle did vary somewhat from plot to plot, and therefore this metric only gives a relative assessment of the success of each treatment for controlling long-term thistle biomass. “Numbers of thistle” indicate all of the thistles present in a given plot – small, medium and large thistles and even partially damaged thistles were counted. Percentage of biomass was calculated by estimating the overall percent of thistle aboveground vegetative biomass: shoots, stems, leaves and flowers.

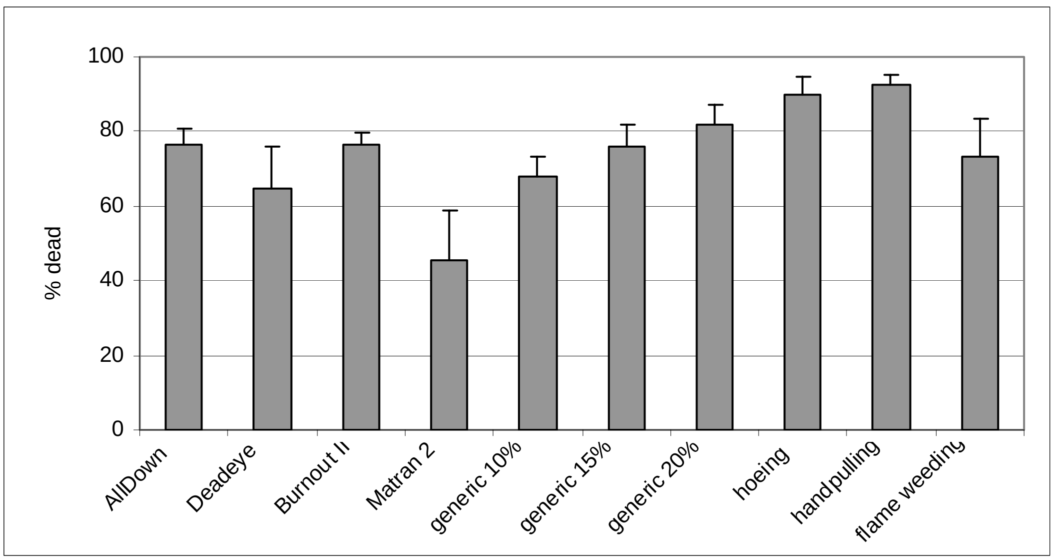
To test the effectiveness of the treatments we primarily studied the changes in plant biomass over time, we also considered the numbers of aboveground shoots in making these calculations. We used the Student Newman-Keuls test to examine if there was significant differences (alpha = 0.05) among treatments at x number plots at each frequency separately. To examine the effectiveness of frequency of application at reducing Canada thistle, we applied an SAS analysis in which the dependent variable was either number of plants or estimated percent of biomass coverage and the dependent variables were treatment method, plot, and frequency of application. For all figures, error bars represent standard error. All statistical analyses were performed using SAS software: SAS. 2001. Proprietary Software Release 8.2. The SAS Institute, Inc. Cary, NC.

Results

Immediate Damage Following Treatment. An analysis of the average percentage of dead or damaged thistle for each treatment method indicates that there was significant variation among the treatment methods (Figure 1). Immediate damage c aused by treatments did not vary significantly as a function of frequency, as mean average dead or damaged thistle for each treatment was approximately the same regardless of the frequency with which it was applied. The mean average of all treatments combined was 74 percent dead or damaged thistle (alpha = 1.89E-4). The treatments with the greatest percentage of dead or damaged thistle were hand pulling and hoeing. Hand pulling was statistically significant (mean avg. 93, alpha = 0.035), hoeing was not significant (mean avg. 90, alpha= 0.067). Other treatments that killed an above average percentage of thistles were generic 20% acetic acid, Burnout II®, AllDown® and generic 15% acetic acid (mean avg. 82, alpha = 0.025, mean avg. 77, Alpha = 5.0E-3, mean avg. 76, alpha =

0.012, mean avg. 76, alpha = 0.019; respectively). Flame-weeding, generic 10% acetic acid and Deadeye®, all killed or damaged below average, (mean avg. 73, Alpha = 0.047, mean avg. 68, Alpha = 0.01, mean avg. 65, Alpha = 0.03 respectively) Matran2® and Matran EC® were significantly lower than the other treatments in post treatment damage (mean avg. 45, Alpha = 0.02).

Figure 1. Mean percent of dead or damaged thistle immediately following treatments (relative to the amount of thistle found prior to each treatment). For each treatment shown, bars indicate total averages for all three frequencies and error bars represent standard error.



Products with Acetic Acid as an Ingredient

AllDown®. After two seasons of treatments, the AllDown® plot treated every eight weeks fluctuated between 50 plants (above-ground shoots) and 10% biomass – up to 85 plants and 50% biomass. There was an overall increase in Canada thistle numbers (+15) and biomass was up 10%. When treated every four weeks there were great fluctuations in thistle numbers and percentage of biomass, but overall, after two seasons, thistles decreased from 125 plants to 60 plants and biomass decreased from 75% to 40%. Plots treated every two weeks decreased from 80 plants and 20% biomass to start the 2005 season, to approximately 5 plants or less and less than 5% biomass. Although plots treated every two weeks and every eight weeks only had a small percentage of thistle to begin with, the amount of thistle increased in the plot treated every eight weeks and decreased in the one treated every two weeks. The plot treated every four weeks had a higher percentage of thistles to begin with, and, although the amount of thistle remained high during 2005 it ultimately went down by 2006.

Deadeye®. After two seasons of treatment the Deadeye® plot treated every eight weeks fluctuated between 70 plants (aboveground shoots) and 15% biomass, up to 80 plants and 50% biomass, and then and then back down to 60 plants, with an overall increase in biomass, ending the 2006 season with 30% – a 15% increase. When treated every four weeks there was a slight increase after the 2005 season starting with 40 plants and 10% biomass and ending the season with 60 plants at 25% biomass. However, by the 2006 season the average dropped to approximately 20 plants and 5% biomass – an overall decrease in thistles. Plots treated every two weeks decreased from 80 plants and 20% biomass to start the 2005 season, to an average of 10 plants and approximately 5% biomass.

10% Acetic Acid with Yucca Based Surfactant. After two seasons of treatment the 10% acetic acid plot treated every eight weeks fluctuated around 50 to 70 plants and ended with an increase in biomass, from 15% in May ’05 up to 30% in September ’06. When treated every four weeks there was a decrease in thistles, beginning the 2005 season with 80 plants and 50% biomass and ending the 2006 season with 60 plants and 25% biomass. Plots treated every two weeks decreased from 50 plants and 10% biomass at the beginning of the 2005 season, to an average of 10 plants and approximately 5% biomass at the end of 2006.

15% Acetic Acid with Yucca Based Surfactant. After two seasons of treatment the 15% acetic acid plot treated every eight weeks increased steadily from 50 plants (aboveground shoots) and 15% biomass in May ‘05, up to 75 plants and 40% biomass by Sept ‘05, and then up to 100 plants in May ’06 and ending the 2006 season with an increase in thistles of 120 plants and 75% biomass. When treated every four weeks there was an increase in thistles, beginning the 2005 season with 35 plants and 10% biomass, increasing to 90 plants by Sept ‘05 and ending the 2006 season with 60 plants and 35% biomass. Plots treated every two weeks decreased from 60 plants and 10% biomass at the beginning of the 2005 season, to an average of 10 plants and approximately 5% biomass at the end of 2006.

20% Acetic Acid with Yucca Based Surfactant. After two seasons of treatment the 20% acetic acid plot treated every eight weeks increased from 50 plants (aboveground shoots) and 15% biomass in May ‘05, up to 100 plants and 75% biomass by Sept ‘05, and then up to 100 plants and 120% biomass in May ’06 and ending the 2006 season with an overall increase in thistles with 75 plants and 30% biomass. When treated every four weeks there was a lot of fluctuation in thistle numbers and percentage of biomass, beginning the 2005 season with 50 plants and 15% biomass, up to 95% biomass to start the 2006 season, and ending the 2006 season with 50 plants and 10% biomass, a slight decrease in thistles overall. Plots treated every two weeks decreased from 75 plants and 20% biomass at the beginning of the 2005 season, to an average of 10-20 plants and approximately 5-10% biomass throughout most of the 2005 and 2006 seasons, ending with no visible thistles remaining – 0 plants and 0% biomass.

Figure 2 Represents the fluctuations in thistle biomass over the 2005 and 2006 experiments for all plots treated with acetic acid solution every eight weeks. All graphs are relative to the control plot, which is always 100% of itself.

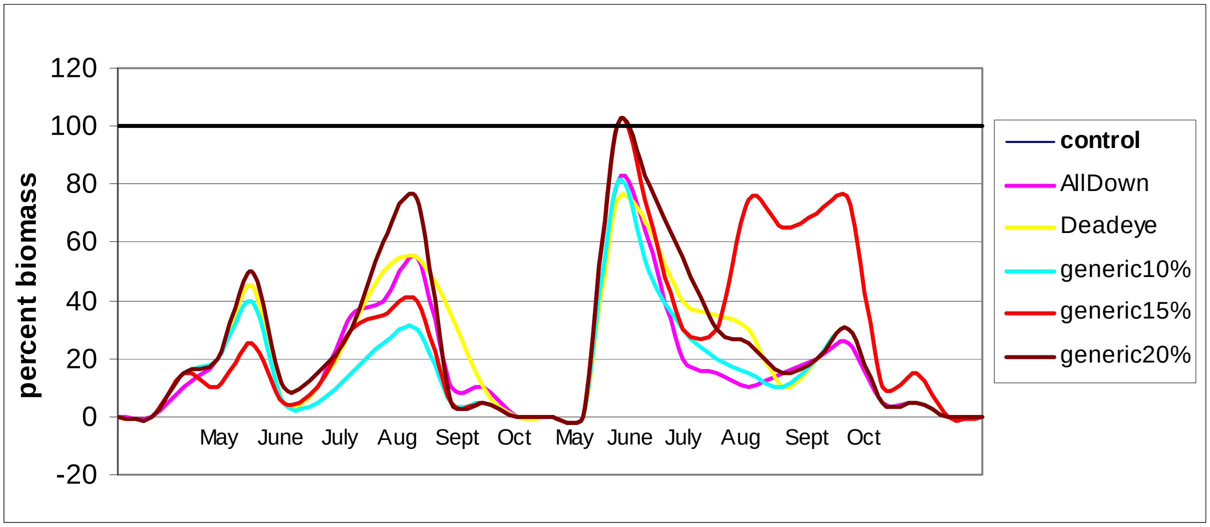


Figure 3 Represents the fluctuations in thistle biomass over the 2005 and 2006 experiments for all plots treated with acetic acid solution every four weeks. All graphs are relative to the control plot, which is always 100% of itself.

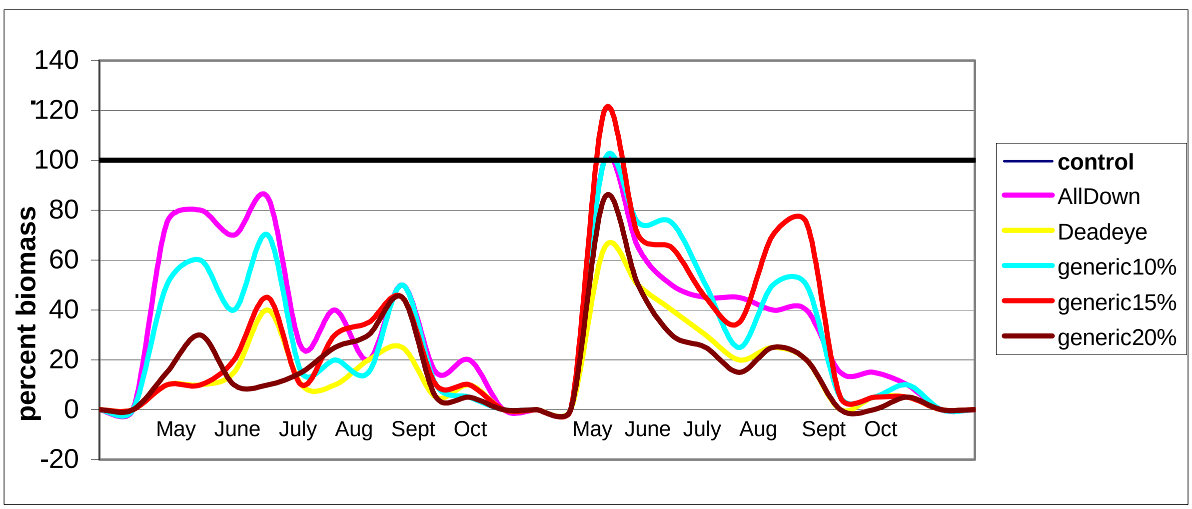
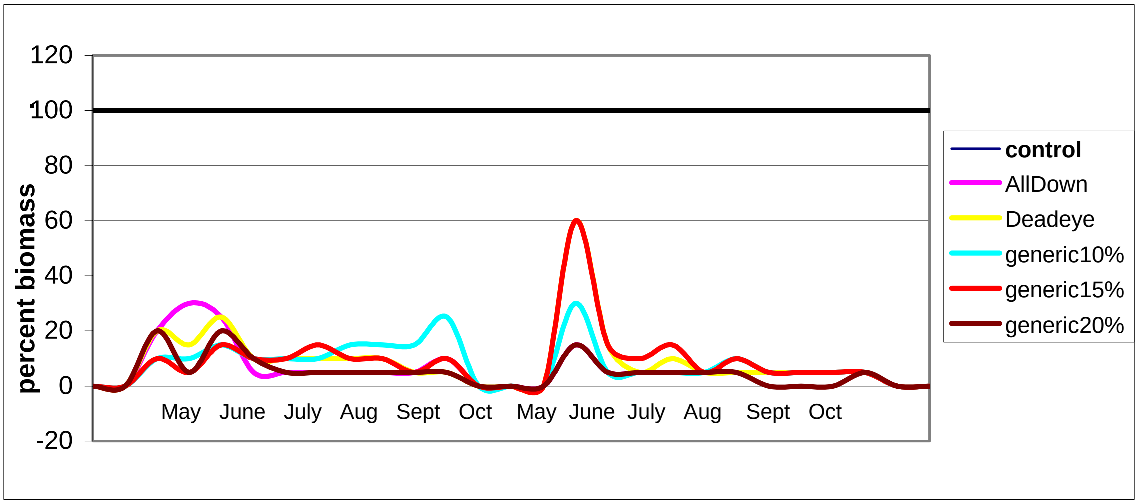


Figure 4 Represents the fluctuations in thistle biomass over the 2005 and 2006 experiments for all plots treated with acetic acid solution every two weeks. All graphs are relative to the control plot, which is always 100% of itself.



Products with Clove Oil as an Ingredient

Burnout II®. After two seasons of treatments, the Burnout II® plot treated every eight weeks increased from 35 plants and 10% biomass in May 2005, to 140 plants and 75% biomass by September 2006. When treated every four weeks there were great fluctuations in thistle numbers and percent biomass, starting in May 2005 with 20 plants and 5% biomass, up to 60 plants and 60% biomass in May 2006, and ending with 50 plants at 5% biomass in September 2006, an overall increase in thistles by 30 plants, with fluctuating percent biomass. Plots treated every two weeks decreased from 80 plants and 20% biomass to start the 2005 season to 45 plants and 10% by September 2006.

Matran 2® (2005) and Matran EC® (2006). After two seasons of treatments the plot treated every eight weeks with Matran2® and Matran EC®_ increased from 35 plants and 15% biomass to 250 plants and 100% biomass, matching or exceeding the control plot during most of both seasons. When treated every four weeks there were great fluctuations in thistle numbers and percent biomass, starting at 80 plants and 45%

biomass, and increasing to 175 plants and 180% biomass, and finally ending in September 2006 with 35 plants and 10% biomass, ending with an overall decrease, but with periods of high numbers throughout both seasons. Plots treated every two weeks increased from 60 plants and 15% biomass in May 2005 to 90 plants and 25% biomass by September 2006.

Figure 5 Represents the fluctuations in thistle biomass over the 2005 and 2006 experiments for all plots treated with clove-oil based solution every eight weeks. All graphs are relative to the control plot, which is always 100% of itself.

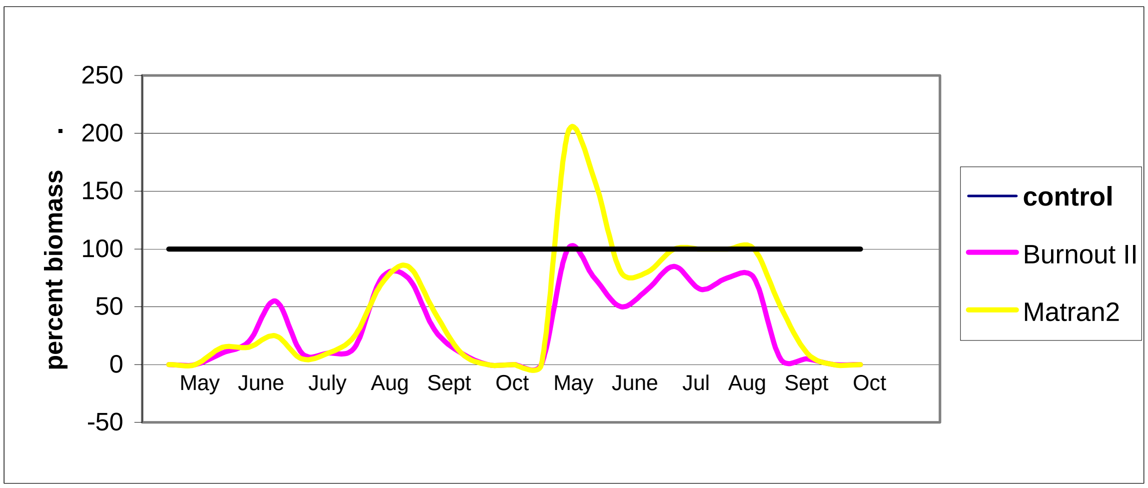


Figure 6 Represents the fluctuations in thistle biomass over the 2005 and 2006 experiments for all plots treated with clove-oil based solution every four weeks. All graphs are relative to the control plot, which is always 100% of itself.

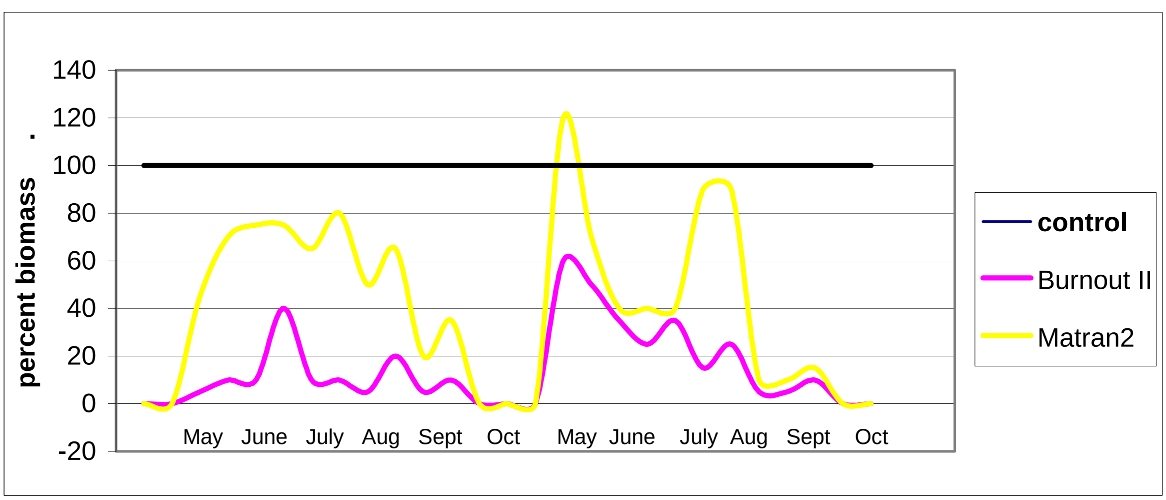
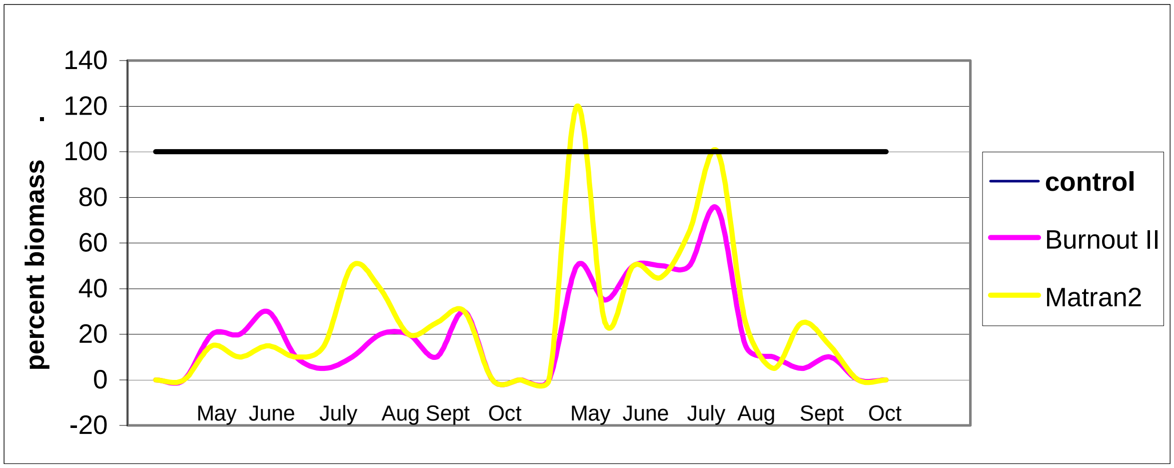


Figure 7 Represents the fluctuations in thistle biomass over the 2005 and 2006 experiments for all plots treated with clove-oil based solution every two weeks. All graphs are relative to the control plot, which is always 100% of itself.



Mechanical and Thermal Methods

Hoeing. After two seasons of treatment the hoeing plot treated every eight weeks increased from 50 plants (aboveground shoots) and 25% biomass in May ‘05, up to 180 plants and 95% biomass by Sept ‘05, and then up to 140 plants and 175% biomass in May ’06 and ending the 2006 season with an overall increase in thistles with 135 plants and 45% biomass. When treated every four weeks there was an increase from 50 plants (aboveground shoots) and 25% biomass in May ‘05, up to 150 plants and 75% biomass by Sept ‘05, and then up to 170 plants and 190% biomass in May ’06 and ending the 2006 season with an overall increase in thistles with 100 plants and 30% biomass. With plots treated every two weeks there were great fluctuations in thistle numbers and percent biomass, starting at 70 plants and 15% biomass, and increasing to 200 plants and 45% biomass, and finally ending in September 2006 with 10 plants and 5% biomass, ending with an overall decrease, but with periods of high numbers throughout both seasons.

Hand Pulling. After two seasons of treatment the hand pulled plot treated every eight weeks increased gradually from 25 plants and 10% biomass in May 2005 to 50 plants and

25% biomass in September 2006. When treated every four weeks there was some fluctuation in thistle numbers and percentage of biomass, with an overall decrease in thistles from 60 plants and 10% biomass in May 2005 to 15 plants and 10% biomass in September 2006. Plots treated every two weeks increased from 75 plants and 20% biomass in May 2005 to 100 plants and 60% in September of 2005, and then decreased during the 2006 season, ending with approximately 10 plants and less then 5% biomass.

Flame Weeding. After two seasons of flame weeding the plot treated every eight weeks fluctuated throughout both seasons, starting with 10 plants and ~5% biomass, up to 65 plants and 45% biomass, ending with a slight increase at 30 plants and 10% biomass. When treated every four weeks there was a significant amount of fluctuation in thistle numbers and percentage of biomass, beginning the 2005 season with 100 plants and 65% biomass, down to 50 plants and 25% biomass in September 2005, and up to 250 plants and 200% biomass to start the 2006 season; ending the 2006 season with 45 plants and 65% biomass, a slight decrease in thistles overall. Plots treated every two weeks decreased from 75 plants and 25% biomass at the beginning of the 2005 season to 10 plants and 5% biomass by September 2006.

Figure 8 Represents the fluctuations in thistle biomass over the 2005 and 2006 experiments for all plots treated with mechanical methods every eight weeks. All graphs are relative to the control plot, which is always 100% of itself.

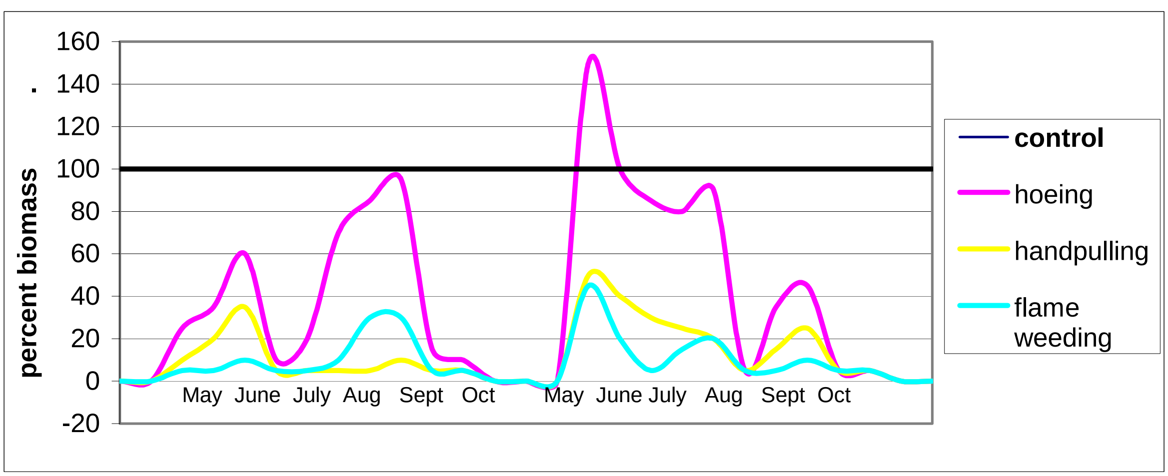


Figure 9 Represents the fluctuations in thistle biomass over the 2005 and 2006 experiments for all plots treated with mechanical methods every four weeks. All graphs are relative to the control plot, which is always 100% of itself.

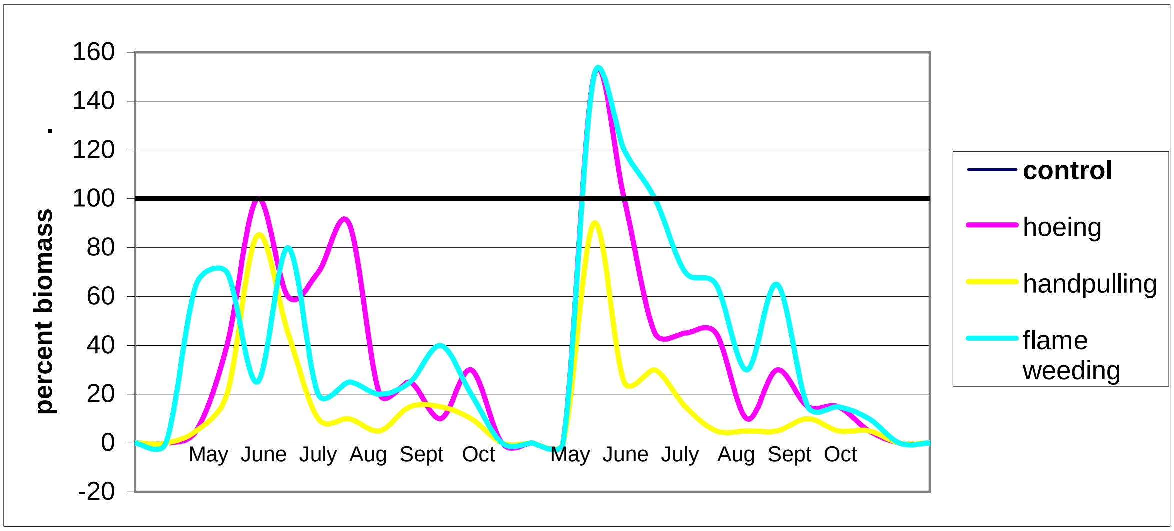
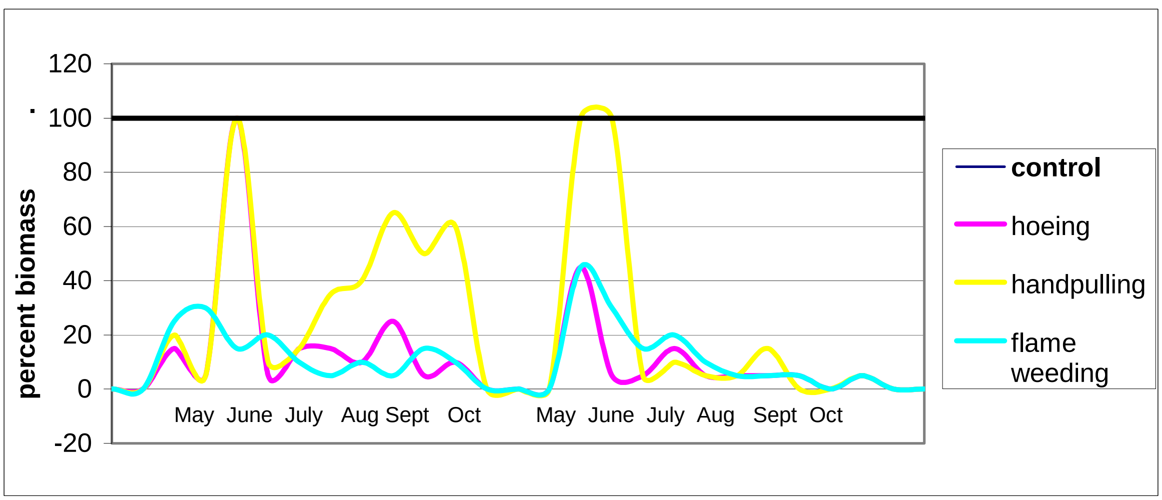


Figure 10 Represents the fluctuations in thistle biomass over the 2005 and 2006 experiments for all plots treated with mechanical methods every two weeks. All graphs are relative to the control plot, which is always 100% of itself.

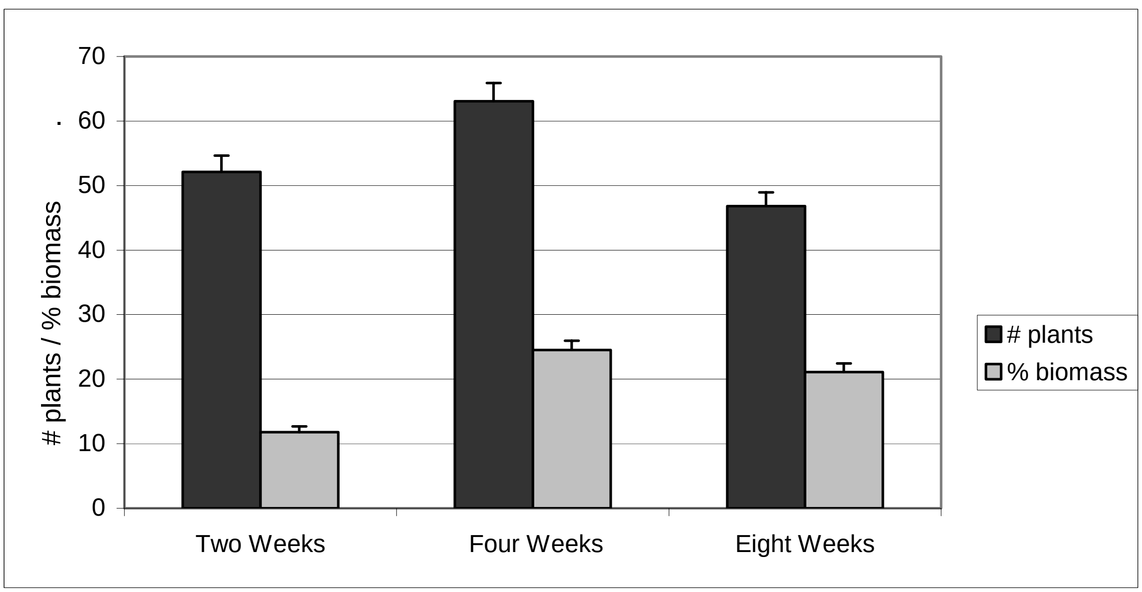


Effects of frequency

SAS analyses of the three frequencies reveal clear differences among them (Figure 11). Plots that were treated every two weeks had a significantly lower percentage of biomass (mean avg. 11.8, $P < 0.05$). Plots that were treated every four weeks had the significantly greatest amount of thistle in terms of both numbers and percent biomass (mean avg. 63, $P < 0.05$ plant numbers, mean avg. 24.5, $P < 0.05$ percent biomass). Log based analyses revealed similar results; plots treated every-other month were log average 3.5, net biomass, log 2.5%, for plots treated every two weeks, the log average plant numbers were 3.6, net biomass, log 2.1%, and plots that were treated monthly were log average 3.8 plants and log average 2.7% .

Figure 11

This graph compares the average results of the three different frequencies. In each frequency along the x-axis, two categories are observed; the average number of thistle plants found within the plots and the average percent of aboveground thistle biomass (relative to the control plots). Frequency of treatments was every two weeks, every four weeks and every eight weeks.



Throughout the experiment, the plots treated every two weeks had a range between twenty-five and one hundred plants, which were reduced to tiny rosettes and spindly stems; there was very little plant growth of any kind and few other weeds. The initial response to the first treatments was rapid re-growth of thistle, which led to high numbers of plants and a high percentage of biomass, followed by a subsequent decline, where numbers remained low. In the plots treated every eight weeks, there was rich plant communities; grasses and other weeds dominated, sharing space with some thistle that were approximately twenty to thirty centimeters tall and relatively healthy looking (green and leafy). These plots had relatively lower numbers of thistles during the first season, but considerably more during the second season. Plots treated every four weeks had a consistently higher percentage of thistles then the other two frequencies in number of plants and percent biomass. Although there was typically a high percentage of damage following each treatment, thistle plants rebounded within weeks and generally were surviving in large numbers.

Weed Management Implications

Costs per acre	At 145 gallons per acre	At 100 gallons per acre
AllDown[1]	$2610	$1800
Burnout II[1]	$1152	$800
Deadeye (concentrate)[1]	$1620	$1125
Matran EC[1]	$1280	$880
10% Acetic acid[1]	$196	$136
15% Acetic acid[1]	$262	$180
20% Acetic acid[1]	$392	$273
Hand pulling[2]	Hourly labor cost	
Hoeing[2]	Hourly labor cost	
Flame weeding[2]	$30-50 per acre for 10 foot boom at $1.44 gallon propane	

[1] These costs assume a broadcast (not spot spray) treatment. Rates in this research were 145 gallons per acre (determined from our broadcast plot sprays – no other rate was used). It is likely that rates can be reduced to 100 gallons per acre, based on some manufacturer recommendations. These costs do not reflect shipping charges.

[2] These are non-spray treatments and have different costs. Flame treatments in this research used a single burner torch. Costs per acre numbers here assume a tractor mounted 10-foot wide boom flame weeder.

Discussion

Results of the experiment indicate that the effectiveness of the particular treatment method to kill or damage aboveground vegetation (Figure 1) is not the sole consideration for long-term control. Successful management of thistle appears to depend on both the type of treatment being employed and, even more significantly, the frequency with which the control methods are applied (Figures 2 – 11). Therefore, these results suggest that both null hypotheses can be rejected, while also lending support to the hypothesis that Canada thistle control is a function of both frequency and method. The results also support the hypothesis that frequency of application has as much or more effect on thistle control than the specific treatment.

From the data collected over the course of this experiment, one can extrapolate that different methods varied in their efficacy, which usually depended on the frequency of application. Many spray herbicides decreased a significant amount of thistle, particularly when applied at high frequencies (Figures 4, 10). For example, AllDown® appears to work best when used at a high frequency (every two weeks) and less well when applied less frequently, as in the plots treated every eight weeks. Flame-weeding, hoeing and hand pulling were also effective at high frequencies (Figure 10). This may indicate that these treatments successfully attacked the thistle's underground carbohydrate reserves, as intended. Hand pulling achieved the best results when compared at all three frequencies, and it was discovered during the second season that any thistles that were pre-treated with any of the sprays (acetic acid based or clove oil) flame weeding or even mowing (about 10 inches aboveground) were easier to pull a week later. Presumably, pre-treating thistles several days in advance has the effect of stiffening the shoots, which makes them sturdier, allowing for a larger segment of the roots to be pulled out.

We had mixed results with Matran2®, Matran EC® and Burnout II®; which were slightly difficult to work with, as they are clove-oil based and had a tendency to separate, we found that sometimes they killed everything (especially towards the end of each season, August and September) and other times they did not appear to have much of an effect. With both the clove-oil products, Burnout II®, Matran2®and Matran EC®, there seemed to be an increase in thistle growth that rivaled, or even exceeded the control plots during the middle of the growing season (June-August) but declined significantly in September through November. Therefore, even though thistle numbers were ultimately brought down by the end of each season, the high thistle numbers during the middle of the growing season enabled thistle to go to seed, compete with crops, and sequester enough below ground carbohydrates to come back strong the following season.

Hoeing was not effective at reducing thistle when performed at intervals four or more weeks apart, and this may indicate that such a method does not successfully attack underground carbohydrates. The strong growth response by Canada thistle to aboveground cutting is believed to be an adaptive response to herbivory (Myers and Bazely, 2003, Anthony, et al. 2004). If cutting thistle (rather than killing the plant on top, such as spray and flame treatments do) produces a hormonal response in the plant to react with immediate and vigorous growth, then the goal of depleting underground carbohydrates is not achieved, since photosynthesis would occur at a rate that allows the thistle to continue sequestering reserve carbohydrates. In other experiments focused on hoeing and other methods of tillage, Engelke and Pallutt (2004) found that results varied with techniques. They showed that the best results came more often from plots that had deep tillage vs. shallow tillage or hoeing.

Other experiments that tested for possible variations amongst different treatment methods demonstrated similar results. Thomas and coworkers (2004) found that hoeing produced different results than plowing and tillage, all of which are similar techniques, but vary in how deep they dig into the soil. They also suggest that perennial species, like Canada thistle, were found at higher densities in fields that underwent reduced and zero tillage compared with fields that were given conventional tilling. Perkrun and Claupein (2004) tested for variations among mechanical treatment methods as well, and likewise found that results varied depending on method and frequency. They concluded that the greatest thistle reduction occurred in fields that were tilled deeply, and treated in both the spring and fall.

Another conclusion of the present study is that frequency is as important as the treatment being applied. Figure 11 demonstrates the significance among various frequencies, where the highest frequency (every two weeks) resulted in the greatest thistle reduction, which indicates that higher rates of treatment generally are important in controlling thistle. Traunicek, and coworkers (2005) examining the most effective season for treatment, found that the best results came from treating in both the spring and fall. They tested frequency, timing and various methods of treatments and found that thistles treated with spray herbicides in the spring, followed by controlled burns in the fall, showed the most pronounced reduction of thistle. In experiments performed between 1993 and 2000, Torresen and coworkers (2002) found that perennial species, such as Canada thistle, increased in thistle density when tillage was reduced, but decreased when tillage was performed in the spring and the fall, and was further reduced when spray herbicides were added to the treatment regime.

There is further evidence to support the hypothesis that frequency of application as well as timing plays a critical role in thistle management, especially for organic farming where synthetic herbicides are not an option. Donald (2000) found that adventitious roots begin to grow out and produce root-buds as early as the beginning of May (even before aboveground biomass is apparent) and 80 percent of root growth takes place in the following 30 to 60 days. This is due to the fact that thistles sequester a great deal of carbohydrates below ground, especially during the cold season. In early spring, when aboveground temperatures are still too cold to risk forming new rosettes above ground – the thistles are beginning to convert carbohydrates to glycogens, which enables them to metabolize cell growth, and the thistles begin root and rhizome growth – spreading underground and growing even before photosynthesis begins aboveground.

Therefore, he argues, emerging thistle patches must be monitored and managed early, before rosettes are evident. The results of my experiment also demonstrated higher growth rates early in the season followed by a decline and a leveling off as the summer progressed (figures 2-10)). This was particularly true for plots treated every two weeks. On the other hand, Wilson and Michiels (2003) found that fields treated in the fall might experience a greater reduction in thistle then fields treated in the spring. They suggest that carbohydrate concentrations in the roots change in response to freezing temperatures, and thus, thistle experiences the greatest mortality if it is treated while it is preparing to over-winter.

Out of the three frequencies tested in this experiment, the plots treated every two weeks showed the greatest net reduction in thistle density (Figure 11) and many of the plots were left bare. This may be an indication that underground carbohydrate reserves of the thistle were depleted. The plots treated monthly, however, had the least amount of thistle reduction, indicating that there may have been enough time in between treatments for thistle to completely recover. Interestingly, in terms of biomass reduction the plots treated every eight weeks seemed to do slightly better than plots treated every four weeks in terms of thistle reduction, contradicting the hypothesis that the higher the frequency the greater the reduction in thistle. It is possible that the reason for this is that in plots treated every eight weeks, there was also a full complement of other grasses and weeds, which may have competed against the thistle for resources. Hausler, and coworkers (2004) experimented with the effectiveness of tillage and crop rotation with intermediate crops that are competitive with thistle, such as clover-grass or winter wheat. They found that crop rotation and tilling decreased thistle more than tilling alone. Competition between plant communities is a dynamic process, and dominant species will likely vary through time (Myers and Bazely, 2003). Such competition between thistle and other local vegetation, however, may change over time, as a result of changes in the weather, available moisture and nutrients or changes in the dynamics of the ecosystem.

Although some treatments seem to produce significant results in the short-term, it is important to consider the long-term effectiveness. Traunicek, and coworkers (2005) performed experiments with different treatments and frequencies. They raised concerns after finding that, while the amount of thistle in the experimental fields was reduced significantly as a result of treatments, closer investigation revealed a higher percentage of non-native versus native seeds in the top 10 centimeters of soil. With this knowledge, it becomes difficult to conceive of any quick and easy control strategies to manage thistle in agricultural settings. But it seems necessary to assume that any management plans will have to involve not only various treatment methods applied early, constantly and with persistence, but a long-term commitment to continued thistle management efforts as well.

While the trends identified in the present study support the hypothesis that variations exist between treatment methods and frequencies, there is also a high level of inconsistency present. Some factors that may have contributed to variations among and within individual plots may have included: edge effects from surrounding thistle which sent shoots from untreated plants into treatment plots, genetic variation among thistle populations which led to different levels of resiliency for individual plants, and resource competition from other weeds and grasses growing in the plots treated Every four weeks and every eight weeks. As previously mentioned, another problem encountered during the course of the experiment concerned the application of Matran2®and Matran EC®. The data suggests that Matran2®and Matran EC® would, at times, kill a high percentage of thistles, while at other times they had little effect. These herbicides were, however, somewhat difficult to work with, as they are clove oil-based and had a tendency to separate if not agitated constantly. This possible separation of the solution could have led to the inconsistent results for Matran2® and Matran EC®. When used properly, these products appeared to reduce thistle numbers and biomass and therefore further testing is necessary before a final evaluation could be offered.

The results of this experiment suggest that a regime of various treatments applied at a range of frequencies is essential for the management of Canada thistle. High frequency applications of certain, non-synthetic spray herbicides, or flame-weeding, applied Every two weeks, demonstrated significant effectiveness at reducing thistle, presumably because this method forced thistle communities to exhaust underground carbohydrate reserves. Hand pulling when thistles were between 15 and 20 centimeters tall also significantly reduced thistle, likewise because this method attacked underground reserves. Therefore, based on individual user’s needs, such as crop rotation and cost consideration, a combination of treatment methods performed at various frequencies should be considered. Future research, therefore, should address both the questions of uncontrolled variables, as stated above, and developing a synergistic approach for thistle management, which combines various treatments and frequencies of applications for the greatest amount of thistle reduction.

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