Wiper Application of Herbicides to *Cirsium arvense*

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**Abstract:** Wiper applicators allow herbicides to be selectively delivered to upright target weeds, thereby avoiding application to nearby lower-growing desirable pasture plants. In this research, we investigated the efficacy of wiper application of four herbicides, clopyralid, metsulfuron, glyphosate and a triclopyr/picloram mixture, to control *Cirsium arvense* (L.) Scop., a troublesome weed of pastures in New Zealand. The results showed that wiper application of herbicides was a useful technique for controlling *C. arvense*. In one trial when plants were treated at the post-flowering stage, stem density reductions in the following season of 93%, 90% and 82% were achieved following a double pass with a rotary weed wiper containing glyphosate, clopyralid and metsulfuron, respectively. A double pass gave better control of dense infestations of *C. arvense* than a single pass for glyphosate and triclopyr/picloram, but not for clopyralid and metsulfuron. Despite wiper applicators usually being selective, some damage to pastures was recorded, very likely due to rain falling soon after wiper application. Overall, the results of this study revealed that wiper application can be used to selectively control *C. arvense* when the plants are treated at the post-flowering stage, though only if plants are actively growing. In addition, among the herbicides tested, glyphosate appears to be the best choice when using weed wipers to manage *C. arvense*, as this herbicide caused the least damage to pasture plants if washed off afterwards by rain.

**Keywords:** Californian thistle; clover; grass; pasture; weed management; wiper applicator

1. Introduction

*Cirsium arvense* (L.) Scop. is one of the most troublesome weeds of pastures in New Zealand [1]. Patches of *C. arvense* may be formed from a single genotype, but often contain individuals with a different genetic background [2]. This weed species possesses a creeping root system that enables it to survive winter and produce new shoots in spring [3]. The root system can grow horizontally by several metres in one season [4]. The well-developed root system makes *C. arvense* a challenging weed species to control using most recommended weed management approaches, including herbicide application [5]. Several systemic herbicides, including clopyralid, glyphosate, metsulfuron, triclopyr and picloram, are known to effectively control *C. arvense* as they are able to translocate downwards and kill the root system [6–8]. However, most of these herbicides cannot be used in broadcast applications as they are too damaging to pastures, especially to clovers [1]. Weed wiping is an important technique that allows selective application of herbicides to target weed species with minimal damage to non-target species [9]. However, this technique requires a height differential between the target weed and the pasture, which is normally improved by grazing the pasture prior to treatment.

To achieve effective control of this species, it is crucial for herbicides to translocate sufficiently to kill the root system [8,10]. In this regard, the growing stage at which herbicides are applied plays a pivotal role as few growth stages have sufficient downward movement of sugar flow from upper parts of the stem to allow good translocation of herbicides to the root system [11]. In *C. arvense*, like many other perennial plant species, root carbohydrate reserves are lowest at the beginning of flowering stage while they...
increase as shoot growth declines in early autumn [3]. Thus, effective control of C. arvense can be achieved when herbicides are applied either when carbohydrate reserves are at their lowest or when roots are the strongest sink. During the early stage of flowering, the root does not act as a strong sink, as sugars from leaves on upper parts of the stem are primarily transported to flowers, and thus application of herbicides to upper leaves at this time results in limited herbicide translocation to the roots [12,13]. However, herbicide application at the post-flowering stage is most likely to result in a greater amount of herbicide transporting to the root system [14]. At this stage, C. arvense replenishes its root carbohydrate reserves for the next growing season and thus systemic herbicides move together with sugars through the phloem to the roots [14]. It has been shown that clopyralid reduced the density of C. arvense by 92% at 8 months after treatment when it was applied in autumn, whereas it only reduced plant density by 33% when treatment was made in the spring [13]. Late spring application of herbicides, when C. arvense is at the bud-to-early bloom stage, is also an important stage to control this species as the plants have expended most of their root reserves to produce the spring flush [15]. The removal of the shoot forces the plant to use its limited carbohydrate reserves for shoot re-growth.

Application of herbicides using weed wipers offers a great opportunity to manage hard-to-control weed species selectively in pastures. In addition, the amount of herbicide used by weed wipers is lower compared to broadcast-application of herbicides, indicating that this technology can potentially reduce environmental contamination and spray-drift problems currently being experienced by broadcast-application due to no formation of fine droplets [9]. However, there are limited published data on the effectiveness of weed wipers for controlling C. arvense at different stages of growth in pastures using different herbicides and how these herbicides affect pastures. Where these data exist, the results are variable which makes it difficult to draw any useful conclusions on the use of weed wipers in pastures [12,16]. In addition, there is also very limited information on the damaging effects of wiping herbicides on pasture plant species [12,17]. Thus, the primary objective of this research was to develop strategies for the control of C. arvense using weed wipers in pastures. Secondary objectives were: (1) to compare the effectiveness of several systemic herbicides for controlling C. arvense in a perennial ryegrass (Lolium perenne L.) and white clover (Trifolium repens L.) pasture; (2) to evaluate the optimum growth stage for application of these herbicides; and (3) to investigate any pasture damage caused by weed wiping.

2. Materials and Methods

2.1. Study Sites

Field experiments were conducted on two sites and in two different seasons in an established perennial ryegrass and white clover pasture. The pastures were located at the Keebles Sheep and Beef Cattle Research Farm of Massey University, Palmerston North, New Zealand (40.39453° S, 175.59865° E). The soil type at both sites was a Tokomaru silt loam. The mean monthly rainfall and average maximum temperature for the trial period are shown in Figure 1.

2.2. Experiment 1

Experiment 1 compared the effectiveness of clopyralid (Versatill, Dow AgroSciences, New Plymouth, NZ), glyphosate (Roundup G2, Monsanto, Wellington, NZ), metsulfuron (Answer, DuPont, Auckland, NZ) and triclopyr/picloram (Tordon Gold, DowAgroSciences, New Plymouth, NZ) when applied at the recommended rate [18], for the control of C. arvense using a Rotowiper rotary weed wiper (Model WCF24, Rotowiper Ltd., Ashburton, NZ, with 2.4 m wide roller, 16 cm diameter) at the early post-flowering stage. The herbicide rates used in this experiment are shown in Table 1. An organosilicone surfactant (Pulse Penetrant, Monsanto, NZ) at a rate of 1ml/L of herbicide solution was added to each herbicide mix to improve herbicide absorption by weeds. In addition, a detergent (Sunlight Liquid, Unilever, Lower Hutt, NZ) at a rate of 22 mL/L of herbicide solution was added to
each herbicide mix to form foam on the roller as a visual indicator of the roller wetness, as recommended by the manufacturer [19].

![Graph showing monthly rainfall and average maximum temperatures](image)

**Figure 1.** Total monthly rainfall (mm) and average maximum temperatures (°C) for the duration of the trial as measured at a weather station 1 km from the trial sites.

**Table 1.** The herbicides and rates used for the experiment.

| Trade Name       | Active Ingredient                      | Rate (Herbicide:Water) |
|------------------|----------------------------------------|------------------------|
| Versatill        | 300 g/L clopyralid (amine salt)        | 1:40                   |
| Roundup G2       | 360 g/L glyphosate (isopropylamine salt)| 1:20                   |
| Answer           | 200 g/kg metsulfuron-methyl            | 3 g/L                  |
| Tordon Gold      | 50 g & 100 g/L triclopyr & picloram (amine salts) | 1:20 |

Treatments were applied when at least 80% of the plants were at the post-flowering stage (early February) and the plots were covered in pappi. Herbicides were applied to the plants using either single or double pass treatments of the wiper. For the single pass treatment, herbicide was applied only to one side of the plants while for the double pass treatments, the plants were wiped from two sides, with the second pass being made at an angle of 180° to the first pass.

During treatment, pasture height was 5–8 cm and the roller height was set at 18 cm. A light vehicle with narrow wheels (110 mm width) was used to tow the wiper travelling at 5 km/hr to minimise flattening of *C. arvense* by wheels. A different roller was used for each herbicide. No rain fell for 2 days after treatment and the maximum temperature on the day of application was 28.5 °C. The stem density of *C. arvense* and botanical composition were assessed prior to treatments and throughout a period of 10 months afterwards. At the time of treatment, *C. arvense* plants were healthy, vigorously growing and the height of plants (the average height = 1.1 m) was fairly uniform.

The experiment was conducted using a randomised complete block design (to ensure similar numbers of stems per treatment) with four herbicide treatments and two number of passes treatments and an untreated control replicated four times. The double pass treatments were laid out in 3 m × 3 m plots with measurements being taken from four 1 m × 1 m quadrats within each plot. Each single pass plots were 3 m × 1 m in size with the measurements being taken from two 1 m × 1 m quadrats. The single pass plots were 1 m from the double pass plots to minimise any possible interference effects.

Pasture composition was assessed using the point analysis method as described by Mountier and Radcliffe [20], at 50 points/quadrat. Botanical composition was categorised into clover, grass, weed and bare ground. Since the pasture was predominantly perennial...
ryegrass and white clover, no attempt was made to differentiate these from other species of grass or clover. Visual damage to *C. arvense*, white clover and grass was assessed using a linear scoring system of 1–10. For *C. arvensis*, a score of 1 denoted total mortality while a score of 10 denoted no visual injury. For clover, a score of one represented abundant clover (up to 15% composition) while a score of ten represented absence of clover in the plots. For grass, a score of one denoted no visual injury while a score of ten denoted visual herbicide effect to all the grass.

### 2.3. Experiment 2

In Experiment 2 the effectiveness of herbicides for control of *C. arvense* was compared at three growth stages, and safety of each product for pasture plants was again assessed. All the herbicides used in Experiment 1 were assessed again, using the same rates of herbicide, surfactant and detergent mentioned above, except for the triclopyr/picloram mixture which was shown to be the least effective. Treatments were applied at three stages of *C. arvense* growth, namely flower bud (late January), early post-flowering (mid-March) and late post-flowering (early April). The herbicides, clopyralid, glyphosate and metsulfuron, were all used for the first two growth stages (flower bud and early post-flowering) while only glyphosate was used for the last stage of late post-flowering as some plots were discarded due to poor condition of *C. arvense*. Their poor condition was due to a combination of moisture stress and aphid infestation. In addition, a few days before the first treatment, some of the flower heads of the *C. arvense* had been eaten by sheep (26%), possibly due to excessive grazing pressure applied to eat pasture between *C. arvense* plants. Pasture was generally grazed to an average height of <10 cm prior to treatment while the roller was set to a height of 18, 16 and 23 cm for the first, second and third treatments depending on the height of the pasture plants not grazed prior to treatment. The *C. arvense* plants were not as uniform in height as it was in Experiment 1 with a height ranging from 15–90 cm.

All the *C. arvense* plants were treated with a single pass, since a single pass had given adequate control in the previous experiment (see the results section), and the density of *C. arvense* was lower at the second site so a double pass was deemed unnecessary. The maximum temperatures and the number of days from application to onset of rain are shown in Table 2. In the second experiment, the experimental design and assessment were the same as those outlined for the first experiment.

### Table 2. The maximum temperature on the day of application and number of days after treatment before the onset of rain.

| Thistle Stage       | Maximum Temperature | Number of Days before Rain |
|---------------------|---------------------|---------------------------|
| Flower bud          | 21.0 °C             | 3                         |
| Early post-flowering| 19.4 °C             | 7                         |
| Late post-flowering | 21.8 °C             | 0 (rained same day)       |

### 2.4. Statistical Analysis

The effectiveness of herbicides for *C. arvense* control was mainly determined by shoot re-emergence in each plot in the following spring and it was expressed as a percentage of the initial density of *C. arvense*. A similar assessment was done for clover content by assessing pre- and post-treatment abundance of clover for each plot. Analysis of grass was based on injury scores. The data from quadrats were pooled together to give a single figure for each plot. Data were then subjected to analysis of variance (ANOVA). For this, data were Log (Y + 1.5) transformed (where Y represents the response variable) in order to normalise the data and meet the assumptions of ANOVA. ANOVA was performed using Proc GLM, SAS (Version 9.1, Cary, NC, USA), and means were separated using Fisher’s test (LSD) and 5% level of probability.
3. Results
3.1. Experiment 1

All herbicide treatments resulted in significant decreases in stem densities of *C. arvense* when assessed 10 months later (Table 3). For the single pass applications, there were no significant differences between clopyralid, glyphosate and metsulfuron, though a single pass for triclopyr/picloram was less effective than these other herbicides (*p* < 0.05). The double pass treatments usually gave better control than the single pass treatments, though the improvement was only significant (*p* < 0.05) for glyphosate and the triclopyr/picloram mixture. The largest decrease in stem density came from the double pass of glyphosate, resulting in an average 0.85 stems m\(^{-2}\) compared with 12.7 stems m\(^{-2}\) in untreated plots (Table 3).

Table 3. The *C. arvense* stem density resulting from single and double passes of wiping four herbicide treatments, assessed 10 months after application.

| Herbicide               | Number of Passes | Number of Stems/m\(^2\)*<sup>f</sup> |
|-------------------------|------------------|-------------------------------------|
| untreated control       | single           | 12.7 a                              |
| clopyralid              | single           | 3.4 c                               |
| clopyralid              | double           | 1.3 cd                              |
| glyphosate              | single           | 3.4 c                               |
| glyphosate              | double           | 0.85 d                              |
| metsulfuron             | single           | 3.0 cd                              |
| metsulfuron             | double           | 2.3 cd                              |
| triclopyr/picloram      | single           | 7.1 b                               |
| triclopyr/picloram      | double           | 2.6 cd                              |

*Within the column, the means that share at least one letter are not significantly different (LSD, *p* < 0.05).*

Herbicide wiping treatments had a dramatic effect on clover despite being under the height of the wiper (Figure 2). The results showed that clover was almost eliminated from plots treated with clopyralid, metsulfuron and triclopyr/picloram while the clover content of glyphosate-treated plots was not different from the untreated control. The content of clover in plots treated with clopyralid, metsulfuron and triclopyr/picloram remained substantially less than that of the untreated control or glyphosate 10 months after treatment. Glyphosate and metsulfuron caused some short-term damage to grass plants at the base of *C. arvense* stems though generally it was minimal (Table 4) with the injury symptoms having disappeared after 8 weeks. The dead grass did not create large bare patches as the plants recovered quickly. No grass damage was recorded in clopyralid- and triclopyr/picloram-treated plots.

Table 4. Injury scores to pasture clovers and grasses for a double pass 5 weeks after application of herbicides, where 1 = total mortality and 10 = no effect.

| Treatment               | Clover Score *<sup>f</sup> | Grass Score *<sup>f</sup> |
|-------------------------|-----------------------------|---------------------------|
| Untreated control       | 10.0 a                      | 10.0 a                    |
| Clopyralid              | 8.9 bc                      | 10.0 a                    |
| Glyphosate              | 9.2 b                       | 9.3 b                     |
| Metsulfuron             | 8.4 bc                      | 9.3 b                     |
| Triclopyr/picloram      | 8.1 c                       | 9.9 a                     |

*Within columns, scores that share at least one letter are not significantly different (LSD, *p* < 0.05).*

Herbicide wiping with metsulfuron also affected the occurrence of other weed species in the plots. Although *Hypochoeris radiata* L., *Taraxacum officinale* L., *Crepis capillaris* (L.) Wallr., *Leontodon taraxacoides* (Vill.) Merat, *Ranunculus repens* L., *Plantago major* L., *Plantago lanceolata* L., *Mentha pulegium* L. and *Veronica serpyllifolia* L. were found in all other treatments, they were absent in metsulfuron-treated plots. There was only a single plant of
Galium aparine L. found in one metsulfuron-treated plot. Thus, metsulfuron plots contained significantly fewer weeds (other than C. arvense) \( (p < 0.05) \) compared to all other herbicide treatments 3 months after treatment (Figure 3), but also little clover. There was also no difference in the occurrence of these weeds between the untreated control plot and those treated with clopyralid, glyphosate, and triclopyr/picloram.

In contrast to Experiment 1, no treatment in Experiment 2 resulted in a significant decrease in C. arvense stems compared with the untreated control when assessed in the following spring (Figure 4). The lowest number of C. arvense stems was recorded for the two metsulfuron treatments and the clopyralid flower bud treatment, and they both were significantly different from glyphosate applied at late post-flowering for which the highest number of C. arvense stems was recorded.
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poorly controlled by selective herbicides because of its underground vegetative structures. 

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Figure 3. Average number of weeds per m\(^{-2}\) for a double pass 3 months after wiper application of herbicides. 
Bars with the same letter are not significantly different (LSD, \(p < 0.05\)).

Figure 4. The number of C. arvense stems/m\(^{2}\) after wiper application of herbicides at different stages. 
Bars with the same letter are not significantly different (LSD, \(p < 0.05\)).

Analysis of clover content showed that the content of clover in both metsulfuron treatments and glyphosate late post-flowering was significantly less than that of the untreated control (Figure 5). However, no significant differences were recorded in clover content between the untreated plot and wiper application of other herbicides. There was no visible grass injury in any of the treated plots and the composition of other weed species was also not affected by treatments (data not shown).

Figure 5. Average clover content of plots at 6 weeks after wiper application of herbicides. 
Bars with the same letter are not significantly different (\(p < 0.05\)).

4. Discussion

There are a few herbicides that can be used to selectively manage weeds in New Zealand pastures using broadcast application [1,21]. However, evolution of resistance to those herbicides in some pasture weeds [22,23] implies that an alternative approach is required to control weeds selectively in pastures. Wiper applicators allow herbicides to be selectively delivered to target weeds, thereby avoiding application to nearby desirable pasture plants. In this research, we assessed if this technology can be deployed to selectively control C. arvense, a problematic weed species in New Zealand pastures which is currently poorly controlled by selective herbicides because of its underground vegetative structures.
Compared with other published reports [3,8,12], the levels of *C. arvense* control achieved in Experiment 1 were the best recorded for a one-off treatment of this weed species in pastures using weed wipers. If these levels of control can be consistently achieved, then this could become the treatment method of choice for selective control of *C. arvense* in pastures where the contours of the land allow use of a weed wiper. Complete control of *C. arvense* generally requires more than a single treatment of herbicides or a combination of control techniques [15]. However, the results of the Experiment 1 showed that a single application of herbicide using a wiper applicator could cause a major decrease in the shoot density of *C. arvense* when measured 10 months later, which would presumably mean the weed would be severely retarded for some time. Similarly, it has been shown that the effects of a single wiper application of glyphosate to *C. arvense* can last for at least 2 years [12]. However, it would not cost much to do a follow-up wiping treatment of the remaining stems in the following year since the amount of herbicide applied is directly proportional to the density of *C. arvense*.

However, comparison of the results of our research to those from different studies is difficult because many studies have used 33% solutions of 360 g L$^{-1}$ glyphosate formulations which was much more concentrated than the 5% solutions used in this experiment [12,24]. It has been shown that more concentrated glyphosate leads to poor control of *C. arvense* as concentrated glyphosate results in rapid tissue death and hence reduced translocation of the herbicide in the treated plants [25]. However, some studies have shown that using 33% solutions of glyphosate resulted in 80% control of *C. arvense* [12], suggesting that there is potential to use more concentrated herbicide where necessary especially when the weed density is high.

Wiper application in two directions (double passes) appeared to have increased the efficacy of glyphosate and triclopyr/picloram, probably by increasing the surface area of foliage to which the herbicide was applied [7]. This would result in more herbicide translocating through the plant in sufficient quantities to kill the root [26,27]. Most farmers would prefer to wipe in only one direction to decrease the time spent treating weeds and may prefer to use much more concentrated herbicides to achieve the desired control.

Although single pass treatments were not quite as effective as double pass treatments, they gave adequate control of *C. arvense* plants and the level of *C. arvense* control in Experiment 1 was better compared to some previous wiping studies [16,25]. It is likely that the high density of *C. arvense* in the first experiment could have compromised the performance of the single pass relative to the double pass treatment. However, the much greater wiping surface of a rotary weed wiper compared with ropewick applicators makes two-way passes less important now than when wiping equipment was first used for weed control in the 1980s [28].

Variable results have also been achieved when *C. arvense* has been treated at different growth stages. Previous research showed that wipe application of glyphosate on *C. arvense* at the bolting to bud stage and at the full flower stage resulted in 20 and 66% control, respectively, with 2,4-D/picloram and 2,4-D/dicamba applied at the bolting stage actually increasing the number of shoots [29]. Grekul et al. [12] noted that wiper application of glyphosate to control *C. arvense* in pastures resulted in a reduction in density from 68 to 80% during a 3-year period. The same study also found that wiping at the flower bud stage was more effective than at later stages. However, the above comparison between different stages was done in different seasons and at different sites making it difficult to make a valid conclusion. In contrast, pot studies have shown that application of glyphosate at the post-flowering stage is more effective than treating at earlier growth stages [3].

In contrast to Experiment 1, the treatments in Experiment 2 were primarily ineffective, and there was also less pasture damage. From these results, it is not possible to conclude the optimum growth stage for the control of *C. arvense* using weed wipers, though the post-flowering stage was very effective in Experiment 1. There are several reasons to explain the poor control of *C. arvense* in the second experiment. Firstly, as flowers act as a strong sink for sugars at the flower-bud stage, applying herbicides to upper parts of the stem at this
stage will result in little movement of herbicides to the roots [13]. Secondly, the C. arvense in Experiment 2 were severely stressed and this could explain the lack of effectiveness of the herbicides. Moisture stress can negatively affect the absorption and translocation of herbicides in plants [30]. In addition, the plants were heavily infested with aphids and covered in sooty mould as well as the drought stress and pest damage, the other possible reason for the poor control of C. arvense could have been due to an alteration of physiology of the plants as a result of the removal of flower heads due to grazing pressure [31]. Rainfall occurring soon after application of the final treatment of glyphosate in Experiment 2 may also have been important. The poor control in the second experiment shows the importance of understanding variables than can affect downward translocation of applied herbicides.

Although wipers provide more selective application of herbicides than broadcast application [9], this study and research elsewhere have shown that some damage to pasture plants does occur from wiper application of herbicides [12,29]. The damage to pasture plants recorded by these other reports did not result in complete elimination of the clover as happened in some treatments in Experiment 1. Various hypotheses have been proposed as to how the damage to pasture plants occurs. It is possible that the damage could be due to dripping from the roller or splattering from plants bouncing up after passing under the roller [12]. Rainfall washing off herbicides from treated plants and exudation from roots could be other potential reasons behind pasture damage after wiper application of herbicides [17,32]. In addition, decomposition of plant tissue can release some levels of residues in the soil leading to pasture damage [33]. As rainfall washing the herbicide off leaves appears the most likely reason for the damage, there may be potential to reduce this by using ester formulations of herbicides which may be less susceptible to washing off after application, though this was not investigated in these experiments.

Results from Experiments 1 and 2 suggest that rainfall after herbicide application was the most likely cause of pasture damage [17]. Several factors, including total rainfall, its distribution, and the number of days between treatment of plants and onset of rain play a pivotal role in determining the severity of the damage [34]. The total rainfall and its onset after treatment was different for the two seasons (Figure 1), and this could have affected the response of C. arvense to herbicides as well as the differences in pasture damage. In Experiment 1, rainfall occurred only 3 days after application which was likely to have washed off herbicide on to neighbouring pasture plants causing substantial damage. In Experiment 2, there was no rain for more than a week after most treatments; hence, there was less pasture damage though clover was damaged under plants in the final glyphosate treatment where it rained on the day of treatment. In the first experiment, glyphosate washed off plants did not cause substantial damage to clover implying that clover can tolerate low levels of this herbicide better than low levels of clopyralid or metsulfuron.

5. Conclusions

The potential of using wiper application technology to selectively manage C. arvense in pastures was investigated in this research. The results showed that the best control of C. arvense was achieved at the post-flowering stage with a double pass when plants were actively growing, though results were poor when plants were stressed. Glyphosate, clopyralid and metsulfuron were similar in effectiveness though glyphosate was generally less damaging to clovers if rain later washed herbicide off treated plants.

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Data Availability Statement: Data is contained within the article.

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