Are root exudation or rainfall on treated plants likely causes of pasture damage after wiper application of herbicides?

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Summary Wiper application of herbicides to weeds sometimes causes damage to pasture plants, especially white clover, growing immediately under the wiped weeds. Two experiments were conducted to determine the potential for either exudation of herbicide from roots or rainfall washing herbicide off treated plants to cause damage to white clover after wiper application. In Experiment 1, Californian thistle and white clover were grown in the same pots within a glasshouse, then either metsulfuron or a triclopyr/picloram mixture were applied to the Californian thistle using a Rotowiper. White clover growing in pots below treated plants was significantly affected by the metsulfuron but not the triclopyr/picloram mixture, when compared with the untreated control plants. In Experiment 2, Californian thistle, white clover and perennial ryegrass were grown in separate pots within a glasshouse. Glyphosate, clopyralid, metsulfuron and a triclopyr/picloram mixture were applied to Californian thistle plants using a Rotowiper. The treated Californian thistle plants were then exposed to artificial rain from a rainfall simulator either 1 or 5 days after herbicide treatment, with pots of white clover and perennial ryegrass positioned under each Californian thistle plant during the rainfall event. All of the herbicides except glyphosate significantly affected white clover for both rainfall events, whereas only metsulfuron significantly affected perennial ryegrass for the Day 1 washing. Thus although damage from herbicide exudation does appear possible, rainfall following wiper applications is probably more likely to cause damage to clover growing under treated plants.

Keywords Herbicide, wiper application, clover damage, root exudation, Californian thistle.

INTRODUCTION

Vegetation growing under tall weeds is often unintentionally affected by application of herbicides using weed wipers (Grekul *et al*. 2005). White clover (*Trifolium repens* L.) damage as a result of application of herbicides to Californian thistle (*Cirsium arvense* (L.) Scop.) using a weed wiper has been recorded in trial work though damage to perennial ryegrass (*Lolium perenne* L.) was found to be negligible (Moyo 2008). Herbicide movement to non-target plants from herbicide-treated plants could occur after wiper application via loss of herbicide from foliage through rainfall (Campbell and Nicol 1998). Herbicide washed off foliage during rainfall landed on pasture and soil where it could be absorbed by plants and cause damage to pasture. Triclopyr, picloram, metsulfuron and clopyralid can remain active in the soil for several months after application, can be absorbed through roots and white clover is very sensitive to all these herbicides (Tomlin 2009). Glyphosate, the other herbicides often used in wipers, would be rendered inactive within the soil (Franz *et al*. 1997), though all herbicides could also penetrate foliage of pasture plants.

Herbicides could also be released from treated weeds through root exudation (Hickman *et al*. 1990). Root exudation is defined as the release of substances from inside a plant by either secretion or passive movement into the surrounding media from plant roots (Baetz and Martinoia 2014). Several herbicides have been shown to move from treated plants and cause injury to untreated neighbouring plants through exudation (Coupland and Peabody 1981, Dinelli *et al*. 2003, Hickman *et al*. 1990). The objective of this study was to evaluate the relative importance of root exudation and rainfall washing off herbicides from treated plants in damaging white clover following wiper application to weeds.

MATERIALS AND METHODS

Experiment 1 In this experiment the occurrence and significance of root exudation of foliar-applied herbicides from Californian thistle was evaluated. Californian thistle root fragments (at least 5 cm long) were collected on 8 November 2006 from pasture near Palmerston North, New Zealand. The root fragments were planted into 2000 cm^3 PB3 planter bags with potting mix as described by Moyo (2008). The bags were kept in a glasshouse and watered with a capillary matting system. White clover seeds were sown into the same planter bags (70 seeds per bag) on 11 December 2006.

The Californian thistle plants were treated using a Rotowiper on 9 February 2007, with either a mixture of 100 g L^{-1} picloram as an amine salt plus 300 g L^{-1} triclopyr as butoxy ethyl ester (Tordon Brushkiller®) at 1 part herbicide to 39 parts water, or with 200 g a.i. kg^{-1} metsulfuron as a methyl ester (Answer®) at 3 g product per litre of water (recommended rates for both products when used in wipers). The plants, supported by concrete blocks, were arranged in a single row on asphalt pavement. The bags and the white clover growing in them were covered by a plastic skirt to prevent any contamination of the clover with herbicide from the wiper. The thistles were at the early post-flowering stage and averaged 60 cm in height.

After treatment and when the plants had dried, the plastic skirts were removed and plants were returned to the glasshouse to sub-irrigated benches. The mean daily temperature in the glasshouse during the experiment ranged from 23.2°C in February to 14.0°C in May. The experiment was a randomised complete block design with three treatments, i.e. the two herbicide treatments and an untreated control. Plants were allocated to blocks based on the amount of white clover in each bag. Each treatment was replicated ten times. Visual assessments of foliar injury symptoms were conducted on average every three weeks until 14 May when the foliage of both the thistles and white clover were separately harvested, dried at 80°C for 24 hours and weighed.

Experiment 2 The objective of this experiment was to investigate whether rainfall might wash off sufficient herbicide from treated plants to damage pasture underneath. Californian thistle plants were established as described for Experiment 1, except root fragments were collected on 6 October 2006 and no clover was grown in the same pots. White clover was instead sown in separate 200 cm^3 pots on 5 January 2007 with 35 seeds per pot. Perennial ryegrass was also established in other 200 cm^3 pots on 10 January 2007 with 32 seeds per pot. All plants were grown in a glasshouse and irrigated as described for Experiment 1.

The herbicides used were Tordon Brushkiller® and Answer® at the same rates as in Experiment 1, clopyralid (Versatill®, 300 g a.e. L^{-1} as amine salt) at 1 part herbicide to 39 parts water, and glyphosate (Roundup Renew®, 360 g a.e. L^{-1} as isopropylamine salt) at 1 part herbicide to 19 parts water. The thistles were treated on asphalt pavement as in Experiment 1 on 9 February 2007 using a Rotowiper, and a different roller was used for each herbicide. Using a rainfall simulator, treated plants later received rainfall 1 or 5 days after the herbicides were applied. The thistles were placed under the simulator for 30 seconds and received the equivalent of 2.0 mm of rainfall. Four pots of white clover and four pots of perennial ryegrass were placed around each Californian thistle plant during rainfall simulation to intercept any herbicide that washed off the treated thistle

The experiment had a randomised complete block design with four herbicide treatments, two untreated controls for each species, and two simulated rainfall periods (1 day and 5 days) after treatment. Treatments were blocked on the size of the thistle plants. Each treatment was replicated six times, and as each of the six thistle plants had four pots of white clover and four pots of perennial ryegrass, each treatment had 24 pots of both clover and ryegrass. Clover and ryegrass were analysed separately. Visual assessments of foliar injury symptoms were recorded by scoring the white clover and perennial ryegrass plants as described for Experiment 1. The scoring was done until the foliage of the clover and ryegrass was harvested in mid-April by cutting at ground level, drying at 80°C for 24 hours then weighed.

Statistical analysis The visual scores and dry weights were subjected to an analysis of variance using the statistical software package SAS (SAS 2004) and means were separated using LSD tests at the 5% level of probability.

RESULTS

Experiment 1 White clover plants growing under Californian thistle plants treated with metsulfuron had significantly lower dry weight than both the untreated control and the triclopyr/picloram treatment (Table 1). Visual injury scores also showed a similar result (data not shown).

The dry weight of the thistle stems treated with either metsulfuron or triclopyr/picloram was similarly reduced relative to the untreated control (Table 1). Injury scores on thistle stems showed a similar result to the dry weight (data not shown). Not all of the thistles died as a result of the treatments with only 60% and 70% of plants dying completely for metsulfuron

Table 1. The dry weight (g pot^{-1}) of white clover and Californian thistle grown together in pots, measured 13 weeks after treatment of the thistle with metsulfuron and triclopyr/picloram mixture.

	White clover	Californian thistle
Metsulfuron	1.65 b*	11.0 b
Triclopyr/picloram	6.64 a	10.3 b
Untreated	7.10 a	16.8 a

* Means with the same letter within a column are not significantly different at P ≤0.05.

and triclopyr/picloram, respectively, probably due to insufficient herbicide being applied.

Experiment 2 There was extensive damage to white clover 20 days after simulated rainfall events at 1 and 5 days after treatment (DAT) had washed off the herbicide from the Californian thistle plants. All herbicides except glyphosate caused significant levels of damage to white clover plants under the Californian thistle when artificial rain was applied (Table 2). Clopyralid and metsulfuron washed off the thistle plants 1 DAT were particularly damaging. Herbicide injury symptoms ranged from minor leaf discolouration to complete necrosis.

Perennial ryegrass showed few signs of being affected 20 days after the simulated rainfall event, with the only significant difference in scores occurring for the metsulfuron washed 1 DAT.

Nine weeks after treatment (WAT) when the plants were harvested, severe herbicide damage to white clover was measured following metsulfuron and clopyralid washing off the Californian thistle plants on both Day 1 and Day 5 (Table 3). There was a smaller amount of damage to clover caused by the triclopyr/picloram mixture, which was significant only for the Day 1 washing. Effects from glyphosate were not significant.

As with the scoring 20 days after the rainfall event, the only significant herbicide damage to perennial ryegrass 9 WAT was a reduction in growth of plants under metsulfuron-treated thistles for the Day 1 washing (Table 4). The ryegrass exposed to metsulfuron at Day 5 was not significantly lower in dry weight than untreated plants, though it was significantly less than ryegrass plants exposed to glyphosate or the triclopyr/picloram mixture. Although white clover exposed to metsulfuron washings at Day 1 had a dry weight only 15% that of untreated plants, the perennial ryegrass plants exposed to metsulfuron at Day 1 were 71% the weight of untreated plants.

DISCUSSION

There was some evidence that root exudation of metsulfuron contributes to pasture damage caused by wiper application of herbicides. Damage caused by exudation in Experiment 1 may have been accentuated as roots were restricted to pots in which they were growing. Other studies have concluded that unless a large amount of the root system of a companion crop comes into contact with roots of treated plants, herbicide release from treated plants appears unlikely to be important (Penn and Lynch 1982).

There is no obvious reason to explain why metsulfuron damaged the white clover in Experiment 1, yet triclopyr/picloram did not, unless metsulfuron is more easily exuded than triclopyr/picloram. Field results from wiper application of herbicides showed that metsulfuron and triclopyr/picloram both caused damage to pasture (Moyo 2008). If exudation of herbicides was the primary cause, then both herbicides in

Table 2. The effect after 20 days on white clover (using scores from 0 = severe damage to 10 = no damage) of herbicides washed off Californian thistle 1 or 5 days after treatment (DAT).

	1 DAT	5 DAT
Clopyralid	5.1 c*	6.1 c
Glyphosate	9.1 a	9.1 ab
Metsulfuron	4.9 c	6.1 c
Triclopyr/picloram	8.0 b	8.7 b
Untreated	10.0 a	10.0 a

* Means with the same letter within a column are not significantly different at P ≤0.05.

Table 3. The dry weight (g pot^{-1}) of white clover plants harvested 9 weeks after being placed under Californian thistle plants from which herbicides were washed off 1 or 5 days after treatment (DAT).

	1 DAT	5 DAT
Clopyralid	2.36 c*	2.37 b
Glyphosate	4.83 a	4.96 a
Metsulfuron	0.78 d	0.98 c
Triclopyr/picloram	3.63 b	4.74 a
Untreated	5.13 a	5.27 a

* Means with the same letter within a column are not significantly different at P ≤0.05.

Table 4. The dry weight (g pot^{-1}) of perennial ryegrass plants harvested 9 weeks after being placed under Californian thistle plants from which herbicides were washed off 1 or 5 days after treatment (DAT).

	1 DAT	5 DAT
Clopyralid	1.23 a*	1.17 ab
Glyphosate	1.19 a	1.24 a
Metsulfuron	0.79 b	0.97 b
Triclopyr/picloram	1.07 a	1.23 a
Untreated	1.12 a	1.15 ab

* Means with the same letter within a column are not significantly different at P ≤0.05.

Experiment 1 should have caused some damage to the white clover growing with the thistles. Unfortunately no soil tests were conducted of herbicide residues within these pots to assist with interpretation of results.

The widespread damage to clover under treated Californian thistles when rain was simulated showed that washing off of herbicides is a more likely cause of pasture damage. The results of this experiment confirm results from earlier weed-wiping studies in which damage was caused to plants by rainfall washing off herbicides from the treated plants (Campbell and Nicol 1998).

Metsulfuron and clopyralid were highly damaging to white clover while the effect of glyphosate was minimal, and the triclopyr/picloram mixture caused moderate damage. The lack of damage to white clover by glyphosate following wiping is in agreement with field studies (Grekul *et al*. 2005, Moyo 2008, Thompson 1983). Low rates of glyphosate tend to be ineffective against both white clover and perennial ryegrass (Casey *et al*. 2000) which could explain the results. The ester formulation of the triclopyr/picloram mixture may have allowed it to enter the Californian thistle rapidly enough to prevent much being washed off by rain. The partial damage to perennial ryegrass by metsulfuron has been noted in the field following wiping (Moyo 2008).

Another possible mechanism for clover under Californian thistle to be damaged by herbicides applied by wipers is through splattering of herbicide at the time of impact by the wiper. This was investigated by Moyo (2008) and appears to be less important than wash off from rainfall.

Although there can be some damage to pasture following rainfall, Moyo (2008) showed that this only occurs with some applications, and no damage appeared if rain did not occur for a few days after application, or if either a small or very large amount of rainfall occurred. These observations involved work with glyphosate, metsulfuron and clopyralid. Thus further research is required about this interaction between rainfall and damage to pasture.

In conclusion, although it appears that herbicide damage can occur due to herbicide washing off pasture plants, observations in the field by Moyo (2008) and results from Experiment 2 suggest that glyphosate causes the least damage to both white clover and perennial ryegrass of the herbicides investigated.

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