Efficacy and crop selectivity of saflufenacil alone and with partner herbicides for weed control in maize

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Abstract The recently developed herbicide saflufenacil was evaluated in six field trials, between 2008 and 2011, for weed control in maize (*Zea mays*) crops. Trial sites varied considerably in soil characteristics and weed spectrum. No phytotoxicity or visual damage symptoms were observed in any of the six cultivars planted. When used alone at 70 or 105 g ai/ha, saflufenacil provided effective control of annual broadleaf weeds including atrazine- and dicamba-resistant fathen (*Chenopodium album*), but had little activity on grass weeds. In combination with acetochlor, both rates of saflufenacil provided good control of annual grass and broadleaf weeds in all but one trial. In crops with a high weed pressure, especially grass weeds, a follow up post-emergence herbicide would be required to maximise control. Combinations of saflufenacil with up to 1200 g ai/ha of dimethenamid-p were generally less effective than with acetochlor. A strong negative relationship was evident between weed density and maize silage or grain yields.

Keywords saflufenacil, Sharpen®, herbicide, pre-emergence, weed control, maize, *Zea mays*, acetochlor, dimethenamid-p.

INTRODUCTION

In general, the cost of controlling weeds in maize (*Zea mays*) is small relative to total production costs. However, economic yield without weed control is a virtual impossibility. In the Waikato region where the weed seed bank is frequently very large (Rahman et al. 2006), competition from uncontrolled weeds has resulted in yield losses of up to 70% (Rahman & James 1992; James & Rahman 1994; James et al. 2000). Pre-emergence grass herbicides, often in combination with atrazine or terbuthylazine, are the major chemical weed control options currently available to maize growers (James et al. 2010). This spray programme usually provides satisfactory control

of most annual weeds in the maize crop. However, in recent years growers have faced problems with herbicide resistance (Rahman et al. 2001, 2008), herbicide persistence (Rahman & James 2002), shortened periods of weed control due to enhanced degradation (James et al. 2010), and changes in weed spectrum towards more difficult to control weeds (James et al. 2007).

Saflufenacil is a new herbicide of the pyrimidinedione chemical class that can be used in a wide range of agricultural situations from pre-emergence through to pre-harvest desiccation in many crops including maize (Liebl et al. 2008). Its mode of action is to inhibit the

enzyme protoporphyrinogen IX oxidase (PPO), which in turn prevents chlorophyll biosynthesis (Grossmann et al. 2010). There is also a rapid loss of membrane integrity and cellular leakage resulting in tissue necrosis and ultimately plant death. After application saflufenacil elicits rapid (within 4 h) light-dependant wilting and necrosis of shoot tissue, as is common with all PPO inhibiting herbicides (Matringe et al. 1993).

The main spectrum of activity for saflufenacil is limited to broadleaf weeds but when mixed with certain partner herbicides, control of grass weeds is often enhanced. Depending on the application situation and dosage, it can exhibit residual and/or contact activity. It is readily absorbed by plant roots, shoots and leaves. Translocation is predominantly via the xylem with little phloem activity. Selectivity is conferred via both physical placement and plant tolerance (Grossmann et al. 2010; Liebl et al. 2008). Saflufenacil can be used in maize pre-emergence at 63–125 g ai/ha for control of broadleaf weeds, including large-seeded species such as velvetleaf (*Abutilon theophrasti*) and cocklebur (*Xanthium strumarium*) (Liebl et al. 2008). This herbicide has been introduced to New Zealand as a 700 g/kg wettable granule formulation (Sharpen® WG) and is pending registration for control of weeds in maize. This paper reports on a series of field trials carried out to determine its selectivity to maize crops, optimum use rates and the most suitable partner herbicide for New Zealand conditions.

MATERIALS AND METHODS

Six field trials were conducted between 2008 and 2011 on commercial maize properties in Waikato and Bay of Plenty, with two trials laid down in each of the three growing seasons. Location of these trials is listed in Table 1, along with some soil details, planting dates and herbicide spraying dates for each trial.

All trials were of a randomised block design and the treatments were replicated four times. The treatments consisted of different rates of saflufenacil applied pre-emergence and their combinations with either acetochlor or dimethenamid-p. These were compared with acetochlor alone, a standard treatment (Treatment 3) and an untreated control (Table 3). Each plot was 10 m long by 3 m wide with 50 cm wide maize rows for Trials 1, 2 and 6 and four 75 cm wide maize rows for Sites 3–5. All pre- and post-emergence treatments were applied to the entire plot with a precision CO₂ powered back pack sprayer using four TeeJet 11003 nozzles at 75 cm spacing and applying 200 litres/ha spray mix at 190 kPa. All trials received starter fertiliser at planting and a side dressing of urea as per commercial practice.

Weed species present in the trials were recorded and herbicide efficacy and level of weed control were assessed visually on three occasions using relative weed ground cover scores (%) and observational notes. Weed species abundance was determined on two occasions for each trial using two representative 0.1 m² quadrats/plot.

Table 1 Some details of the six field trials.

Trial No.	Location	Soil texture	Soil pH	Organic C (%)	Planting date	Pioneer® cultivar	Spraying date	
							Pre	Post ²
1	Horotiu	Sandy loam	5.8	4.8	11.11.08	33G26	12.11.08	15.12.08
2	Gordonton	Clay loam	6.2	4.1	21.10.08	35A30	22.10.08	3.12.08
3	Tamahere	Sandy loam	7.2	5.3	13.10.09	38P05	19.10.09	10.12.09
4	Matamata	Silt loam	7.1	5.7	4.11.09	37Y12	7.11.09	10.12.09
5	Matata ¹	Loamy sand	5.6	5.0	13.10.10	35Y33	15.10.10	11.11.10
6	Gordonton	Peaty loam	5.5	17.4	30.10.10	34P88	3.11.10	3.12.10

¹Bay of Plenty, the other five sites all in Waikato.

²Post-emergence applied to Treatment 3 only.

Within each quadrat individual weed species were identified and counted.

Maize silage yields were measured in February/March at the time of commercial silage harvest. Five representative maize plants per plot were cut at 10 cm above ground level and the fresh weight recorded on site. Ten representative plants from each trial were collected and taken to the lab, placed in the oven at 80°C until dry to determine dry matter weights and calculate silage yield. Maize grain yield was measured by collecting all cobs along two 4 m representative strips from two central rows of maize in each plot. The number of maize plants was counted along these two 4 m strips to determine plant populations. The cobs were air-dried before shelling. A sub-sample was dried in the oven at 105°C for 40 h to determine the moisture content of the grain. The shelled maize weight was recorded and yields were adjusted to 14% moisture content.

All data were subjected to ANOVA to separate the means. The treatment arithmetic means and least significant difference (LSD) are presented for the visual control scores and silage and grain yields for each trial site.

RESULTS AND DISCUSSION

Herbicide compatibility and crop selectivity

Thorough mixing and stirring was required for the saflufenacil WG formulation to ensure that all the granules had dissolved properly and were not left on the bottom. Once mixed and dissolved it remained in suspension well. It also mixed easily with other products used in these trials.

Six different maize cultivars (Table 1) were planted by the growers at these trial sites, each with different growth characteristics. Visual observations of maize plants following emergence and during the growing season showed no phytotoxic damage symptoms in any of the trials from saflufenacil or any of the other herbicides at the rates evaluated.

Herbicide efficacy and maize yield – 2008/09

The site for Trial 1 had a very low weed seed bank, with little weed pressure throughout the growing season (Table 2). At 5 weeks after treatment (WAT), little difference in weed cover was evident between different plots and by January 2009 (8 WAT) the untreated control had only 33% weed cover (Table 3). Even by February

Table 2 Major weed species and their density (number/m²) in untreated plots at two assessment times (around the time of post-emergence spraying and near the end of the trial).

	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5		Trial 6	
Weeks after treatment	5	13	6	12	8	13	7	10	6	10	6	8
Broadleaf weeds												
<i>Chenopodium album</i>	-	-	66	70	6	11	104	49	230	95	94	101
<i>Solanum nigrum</i>	4	6	-	-	-	-	-	-	-	-	5	6
<i>Persicaria maculosa</i>	-	-	3	6	-	-	-	-	-	-	13	3
<i>Rumex obtusifolius</i>	-	-	-	-	-	-	23	7	-	-	3	-
<i>Lepidium didymum</i>	-	-	6	-	4	3	-	-	-	-	-	-
<i>Polygonum aviculare</i>	-	-	11	3	-	-	-	-	-	-	-	-
<i>Capsella bursa-pastoris</i>	-	-	-	-	9	3	-	-	-	-	-	-
<i>Amaranthus</i> spp.	-	-	-	-	8	9	3	1	-	-	-	-
<i>Oxalis</i> spp.	-	-	-	-	29	14	-	-	-	-	-	-
Grass weeds												
<i>Digitaria sanguinalis</i>	10	14	14	5	-	-	11	3	2000	960	28	31
<i>Panicum dichotomiflorum</i>	-	-	-	-	-	-	8	6	20	15	9	6
<i>Setaria pumila</i>	-	-	45	16	-	-	-	-	-	-	-	-
<i>Lolium multiflorum</i>	-	-	3	-	6	4	-	-	-	-	-	-

(13 WAT) the weed cover had reached only 40%, with an average of six *Solanum nigrum* and 14 *Digitaria sanguinalis* plants/m² (Table 2). There were also a few plants of the perennial weeds, *Cirsium arvense* and *Paspalum distichum*, which none of the treatments controlled well.

The combination treatments of acetochlor and saflufenacil provided good control of *D. sanguinalis* and broadleaf weeds, as shown by weed cover scores at 8 WAT in Table 3. Dimethenamid-p also gave good control of summer grass and in combination with the high rate of saflufenacil (Treatment 14) was equivalent to acetochlor combinations for efficacy in this trial. Maize silage yield was good in all plots in Trial 1, with no significant differences between treatments. This was indicative of the low weed pressure at this site, as the untreated control had equally good silage yield (Table 4). The grain yield was not determined at this site because a late decision was made by the grower to harvest for silage.

The site for Trial 2 had moderate weed pressure including both the annual broadleaf and grass species. By 6 WAT, the untreated plots had 46% weed cover, with an average infestation of 86/m² and 62/m² of broadleaf and grass weeds, respectively (Table 2). Nearly complete weed ground cover occurred at around 8 weeks. The combinations of saflufenacil with both acetochlor and dimethenamid-p (Treatments 9, 10 and 14) provided effective season-long weed control, having significantly less weed cover than their single herbicide counterparts (Table 3). Saflufenacil alone at 70 or 105 g/ha (Treatments 5 and 6), although providing good broadleaf control (data not shown), did not control the grass weeds that contributed to the higher cover scores (Table 3). In combination with acetochlor both these rates performed as well as the acetochlor plus the post-emergence treatment (Treatment 3). The weed cover in plots treated with acetochlor alone (Treatment 2) at 8 WAT consisted mainly of broadleaf weeds, *C. album* and *Polygonum aviculare*, with a few plants of *Setaria pumila*.

In Trial 2 the untreated control produced significantly less silage than the saflufenacil

combination treatments and less grain yield than all treatments (Table 4). Grain yield was very good for all treatments that had effective broadleaf control, ranging between 14.2 and 15.6 t/ha (Table 4).

Herbicide efficacy and maize yield – 2009/10

Weed growth was slower during this season as 100% weed cover in untreated plots occurred 2–4 weeks later than the 2008/09 season. In Trial 3 all herbicide treatments had less than one quarter of the weed cover recorded in untreated plots at 7 WAT (Table 3), which comprised mostly the hard-to-control weed species (*Oxalis vallicola*, *Lolium multiflorum* and *Solanum tuberosum*). In Trial 4 assessment of individual weeds at 5 WAT also showed good control of annual broadleaf weeds including *C. album*, known to have resistance to dicamba (Rahman et al. 2008), but the perennial species *Rumex obtusifolius* and *C. arvense* had patches in many plots, leading to high weed cover scores. Final weed cover scores and weed counts for both trials showed that overall the two low rate combinations with dimethenamid-p (Treatments 12 and 13) were not adequate for long term broadleaf weed control. The combinations of saflufenacil with acetochlor were more effective than those with dimethenamid-p. The higher level of broadleaf control offered by acetochlor combinations appears to have resulted in this difference (data not shown). The addition of post-emergence nicosulfuron to the standard treatment of acetochlor/atrazine (Treatment 3) reduced the combined cover of broadleaf and grass weeds to 11% (Table 3).

In Trial 3 all treatments resulted in silage and grain yields significantly higher than the untreated control. No differences in yields were recorded between treatments (Table 4), indicating good efficacy of all treatments in providing good weed control until canopy closure. Results for silage yield were similar in Trial 4, although the grain yield was lower in Treatment 12, which had a high infestation of *C. arvense* competing early with the growing crop.

Table 3 Weed cover scores (%) for the six trials at the time of post-emergence spraying and near maximum weed cover in untreated plots.

Treatment and rate (g ai/ha) Weeks after treatment		2008/09 Season				2009/10 Season				2010/11 Season			
		Trial 1		Trial 2		Trial 3		Trial 4		Trial 5		Trial 6	
		5	8	6	8	7	12	5	10	4	6	4	8
1	Untreated	8	33	46	98	35	97	25	96	73	100	33	96
2	acetochlor 2520	3	7	4	18	-	-	-	-	23	80	8	41
3	Acetochlor 2520/atrazine 1500 + Post-em ¹	3	1	5	1	5	10	13	11	18	9	6	1
4	saflufenacil 53	-	-	-	-	-	-	-	-	41	91	-	-
5	saflufenacil 70	5	23	18	70	-	-	-	-	40	93	16	58
6	saflufenacil 105	5	13	23	73	-	-	-	-	38	92	13	61
7	saflufenacil 140	-	-	-	-	-	-	-	-	-	-	8	50
8	saflufenacil 53 + acetochlor 2520	-	-	-	-	2	10	17	34	23	80	-	-
9	saflufenacil 70 + acetochlor 2520	3	4	0	1	3	10	16	28	13	66	3	12
10	saflufenacil 105 + acetochlor 2520	3	8	0	1	-	-	-	-	13	66	2	8
11	saflufenacil 140 + acetochlor 2520	-	-	-	-	-	-	-	-	-	-	3	11
12	saflufenacil 53 + dimethenamid-p 441	-	-	-	-	8	23	38	86	-	-	-	-
13	saflufenacil 70 + dimethenamid-p 600	-	-	-	-	9	21	23	54	33	87	9	35
14	saflufenacil 105 + dimethenamid-p 936	2	6	0	1	4	15	17	28	29	88	8	24
15	saflufenacil 140 + dimethenamid-p 1200	-	-	-	-	-	-	-	-	-	-	5	29
LSD (P<0.05)		4.5	12.5	12.8	28.3	6.8	13.1	15.3	19.1	9.2	11.6	5.2	14.7

¹Post-emergence herbicides for Trials 1 and 2 were atrazine (1500) + dicamba (200); Trial 3 dicamba (200); Trial 4 nicosulfuron (60); Trials 5 and 6 mesotrione (96) + atrazine (500).

Table 4 Silage (tDM/ha) and grain yield (t/ha) for the six trials.

Treatment and rate (g ai/ha)	2008/09 Season			2009/10 Season				2010/11 Season			
	Trial 1	Trial 2		Trial 3		Trial 4		Trial 5		Trial 6	
	Silage	Silage	Grain	Silage	Grain	Silage	Grain	Silage	Grain	Silage	Grain
1 Untreated	23.2	24.1	11.04	16.8	10.15	22.3	11.98	3.3	0.87	18.2	11.12
2 acetochlor 2520	22.3	33.4	15.48	-	-	-	-	9.8	5.38	24.9	15.16
3 acetochlor 2520/atrazine 1500 + Post-em ¹	22.5	33.1	14.43	22.6	13.80	27.6	15.04	19.0	11.91	29.9	14.66
4 saflufenacil 53	-	-	-	-	-	-	-	4.4	2.83	-	-
5 saflufenacil 70	-	-	14.06	-	-	-	-	6.3	2.17	24.4	12.84
6 saflufenacil 105	-	-	14.20	-	-	-	-	7.1	3.09	23.2	13.35
7 saflufenacil 140	-	-	-	-	-	-	-	-	-	24.0	13.58
8 saflufenacil 53+acetochlor 2520	-	-	-	22.8	13.44	26.5	14.23	14.2	8.47	-	-
9 saflufenacil 70+acetochlor 2520	22.7	34.6	14.56	21.9	13.31	27.6	14.54	15.7	8.01	28.2	15.37
10 saflufenacil 105+acetochlor 2520	21.3	34.3	15.13	-	-	-	-	13.5	8.30	27.4	15.08
11 saflufenacil 140+acetochlor 2520	-	-	-	-	-	-	-	-	-	28.5	14.86
12 saflufenacil 53+dimethenamid-p 441	-	-	-	22.8	12.70	24.4	12.19	-	-	-	-
13 saflufenacil 70+dimethenamid-p 600	-	-	-	23.2	13.07	27.9	14.68	10.8	5.61	26.1	12.09
14 saflufenacil 105+dimethenamid-p 936	22.4	36.5	15.59	23.5	13.45	25.9	14.83	11.1	6.06	22.9	14.95
15 saflufenacil 140+dimethenamid-p 1200	-	-	-	-	-	-	-	-	-	25.9	14.01
LSD (P<0.05)	2.43	9.41	2.87	3.23	1.79	3.12	2.09	4.08	2.11	5.45	2.00

¹Post-emergence herbicides (g ai/ha) for Trials 1 and 2 were atrazine (1500) + dicamba (200); Trial 3 dicamba (200); Trial 4 nicosulfuron (60); Trials 5 and 6 mesotrione (96) + atrazine (500).

Herbicide efficacy and maize yield – 2010/11

Trial sites for this growing season were selected for high weed pressure (Trial 5) or for high soil organic matter content (Trial 6). At both sites the growers have had to apply a post-emergence herbicide in past years to achieve good weed control and crop yield. Weed counts 6 WAT in Trial 5 showed total numbers of up to 2800/m² in some plots, with 100% weed cover occurring in the untreated plots by this stage (Tables 2 and 3). Grass weed species dominated this trial, with approximate composition of 65% *D. sanguinalis*, 5% *Panicum dichotomiflorum* and 30% *C. album*. Trial 6 had an organic C content of 17.4% (Table 1), and a moderate initial density of around 150 weeds/m² in the untreated plots, with similar proportion of broadleaf and grass species overall.

The extremely high pressure of grass weeds in Trial 5, coupled with poor activation of the pre-emergence herbicides due to lack of soil moisture (15 mm of rainfall in the 4 WAT) resulted in poor weed control at this site. The weed cover scores in Table 3, however, do not provide the complete picture, because although cover scores were relatively high, in Treatments 9 and 10, the vigour/height of weeds was much lower. This was reflected in weed control scores (data not shown) and also in the silage and grain yields from this site (Table 4). These weed control scores showed that broadleaf weed control was adequate in all treatments, except acetochlor alone (Treatment 2). Overall, none of the treatments provided good weed control past 4 WAT when the grass weeds started to appear. The saflufenacil alone treatments, although providing good broadleaf control, performed poorly in this grass dominated site and at 6 WAT weed cover in these plots was similar to the untreated control (Table 3). Efficacy of all treatments declined considerably from 4 WAT, but saflufenacil/acetochlor combinations at the two higher rates (Treatments 9 and 10) still provided significantly better weed control than other treatments at all future assessments. The exception to this was Treatment 3 where mesotrione was applied post-emergence at 4 WAT and good control of grass

weeds was achieved. Additional use of a post-emergence herbicide is becoming more common now in maize crops due to increasing infestation of grass weeds in many fields (Rahman & James 2010), and the need as well as the benefit of such a follow up treatment is evident from results of Trial 5.

In Trial 6 saflufenacil alone, particularly at the two low rates (Treatments 5 and 6), had higher cover of weeds at 4 WAT than the combination treatments (Table 3). By 8 WAT only the combinations of saflufenacil with acetochlor and the standard treatment (Treatment 3) were still providing good weed control, while plots treated with combinations of dimethenamid-p had 24-35% cover of weeds. Because of the high organic C content in the soil, a higher rate of saflufenacil (140 g/ha) was evaluated in this trial. However, there appeared to be no added benefit at this rate, especially when used in combination with acetochlor (Table 3).

Silage and grain yields reflected the level of weed pressure in Trial 5 (Table 4). Saflufenacil alone treatments had low yields due to lack of grass weed control and the resulting competition of resources between weeds and the crop. The treatments that provided adequate early grass weed suppression (Treatments 8-10) gave high yields, with Treatment 3, that had a post-emergence spray application, providing the best yield. In Trial 6 all treatments provided significantly higher silage and grain yields compared to the untreated (Table 4), and the best performing treatments were again those that provided the longest period of weed suppression (Treatments 3, 9, 10 and 11).

To demonstrate the value of weed control and the benefit of using appropriate herbicide, the silage yield data were plotted against the weed cover at 4 WAT (Figure 1). This clearly shows the strong negative relationship between the two factors, i.e. the higher the weed cover at this time, the lower the yield. The R² values are very similar for both trials, although the treatment effects are less clearly separated in Trial 6, reflecting the considerably lower weed pressure at this site. This relationship was also similar with the grain yields,

Figure 1 Scatter plot showing the relationship between weed cover at 4 weeks after treatment and maize silage yield for selected treatments of Trials 5 and 6. For details of treatments 1–14 refer to Table 3.

with R^2 values of 0.68 and 0.70 for Trials 5 and 6, respectively. The silage yields in Figure 1 also show that the use of a post-emergence herbicide with the standard treatment of acetochlor/atrazine (Treatment 3) in Trial 5 resulted in the highest yield followed by saflufenacil/acetochlor combinations that suppressed the grasses only for 6–8 weeks.

CONCLUSIONS

Results of the six field trials presented here show that saflufenacil can be used as a selective pre-emergence herbicide for control of weeds in maize crops. No phytotoxicity or visual damage symptoms were observed in any of the six cultivars planted in these trials. When used alone at rates of 70 or 105 g/ha, it provided effective control of annual broadleaf weeds including atrazine- and dicamba-resistant fathen, but had little activity on grass weeds. Both these rates in combination with acetochlor at 2.52 kg/ha provided good control of annual grass and broadleaf weeds throughout the growing season in all but one trial, with the higher rate proving slightly better in only one assessment. In crops with a high weed pressure, especially of grass weeds, a follow up post-emergence herbicide would be essential for maximum yield. A higher

rate of 140 g/ha evaluated in a high organic matter peaty soil did not provide any added benefit. Combinations of saflufenacil with up to 1.2 kg/ha of dimethenamid-p were generally not as effective as with acetochlor as they did not provide season long control of weeds in most trials, sometimes leading to lower silage and grain yields. A strong negative relationship was evident between the weed density (measured at 4 WAT) and the maize silage and grain yields. This correlation was noted in sites with moderate as well as high weed pressures, although the treatment effects were more clearly separated at the high weed pressure.

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