EFFICACY AND ENVIRONMENTAL RUNOFF IMPACT OF ALTERNATIVE PRE-EMERGENT HERBICIDES TO DIURON APPLIED ON TRASH BLANKETED RATOONS

By

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KEYWORDS: Pre-Emergent Herbicides, Runoff Losses, Trash Blanket, Eco-Toxicology, Diuron.

Abstract

THE EFFICACY OF alternative pre-emergent herbicides to diuron applied just after harvest on green trash blanketed ratoons was investigated in three field trials in the wet tropics, Far North Queensland. The study also compared the losses of the tested pre-emergent herbicides in runoff using rainfall simulations. The commercially available pre-emergent herbicide Bobcat®i-MAXX (imazapic + hexazinone), was as efficient as Barrage (diuron + hexazinone), while other tested active ingredients like imazapic, isoxaflutole and amicarbazone were effective only on some weed species. All tested herbicides were found in runoff water at levels aligned with their application rate. Herbicides applied at lower application rates such as imazapic and isoxaflutole had minimal environmental runoff footprints when compared with diuron. All tested alternatives were proven more environmentally friendly than diuron.

Introduction

Sugarcane productivity is intrinsically linked to weed management, through direct competition between weeds and cane for water, light and nutrients, the influence of weeds on other pests such as rats and also the collateral damage of herbicides to cane.

Weed infestation potentially reduces yields of ratoon cane by 38% if it occurs between 30–60 days after harvest (Singh and Tomar, 2005). A green cane trash blanket (GCTB) impedes the development of most weed species, especially grasses (Azania *et al.*, 2002; Correia and Durigan, 2004; Manechini *et al.*, 2005; Sampietro and Vattuone, 2006; Villegas *et al.*, 2007; Fillols and Callow, 2010); however, a GCTB does not totally prevent weeds from growing and the application of pre-emergent herbicides remains relevant in some situations.

Selim *et al.* (2001), Perez and Chao (2004) and Fillols and Callow (2010, 2011) noted a selection of pre-emergent herbicides applied on ratoons were efficient even when applied on trash blanket.

Early pre-emergent herbicides such as diuron, hexazinone, isoxaflutole or imazapic applied just after harvest are effective weed management strategies as they are only incorporated and activated with the first rainfall, which often coincides with weed emergence and need for weed control. They can control weed emergence for up to three months (Fillols, 2012).

However, significant increase in cane yield rarely results from the application of pre-emergent herbicides on GCTB, because the weed infestation is partially suppressed by the GCTB itself (Fillols and Callow, 2010, 2011; Fillols, 2012).

Since 2014, Sugar Research Australia (SRA) has undertaken field trials to optimise the use of pre-emergent herbicides in GCTB ratoons in the wet tropics, so as to give better advice to sugarcane growers who want to maintain or improve their profitability while complying with the current Great Barrier Reef (GBR) legislation.

The Great Barrier Reef Catchment Loads Monitoring Program monitors concentrations of pesticides in key GBR rivers and the Reef Water Quality Protection Plan reports on results relating to the four Photosystem II (PSII) herbicides, diuron, hexazinone, atrazine and ametryn, which are used in sugarcane. Pesticide presence is of interest when concentrations exceed guideline trigger values for ecosystem protection.

Continued exceedances in permissible pesticide levels in watercourses has already resulted in the restriction of use of products such as diuron.

This paper reports on the efficacies of alternative pre-emergent herbicides to diuron applied on GCTB just after harvest and their associated environmental impact.

Methodology

Three trials in green cane trash blanketed ratoon cane compared the efficacy on weeds of herbicide treatments applied broadcast just after harvest. The trials were located in Far North Queensland in high rainfall areas, in soil types varying from well to poorly drained.

To assess the runoff potential of the tested herbicides, rainfall simulations were carried out in similar soil types as efficacy trials 1 and 2, which have different drainage properties.

Details of the three efficacy trials and the two runoff trials are reported in Table 1. Efficacy trial 2 and runoff trial 2 were carried out in the same cane block.

Table 1—Details of the three efficacy trial sites and two runoff trials.

Trial site	1	2	3
Area	High rainfall, poorly drained	High rainfall, well drained	High rainfall, moderately drained
Soil type	Coom-Tully Seasonally wet soils requiring drainage or special management – Hydrosols	Liverpool (and wet variant) Deep sandy soils – Tenosols, Rudosols	Tully Friable non-cracking clay or clay loam soils – Dermosols, Ferrosols
Efficacy trials			
Location	Tully – Feluga	Mulgrave – Aloomba	Mossman – Daintree
Cane variety and ratoon number	Q200$^{\phi}$ 3R	Q200$^{\phi}$ 4R	Q219$^{\phi}$ 2R
Date sprayed	21/08/2015	28/08/2015	30/10/2015
Equipment used	6 tank sprayer with boom and 04 air inducted flat fan nozzles		
Runoff trials			
Location	Babinda	Mulgrave – Aloomba	
Cane variety and ratoon number	Q208$^{\phi}$ 3R	Q200$^{\phi}$ 4R	
Crop age	Just after harvest	A few months after harvest, cane slashed	
Date sprayed	29/08/2016	05/04/2016	
Equipment used	6 tank sprayer with boom and 04 air inducted flat fan nozzles		
Date rainfall simulations	31/08/2016	07/04/2016	
Equipment used	SRA rainfall simulator and two 0.75 m * 3m quadrats		

Each efficacy trial was designed as a randomised complete block (RCB) with adjacent controls and three replicates. Seven treatments (T1 to T7) were common to the three trials (Table 2).

For each trial, the first assessment was carried out when the weeds started to emerge in the untreated plots, which was closely related to the first rainfall event after herbicide application.

The first rainfall event triggers weed emergence and activates the pre-emergent herbicides. Subsequent assessment dates in each trial were grouped according to the number of days since the first assessment date (Table 3).

Table 2—Details of treatments in the three efficacy trials.

Treatment	Treatment description	Active	Rate kg or L/ha	Water rate L /ha	Indicative cost $/ha
T1	Barrage full rate (as reference product),	Diuron 468 g/L hexazinone 132 g/L	4	300	$74
T2	Barrage low rate (as per new label)	Diuron 468 g/L hexazinone 132 g/L	0.9	300	$17
T3	Flame® max label rate	Imazapic 240 g/L	0.4	300	$10
T4	Balance®750WG max label rate	Isoxaflutole 750 g/kg	0.2	300	$35
T5	Clincher®Plus max label rate	Metolachlor 960 g/L	2.7	300	$49
T6	AmiTron® max label rate (pending registration)	Amicarbazone 700 g/kg	1.4	300	TBA
T7	Bobcat®i-MAXX max label rate	Imazapic 25 g/L hexazinone 125 g/L	3.8	400	$86
T1,T3,T4,T7	Shirquat®250 added to tank mix to prevent cane foliar uptake	Paraquat 250 g/L	1.2	300	$5

Table 3—Assessment dates for the three efficacy trials (DAT: days after herbicide application).

Trial	Assessment 1	Assessment 2	Assessment 3	Assessment 4	Assessment 5
Number of days since Assessment 1	0	14	28	40	71
1	60 DAT 20/10/2015	74 DAT 3/11/2015	88 DAT 17/11/2015	104 DAT 3/12/2015	137 DAT 5/01/2016
2	13 DAT 10/09/2015	28 DAT 25/09/2015	46 DAT 13/10/2015	56 DAT 23/10/2015	74 DAT 10/11/2015
3	68 DAT 6/01/2016	83 DAT 21/01/2016	101 DAT 8/02/2016	112 DAT 19/02/2016	143 DAT 21/03/2016

Efficacy data were expressed in percentage reduction of total weed coverage, grass coverage, broadleaf coverage and vine coverage compared with the untreated controls. Results of the three efficacy trials were combined and each variable statistically analysed using the model described in Table 4.

Table 4—Statistical model information for the efficacy trial data.

Dependent variable	Percentage reduction (total, grass, broadleaf, vine)
Covariance structures	Variance Components, Spatial Power
Subject effect	Site*Rep*Treatment
Group effect	Site
Estimation method	REML
Residual variance method	None
Fixed effects se method	Kenward-Roger
Degrees of Freedom Method	Kenward-Roger

A rainfall simulator built according to Loch *et al*. (2001) specifications was used to apply 80 mm of rain in a one hour event (80 mm/h is considered a one in five year extreme rainfall event in North Queensland) (Figure 1). Each herbicide treatment (T1 to T7) was applied on a 4 m × 1m plot area and replicated three times.

To avoid chemical reactions between herbicides, a maximum of four products were mixed together and applied to the same plot area, while taking into account product compatibility as per product labels. T1, T4 and T6 were applied as one mix (Mix 1) on three replicated plots, and T2, T3, T5 and T7 were applied as another mix (Mix 2) on another three replicated plots.

Mix 1 and Mix 2 plots were adjacent to enable runoff collection during the same rainfall simulation event.

Rainfall was applied 48 h after herbicide application. For each rainfall simulation event, two 0.75 × 3 m quadrats were placed on two adjacent plots and sealed in the ground (2–3 cm depth). Three rainfall simulation events were necessary to collect runoff from the three replicates. Runoff water samples from each quadrat (plot) were collected every 5 minutes.

Cane trash samples and top soil samples (2 cm depth) were taken from six randomised positions in each plot (12 cm × 8 cm area) just after spraying and just after rainfall. Water, trash and soil samples were kept between 0 and 4 °C, protected from light and sent to ACS laboratories, Melbourne for pesticide analysis. Herbicide loss data are presented as the mean with standard deviation of the replicated treatments.

Fig. 1—SRA Rainfall simulator installed on replicate 1 (Mix 1 was applied to the left plot, Mix 2 was applied to the right plot).

Results

Soil analysis and herbicide sorption properties

Soil samples were taken from each trial site, analysed and interpreted by the SRA laboratory. Relevant chemical characteristics for the tested pre-emergent herbicides were:

- All soils had a Cation Exchange Capacity (CEC) lower than 4.5 meq/100g but above 3 meq/100g, meaning they had a reduced capacity to adsorb Balance® in the soil, resulting in the herbicide potentially leaching past the weed root zone into the cane root zone. Balance® is only recommended at a reduced rate on these soil types. It was used at full rate in all three trials, without any phytotoxicity impact on cane.
- Organic Carbon (Dumas) was 3.63%, 2.60%, 1.22% and 2.26% and pH was 4.99, 5.24, 5.05 and 5.61 in trials 1 (Efficacy Tully), 1 (Runoff Babinda), 2 and 3 respectively. Soils with higher carbon content have higher adsorption potential. Shaw *et al.* (2013) reported that total organic carbon (TOC) was a significant explanatory variable in the observed degradation rates for many of the herbicides. Herbicides like metolachlor, diuron, and hexazinone are sensitive to carbon content, which influences their runoff properties. Rocha *et al* (2013) also reported that increases in soil organic content and pH increase diuron sorption. Shaw *et al.* (2013) reported that acidic pesticides like imazapic are known to persist longer in soil with low pH.

Efficacy on weeds

Results in untreated plots

The weed populations in all three efficacy trials consisted mainly of grasses and broadleaf weeds, however the level of weed infestation and the weed species varied in each trial (Table 5).

In trial 1, the main grass species were Guinea grass (new seedlings) and summer grass, the main broadleaf species were blue top and square weed and there were a few calopo vines. Two and a half months after harvest, the weed population in the untreated plots reached a maximum of 45% ground coverage.

In trial 2, the main grass species were awnless Barnyard grass, summer grass and Guinea grass (new seedlings). The main broadleaf species were blue top and spiny spider flower. There were a few pink convolvulus and balloon vines. Three months after harvest, the weed population in the untreated plots reached a maximum of 90% ground coverage.

In trial 3, the main broadleaf species were blue top and square weed and the main grass species were sour grass (new seedlings) and paspalums. Rushes were also present and counted as grasses. There were a few calopo vines. Four and a half months after harvest, the untreated plots reached a maximum of 20% ground coverage.

Table 5—Common name and Latin name of the weed species encountered in the efficacy trials.

Common name	Latin name	Present in trial
Awnless barnyard grass	*Echinochloa colona*	2
Guinea grass	*Panicum maximum var maximum*	1,2
Paspalum	*Paspalum dilatatum, P. virgatum*	2,3
Rushes	*Juncus* spp.	3
Sour grass	*Paspalum conjugatum*	2,3
Summer grass	*Digitaria ciliaris*	1,2
Blue top	*Ageratum conizoides*	1,2,3
Spiny spider flower	*Cleome aculeata*	2
Square weed	*Spermacoce latifolia*	1,2,3
Balloon vine	*Cardiospermum halicacabum*	2
Calopo	*Calopogonium mucunoides*	1
Pink convolvulus	*Ipomoea triloba*	2

Combined efficacy results on grasses

The combined analysis showed no significant difference for the interaction Treatment × Date (P = 0.92) and no significant differences between treatments (P = 0.41). Bobcat®i-MAXX (T7) tended to perform particularly well to control the grasses across the three sites (Figure 2). Barrage low rate (T2), AmiTron® (T6) and Clincher®Plus (T5) efficacies against the grasses were mediocre (50 to 70%).

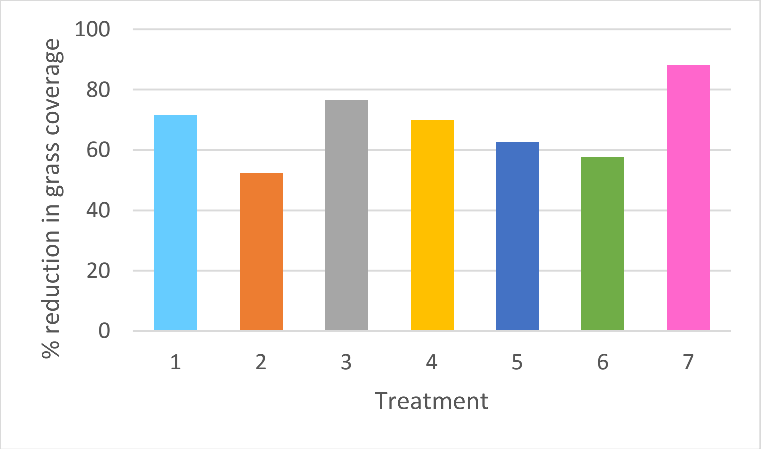

Fig. 2—Mean of percentage reduction of grass coverage compared with the adjacent untreated controls for the three trials. Data presented as the means of the five assessment dates. See Table 2 for the details of treatments.

Combined efficacy results on broadleaves

The combined analysis showed no significant difference for the interaction Treatment × Date (P = 0.06), whereas significant differences existed between treatments (P<0.001). Mean comparisons are embedded in Figure 3.

The results showed that AmiTron® (T6) and Bobcat®i-MAXX (T7) were as effective as Barrage (T1) to control the broadleaves across the three trial sites. Both Balance® (T4) and Flame® (T3) were only 60–70% effective. Imazapic alone (T3) was far less effective on broadleaves compared with Bobcat®i-MAXXx (T7), which is a mixture of imazapic and hexazinone. Balance® (T4) had a poor efficacy against square weed in all trials. Clincher®Plus (T5) was ineffective against broadleaves.

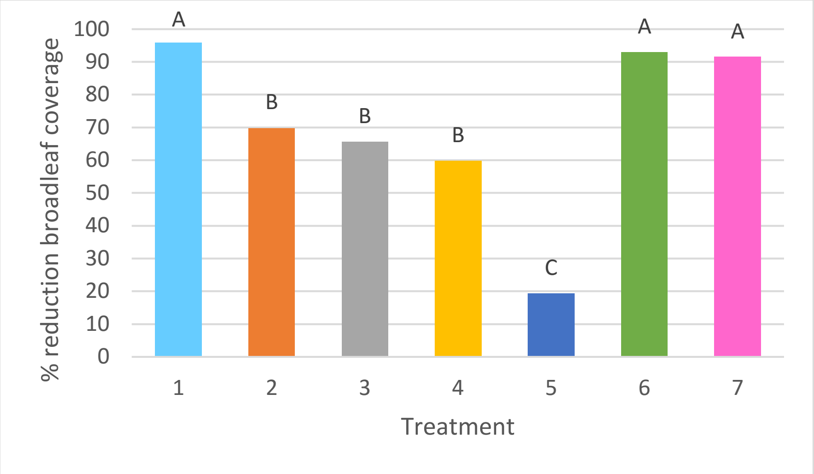

Fig. 3—Mean of percentage reduction of broadleaf coverage compared to the adjacent untreated controls for the three trials. Data presented as the means of the five assessment dates. Means with the same letter are not significantly different (P = 0.05).

Combined efficacy results on vines

The combined analysis shows no significant difference for the interaction Treatment × Date (P = 0.45) and no significant difference for Treatment (P = 0.5). Only Clincher®Plus tended to be visibly less effective compared with the other treatments (Figure 4).

AmiTron® (T6) seemed particularly effective for vine control. Imazapic (T3) was inefficient against calopo vines, but the addition of hexazinone in Bobcat®i-MAXX (T7) improved calopo control. Balance® (T4) tended to be particularly effective to control calopo.

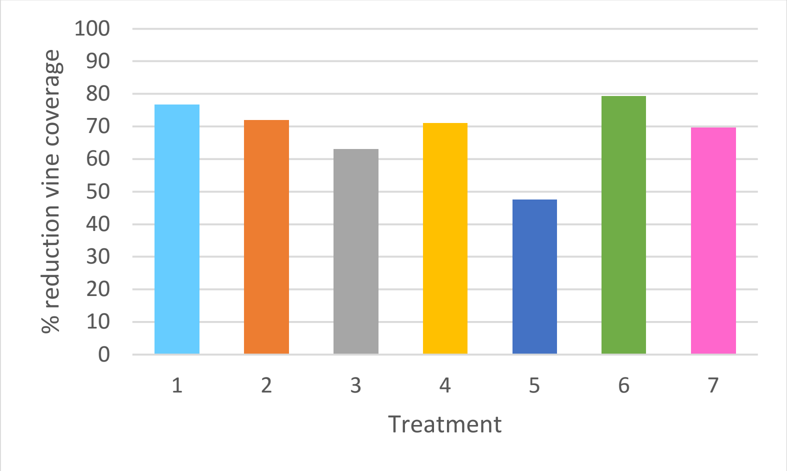

Fig. 4—Mean of percentage reduction of vine coverage compared with the adjacent untreated controls for the three trials. Data presented as the means of the five assessment dates.

Combined efficacy results on total weed coverage

The combined analysis showed no significant difference for the interaction Treatment × Date (P = 0.57), whereas significant differences exist between treatments (P<0.001). Mean comparisons are embedded in Figure 5.

Results showed that Bobcat®i-MAXX (T7) was more effective than Barrage low rate (T2) and Clincher®Plus (T5) across the three sites. Results also showed that Bobcat®i-MAXX (T7) was as effective as Barrage full rate (T1). AmiTron® (T6) showed promise with no significant differences from the best performing herbicides. Despite no significant differences between Barrage full rate (T1), Flame® (T3), Balance® (T4) or Barrage low rate (T2), the use of individual herbicides tended to control not enough weed species to match Barrage performance.

These results demonstrate the benefit of using two actives to widen the spectrum of efficacy: Bobcat®i-MAXX and Barrage are a pre-mix of imazapic or diuron as a grass control and hexazinone as a broadleaf control.

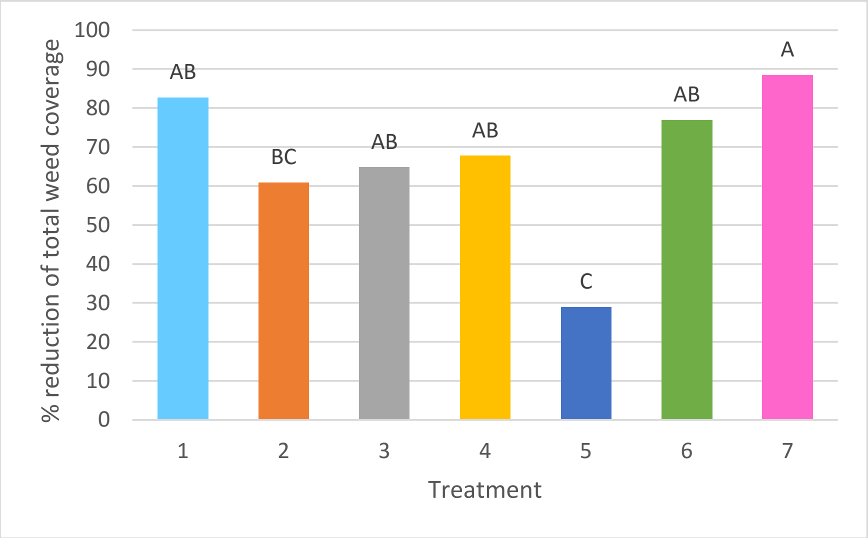

Fig. 5—Mean of percentage reduction of total weed coverage compared with the adjacent untreated controls for the three trials. Means with the same letter are not significantly different (P = 0.05).

Efficacy results summary and additional comments

Barrage high rate was a very effective herbicide across all trial sites, regardless of the soil type and the weed composition. It was particularly stable during the dry period that preceded its incorporation, and had a long period of activity after activation (data not shown). The high application rate of this product used in this study is currently not permissible in the wet tropics.

Bobcat®i-MAXX was the most efficient herbicide across all trial sites. Like Barrage high rate, it had a particularly long period of efficacy regardless of the soil type and the rainfall amount when compared with other herbicides like imazapic and isoxaflutole (data not shown).

Against broadleaves, AmiTron® was as effective as Bobcat®i-MAXX or Barrage high rate, however its efficacy against grasses was quite low and short lasting (data not shown).

Flame® performance varied in relation to the weed species present in the trials. It was particularly effective against the grasses but its efficacy against broadleaves was only short lived (data not shown). It did not control legume vines like calopo.

Balance® performance varied in relation to the weed species present in the trials. It was more effective against the grasses than the broadleaves. Its main downfall was a short period of efficacy (data not shown). It was particularly effective against legume vines (calopo), but controlled poorly the broadleaf square weed. No phytotoxicity on cane was observed, even at full rate.

Barrage low rate did not perform well, on broadleaves or grasses and its period of efficacy was short.

Clincher®Plus efficacy was mediocre on broadleaves; however it had some relative efficacy against grasses in two trials. Overall, it was unsatisfactory. The product label mentions application to moist soil and incorporation after 10 days; however, application on moist conditions followed by rainfall 10 days after application in trial 2 still resulted in suboptimum control (data not shown). Metolachlor is readily absorbed by organic matter, which may suggest that metolachlor was mainly locked in the trash blanket and therefore not efficacious.

Herbicide runoff losses

The surface runoff was highly variable for each of the plots across the rainfall simulations for the two sites. For site 1, runoff ranged between 16 and 56 mm with a mean of 36 mm, while site 2 varied from 21 to 51 mm with a mean of 40 mm (data not shown). The differences in runoff within a paddock could reflect preferential wheel traffic and fine scale soil pore variability. In any case, these results highlight that a high proportion of surface runoff (in the order of 30–50%) can occur during intense rainfall events.

The grams per hectare surface runoff herbicide losses generally displayed consistent relative trends across the two sites with diuron (high rate), metolachlor, hexazinone and amicarbazone having relatively higher amounts lost, while diuron (lower rate), hexazinone (lower rate), isoxaflutole and imazapic generally having lower amounts lost (Figure 6).

In each trial, losses were directly aligned with the amount of herbicide applied. Diuron in T1, metolachlor in T5, amicarbazone in T6 and hexazinone in T1 and T7 were applied at rates between 0.5 to 2.6 kg active ingredient per ha, whereas diuron and hexazinone in T2, isoxaflutole in T4 and imazapic in T3 and T7 were applied at lower rates between 96 to 420 g/ha.

Trial 1, on clay soil with OC 2.60% recorded slightly higher losses across all herbicides (except for diuron high rate) compared with trial 2, on sandy soil with OC 1.22%. We would have expected opposite trends as the soil with more adsorption (trial 1) should have retained the herbicides better than the sandy soil (trial 2) and generate less runoff losses.

Herbicide concentration in soil after rainfall were very similar between the two trials and differences cannot be explained by the soil composition (Table 6). These herbicide concentrations in the soil were influenced by the sorption/desorption of the trash blanket layer above the soil.

These results show that, in a trash blanketed ratoon scenario, the soil type may not be the main driver for herbicide fate and its susceptibility to runoff.

The presence of weathered cane residues in trial 2 (the block was slashed for the trial establishment so a combination of weathered and fresh residues were present) compared with fresh trash blanket in trial 1 could explain a better sorption of herbicides on the mulch and therefore lower runoff losses.

Aslam *et al.*, (2012) reported that metolachlor adsorption on mulch residues was quite strong and increased with mulch decomposition. Metolachlor desorption from mulch residues decreased with mulch decomposition.

Herbicide concentrations on trash before and after rainfall were used to calculate desorption from trash for each herbicide (Table 7). Caution needs to be taken when interpreting these data because of the extreme variability between plots (illustrated by the standard deviation value). Calculated desorption values were lower on trial 2 but only for diuron, isoxaflutole and imazapic. Hence the degree of trash decomposition may not be the main driver for herbicide susceptibility to runoff.

Efficacy results showed that metolachlor was not effective when sprayed on trash blanket. As this product is effective when sprayed on bare soil, it would suggest metolachlor was sorbed on the trash blanket and did not reach the soil. Herbicide results on trash and soil (Tables 5 and 6) indicated that metolachlor was desorbed from trash and reached the soil after 80 mm rainfall (38 to 63% of metolachlor desorption from trash). However smaller rainfall events occurring in the efficacy trials may not have been sufficient to release the metolachlor from the trash blanket.

The variable loss pathways between the two soil types may also have played a key factor in the runoff losses of the herbicides where more herbicide is likely to have been lost via deep drainage in the sandy soils (not quantified in this study) compared with the soil with higher clay contents. However, similar volumes of runoff and delay before runoff at these two sites did not point to any major differences in loss pathways.

These results show that the main driver or combination of drivers to explain the herbicides fate and their susceptibility to runoff in sugarcane farming systems are yet to be identified.

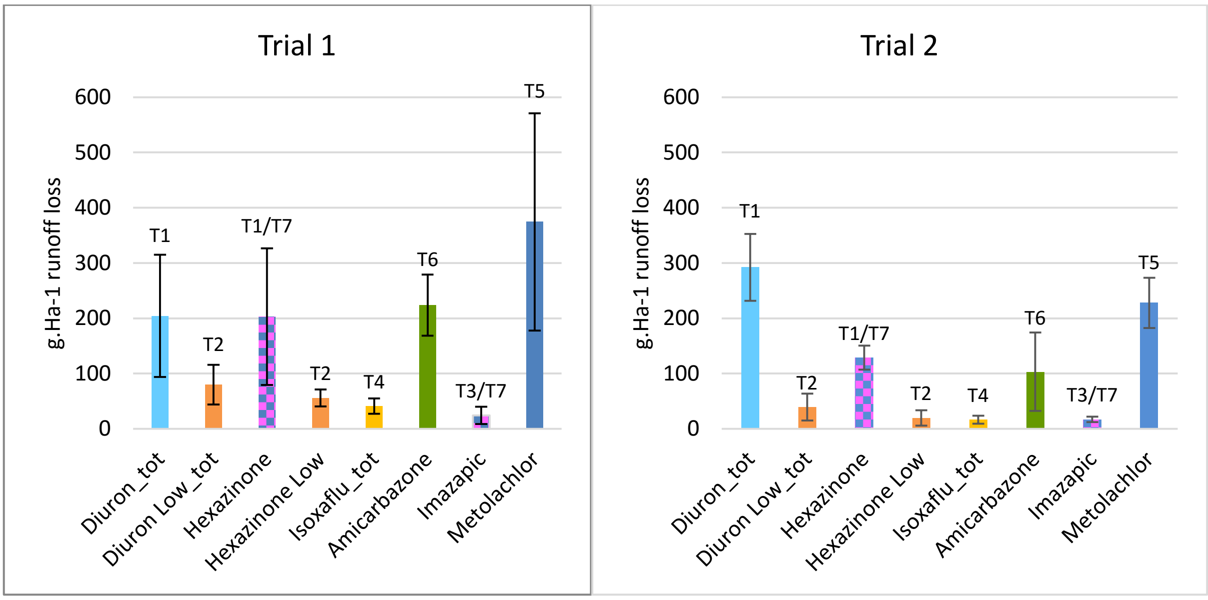

Fig. 6—Means of herbicide surface runoff losses as grams per hectare at trial 1 (left graph) and trial 2 (right graph). Active ingredients followed with '–tot' include their metabolites. Herbicide treatment codes are labelled above each mean bar. The error bars represent the standard deviations for the three replicates.

Table 6—Mean concentrations of herbicides in soil samples (mg/kg) after rainfall. Standard deviation values between the three plots are in brackets.

Active ingredient	Trial 1	Trial 2
Diuron H	0.94 (0.32)	1.21 (0.33)
Diuron L	0.80 (0.22)	0.36 (0.06)
Hexazinone H	0.32 (0.07)	0.38 (0.09)
Hexazinone L	0.15 (0.02)	0.11 (0.03)
Isoxaflutole	0.09 (0.06)	0.10 (0.02)
Amicarbazone	0.41 (0.05)	0.51 (0.08)
Imazapic	0.02 (0.00)	0.07 (0.02)
Metolachlor	1.04 (0.12)	0.95 (0.43)

The mean runoff concentration for each of the herbicides (for each rate) for each trial site was combined with the relative toxicity data (relative to diuron where > 1 is more toxic and < 1 is less toxic), to produce the relative risk of these herbicides relative to the 'high rate' (1 872 g/ha) of diuron application (Table 8). The relative toxicity data were compiled from three sources that have different levels of confidence.

For hexazinone, the relative toxicity factor (to diuron) calculated by Smith *et al.* (2017) was used. This method compiled a large amount of relevant ecotoxicity data and used the latest recognised statistical approaches to provide relative toxicity values to diuron and hence these factors have the highest level of confidence. For the remaining factors, with the exception of amicarbazone, the toxicity factors calculated by Poggio *et al.* (2014) were applied.

Table 7—Mean concentrations of herbicides in trash samples before and after rainfall and calculated desorption of herbicides from trash. Standard deviation values between the three plots are in brackets.

	Trial 1			Trial 2		
Active ingredient	Concentration in mg/kg before rain	Concentration in mg/kg after rain	Desorption	Concentration in mg/kg before rain	Concentration in mg/kg after rain	Desorption
Diuron H	42.8 (34.5)	13.7 (10.5)	68%	27.3 (14.8)	19.4 (3.5)	29%
Diuron L	15.8 (16.5)	6.3 (2.0)	60%	6.9 (1.1)	6.2 (1.8)	10%
Hexazinone H	21.9 (19.9)	8.0 (1.2)	64%	13.7 (5.5)	4.6 (0.3)	66%
Hexazinone L	5.5 (5.3)	3.1 (0.7)	43%	3.0 (0.4)	1.4 (0.2)	53%
Isoxaflutole	8.4 (10.1)	2.2 (0.9)	74%	5.8 (0.4)	2.4 (0.5)	58%
Amicarbazone	25.1 (26.9)	11.5 (1.9)	54%	18.3 (1.8)	8.9 (1.6)	51%
Imazapic	3.3 (3.5)	0.7 (0.1)	79%	0.6 (0.5)	0.5 (0.0)	62%
Metolachlor	73.7 (61.1)	46.0 (8.0)	38%	60.7 (11.5)	22.5 (1.6)	63%

These factors were produced using a relatively smaller pool of ecotoxicity data with a relatively lower amount of statistical analysis (i.e. relative to Smith *et al.*, 2017) and are considered to have a medium level of confidence.

Finally, the toxicity factor for amicarbazone relative to diuron was calculated using the available ecotoxicity data for phototrophs listed in the Pesticide Properties Database (http://sitem.herts.ac.uk/aeru/ppdb/en/), which included acute EC_{50} 72 h exposure for growth of algae and acute EC_{50} 7 day biomass growth for aquatic plants. In this case, the highest value relative to diuron was recorded for the relative toxicity of amicarbazone and it is noted that this approach has lower confidence but provides some relative measure of toxicity.

For products with two active ingredients (Barrage and Bobcat®i-MAXX), relative risk was calculated as the sum of the risk factors of each of the actives. The relative risk calculations suggest that all applied herbicides have a much lower offsite risk relative to the high rate application of diuron (1 872 g/ha) (Table 6).

In fact, most herbicides (main exception is metolachlor) have a relative risk of > 10 fold lower than the diuron high rate under these scenarios. Overall the data generally show that the possible alternatives to diuron pose less of a risk than diuron applied at standard rates.

Conclusions

At both these trial sites, the best control option was T7 (Bobcat®i-MAXX), which was eight and 14 times less toxic than using Barrage full rate in trial 1 and 2 respectively. T3 (Flame®), T4 (Balance®750WG) and T6 (AmiTron®) would be more effective if used in a mixture to extend their efficacy spectrum, they were environmentally 13 to 170 times less toxic than diuron full rate in trial 1 and 34 to 270 times less toxic in trial 2.

A combination of Balance®750WG + AmiTron® may be another effective option in the future with an equivalent environmental impact to Bobcat®i-MAXX.

These data were produced using current knowledge on herbicide behaviour in runoff and are likely to be refined as more data are generated.

This study demonstrated cost-efficient alternatives to diuron that are more environmentally friendly. Some tested herbicides like imazapic, isoxaflutole and amicarbazone are only effective on some weed species.

These herbicides require a good knowledge of the weed issues in the paddock to make a smart herbicide choice. Combining these herbicides according to the weed problem is also a possible option.

Table 8—Summary of relative risk, efficacy and cost for each treatment at the two trial sites. Revised relative toxicity data to diuron (extract from draft consensus in review 2017) and mean surface runoff concentrations from the runoff trials were used to calculate the relative risk to diuron. Note all treatments were safe on cane.

T	T1		T2		T3	T4	T5	T6	T7	
Treatment	Barrage high rate		Barrage low rate		Flame ®	Balance ®	Clincher	Amitron	Bobcat®i-MAXX	
Active per ha	Diuron 1872 g	Hexazinone 528 g	Diuron 421.2 g	Hexazinone 118.8 g	Imazapic 96 g	Isoxaflutole 150 g	Metolachlor 2592 g	Amicarbazone 980 g	Imazapic 95 g	Hexazinone 475 g
Toxic equivalent factor to diuron	1	0.19	1	0.19	0.062	0.34	0.19	0.087	0.062	0.19
Trial 1 runoff mean concentration (μg.L^{-1})	563	533	210	150	63	110	1017	603	63	480(*)
Trial 1 Relative risk of a.i. to diuron high rate(**)	1	0.18	0.37	0.051	0.007	0.07	0.34	0.093	0.007	0.16
Trial 1 Relative risk of product to diuron high rate	1.18		0.42						0.17	
Trial 2 *runoff mean concentration (μg.L^{-1})*	722	310	105	51	41	49	550	267	41	279(*)
Trial 2 Relative risk of a.i. to diuron high rate(**)	1	0.082	0.15	0.013	0.004	0.023	0.14	0.032	0.004	0.073
Trial 2 Relative risk of product to diuron high rate	1.08		0.16						0.077	
Indicative cost per ha	$74		$17		$10	$35	$49	TBA	$86	
Product efficacy	Very efficient		Moderate efficacy		Efficient on grasses	Efficient on grasses	Moderate efficacy on grass only	Very efficient mainly on broadleaves	Very efficient	

(*) Calculated value derived from hexazinone 528g concentration

(**) Relative risk of a.i. to diuron = (runoff mean concentration of a.i.) * (toxic equivalent factor of a.i.to diuron) / (runoff mean concentration of diuron).

These alternative herbicides are currently available to growers or pending registration (amicarbazone).

Acknowledgements

We would like to thank the following sugarcane growers, Greg Clarke, David Laurenson, Harkarn Singa Mavi and Bill Mackay, for hosting the trials in Far North Queensland; Tim Staier, Lisa Derby and Zofia Ostatek-Boczynski from SRA for their technical assistance in the field and in the laboratory; and Greg Hicks from ACS for the pesticide analysis.

We would also like to thank Sugar Research Australia and QDAF for funding the project that generated these data.

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