Proceedings of the Australian Society of Sugar Cane Technologists, volume 42, 433–443, 2020

Peer-reviewed paper

Soil-binding adjuvants can reduce herbicide loss via runoff

EF Fillols[1] and AM Davis[2]

[1]*Sugar Research Australia Limited, Meringa, Qld 4865*; efillols@sugarresearch.com.au
[2]*Tropwater, James Cook University, Townsville, Qld 4811*

Abstract Concentrations of a range of pesticides exceed water-quality guidelines throughout the year in many fresh and estuarine water bodies of the Great Barrier Reef catchment. To mitigate its impact and maintain its productivity, the Australian sugar industry is looking at innovative options to reduce the movement of herbicides off site. Three oil-based adjuvants (Grounded® applied at 3 L/ha, Atpolan® soil Maxx applied at 0.4 L/ha and Ad-Here™ applied at 1L/ha according to their respective labels), a terpene-based adjuvant (Flextend® applied at 1.2 L/ha) and a polyol-based adjuvant (Watermaxx®2 applied at 9.35 L/ha), were tested on bare soil and on a trash blanket for their potential to reduce runoff losses as well as improving the weed control efficacy of four registered pre-emergent herbicides applied at full label rate: imazapic (96 g/ha), hexazinone (975 g/ha), isoxaflutole (150 g/ha) and amicarbazone (700 g/ha). Herbicide-efficacy trials were implemented as randomised complete-blocks with three replicates and adjacent untreated controls. Losses of the tested pre-emergent herbicides in runoff were monitored using replicated rainfall simulations, delivering 80 mm of simulated rain, 48 h or 3 weeks after herbicide application. On green-cane trash-blanket, all oil-based adjuvants significantly increased the runoff of the tested herbicides, Flextend did not affect herbicide runoff and Watermaxx®2 slightly reduced herbicide concentration in runoff by up to 25%. On bare soil, three of the tested adjuvants significantly reduced herbicide runoff losses. Grounded® achieved the best outcomes by reducing herbicide concentration in runoff by about 35% when runoff occurred 48 h after application. Most of the tested products slightly increased herbicide efficacy on weeds in the efficacy trials, but the differences were not significant. If validated in other soil types and in bare soil ratoon cane, the use of Grounded® could assist in improving the quality of runoff water leaving sugarcane paddocks and, therefore, reduce canegrowers' impact on freshwater water and marine ecosystems.

Key words Adjuvant, pre-emergent herbicide, runoff, water quality, soil-binding

INTRODUCTION

Weed management is an essential component of sugarcane productivity as weeds directly compete with cane for resources like water, light and nutrients. Poor weed management also promotes other pests such as rats, which are detrimental to cane productivity.

Yield reduction in ratoons can exceed 38% if weed infestation occurs between 30–60 days after harvest (Singh and Tomar 2005). Some weed species, especially grasses can be impeded by the presence of green-cane trash-blanket (GCTB) (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, pre-emergent herbicides remain the best option in some situations where the GCTB does not totally prevent weeds from growing.

Some pre-emergent herbicides, such as diuron, hexazinone, isoxaflutole, imazapic, hexazinone or amicarbazone have been proven effective when applied on trash blanket (Selim *et al.* 2001; Perez and Chao 2004; Fillols and Callow 2010, 2011). They are easy to use as they can be applied just after harvest, and get incorporated and activated with the first rainfall, which often coincides with weed emergence and need for weed control. Once activated, they can control weed emergence for up to 3 months (Fillols 2012). However, their use on GCTBs rarely results in significant cane yield increase, because the weed infestation is partially suppressed by the GCTB itself (Fillols and Callow 2010, 2011; Fillols 2012).

The Great Barrier Reef (GBR) Catchment Loads Monitoring Program monitors concentrations of pesticides in key GBR rivers. The most commonly detected herbicides are herbicides that inhibit electron transport at photosystem II (PSII) in plants and include diuron, atrazine, hexazinone, ametryn, simazine and tebuthiuron (Haynes *et al.* 2000a; Shaw and Müller 2005; Shaw *et al.* 2010). Their concentrations can at times exceed GBR ecological water-quality protection guideline trigger values for up to several weeks.

Traditional extension messages to growers focus on reducing the amount of surface area sprayed (i.e. band spraying) with these herbicides and the use of alternative herbicides. The Queensland sugar industry has commenced minimising reliance on the priority PSII herbicides and adopting 'alternative' herbicides for weed control (Davis *et al.* 2014; Fillols *et al.* 2018). Despite these initiatives, there is still considerable uncertainty on the most appropriate herbicide mix and application that provides suitable weed control while also achieving desirable water-quality outcomes.

We have been investigating if a different approach consisting of adding adjuvants with specific properties to the spray tank would assist in reducing herbicide losses via runoff, while maintaining or increasing the pre-emergent herbicides efficacies.

Some adjuvants are promoted by the manufacturer for their soil-binding properties, mostly regarding reduction of leaching. Research by Woznica *et al*. (2016) indicates that Atpolan® soil Maxx decreased leaching and increased efficacy of pre-emergent herbicides metazachlor and clomazone. Kocarek *et al.* (2018) showed that Grounded® increased herbicide soil sorption, with significant results for pendimethalin.

Five adjuvants with properties likely to assist in soil binding were tested in the Australian sugarcane cropping system. It is to be noted these products have not been specifically developed to sustain tropical climate, heavy downpour or application on trash blanket. Their ability to reduce herbicide losses via runoff in these environmental conditions is unknown to the manufacturers. Some of the tested adjuvants are commercially available in Australia, others are only retailed overseas.

METHODOLOGY

Herbicide efficacy

Two trials in GCTB ratoon cane and two trials in bare soil compared the efficacy on weeds of herbicide treatments with and without the tested adjuvants applied broadcast just after harvest (Table 1). The trials were located at Meringa, in northern Queensland in a high-rainfall area, in soil types varying from well to poorly drained. To assess the runoff potential of the tested herbicides, rainfall simulations were carried out in the same blocks or in adjacent blocks to the runoff trials.

Trials 1 and 2 tested three oil-based adjuvants added to the herbicide imazapic and hexazinone: Atpolan® soil Maxx from Agromix (Poland); Grounded® from Helena (USA now retailed in Australia by Relyon) and Ad-Here™ from Victorian Chemicals. These three adjuvants are promoted for their soil binding properties.

Trials 3 and 4 tested two other adjuvant types added to the herbicide mixes imazapic+hexazinone and isoxaflutole+amicarbazone: Watermaxx®2 made of glucoethers and alkoxylated polyols, from Loveland Products, and Flextend®, pinene based from Agspec Australia. Watermaxx®2 is promoted to enhance infiltration of rainfall into the soil by enabling the hydration of water repellent soil particles. We tested the hypothesis that enhanced water infiltration would result in better herbicide retention into the soil. Flextend® key benefits is to fix the herbicide to the leaf surface so it does not runoff with rain or irrigation events. We tested if this adhesion would also apply to trash blanket or soil particles.

Each herbicide efficacy trial was designed as a randomised complete-block (RCB) with adjacent controls and three replicates. Details of the treatments are shown in Table 2. 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 since herbicide application.

The first rainfall event triggers weed emergence and activates the pre-emergent herbicides. Subsequent assessment dates in each trial were done fortnightly unless access to the block was impossible due to flooding (no assessment in February 2018 at trial 1). Weed species present in the trials are shown in Table 3.

Table 1. Details of trial sites.

Trial site	1	2	3	4
Ground cover	Trash blanket	Bare soil	Trash blanket	Bare soil
Area	Moderate rainfall, well drained	Moderate rainfall, poorly drained	Moderate rainfall, poorly to well drained	Moderate rainfall, poorly drained
Location	Meringa – Sugar Research Australia research station			
GPS coordinates	17.069342°E, 145.773780°S			
Cane variety and ratoon number	Mixed varieties, 3R	No cane, soil prepared for planting	Q208	No cane, soil prepared for planting
Soil type	Mission-Bicton: Red, yellow or grey loam or earth soils	Clifton: Red, yellow or grey loam or earth soils	Clifton (runoff trial), Mission-Bicton (efficacy trial)	Clifton
Date product applied	Runoff trial: 30/10/2017, Efficacy trial: 17/11/2017	Runoff trial: 21/05/2018 (3 weeks), 18/06/2018 (48h), Efficacy trial: 23/5/2018	Runoff trial: 31/07/2018, Efficacy trial: 8/11/2018	Runoff trial: 24/07/2018, Efficacy trial: 7/11/2018
Weather conditions at application	30/10/2017: Temp 38.5ºC, H% 42.3, Delta T 11.1, Wind ESE, average 2.3 km/h, max 4.5 km/h 17/11/2017: Temp 30.3ºC, H% 61.5, Delta T 6.0, Wind SSE, average 0.8 km/h, max 6.7 km/h	21/05/2018: Temp 25.3ºC, H% 72.1, Delta T 3.7, Wind SSW, average 0.6 km/h, max 4.3 km/h 23/5/2018: Temp 22.6ºC, H% 71.8, Delta T 4.1, Wind SSE, average 2.5 km/h, max 7.2 km/h 18/06/2018: Temp 24.3ºC, H% 47.7, Delta T 7.0, Wind SSE, average 1.2 km/h, max 4.3 km/h	31/07/2018: Temp 18.7ºC, H% 72.4, Delta T 3.5, Wind SSE, average 2.5 km/h, max 4.1 km/h 8/11/2018: Temp 30.5ºC, H% 55.8, Delta T 8.0, Wind SE, average 0.8 km/h, max 11.9 km/h	24/07/2018: Temp 23.6ºC, H% 81.2, Delta T 2.6, Wind S, average 0.2 km/h, max 0.6 km/h 7/11/2018: Temp 32.3ºC, H% 54.9, Delta T 8.0, Wind SE, average 2.3 km/h, max 5.2 km/h
Spray equipment	6-tank research sprayer			
Rainfall simulation dates	1/11/2017 (48 h) 20/11/2017 (3 weeks)	11/06/2018 (3 weeks) 20/06/2018 (48 h)	2/08/2018 (48 h) 21/08/2018 (3 weeks)	26/07/2018 (48 h) 14/08/2018 (3 weeks)

Table 2. Details of treatments in the efficacy trials.

Trial	Treatment	Adjuvant type	Adjuvant name and application rate	Herbicide and rate of application
1 and 2	T1	Oil-based	Grounded® at 3%	Flame® at 0.4 L/ha equivalent to imazapic at 96 g/ha
	T2		Atpolan® soil Maxx at 0.4%	
	T3		Ad-Here™ at 1%	
	T4	None		
	T5	Oil-based	Grounded® at 3%	
	T6		Atpolan® soil Maxx at 0.4%	
	T7		Ad-Here™ at 1%	
	T8	None		
3 and 4	T1	Resin-based	Flextend® at 1.2 L/ha	Bobcat®i-MAXX at 3.8 L/ha equivalent to imazapic at 95 g/ha + hexazinone at 475 g/ha
	T2	Polyol-based	Watermaxx®2 at 9.35 L/ha	
	T3	None		
	T4	Resin-based	Flextend® at 1.2 L/ha	Balance®750WG at 0.2 kg/ha equivalent to isoxaflutole at 150 g/ha + AmiTron® at 1 kg/ha equivalent to amicarbazone at 700 g/ha
	T5	Polyol-based	Watermaxx®2 at 9.35 L/ha	
	T6	None		

Note: Adjuvant rates followed manufacturer specifications.

Table 3. Weed species in the efficacy trials.

Common name	Identity	Present in trial
Awnless barnyard grass	*Echinochloa colona*	2
Rushes	*Juncus* spp.	3
Navua sedge	*Cyperus aromaticus*	1,3,4
Fimbristyle	*Fimbristylis spp.*	1
Blue top	*Ageratum conizoides*	1,2,3
Budda pea	*Aeschynomene indica*	4
Chinese violet	*Asystasia gangetica*	4
Praxelis	*Praxelis clematidae*	1,2,3,4
Rattlepod	*Crotalaria spp.*	1
Sensitive weed	*Mimosa pudica*	3
Spiny spider flower	*Cleome aculeata*	2,3
Square weed	*Spermacoce latifolia*	1,2,3
White eclipta	*Eclipta prostata*	1
Willow primrose	*Ludwigia octovalvis*	2,3,4

Efficacy data were expressed in percentage reduction of total weed coverage, grass coverage, broadleaf coverage and vine coverage compared with the untreated controls. A linear mixed model considering the measurement dates as repeated measurement was fitted to the data for traits measured across all the ratings using ASRem-r statistical package.

The analysis model accounted for the correlation between the repeated measurements by fitting appropriate covariance structure that accounts for the correlation between measurements over time.

The model can be written as:

Total_%_reduction = date + Treatment + Treatment:date + total_%_coverage + Rep.

Rep was fitted as a random effect. Trait of interest here is total percent reduction (total_%_reduction) with total percent coverage fitted as a covariate.

Herbicide run-off

We used a rainfall simulator, built to the design of Loch *et al.* (2001), to apply 80 mm of rain in a 1-hour event (80 mm/h is considered a one-in-five-year extreme rainfall event in northern Queensland). Each herbicide treatment (T1 to T8 for trials 1 and 2, T1 to T6 for trials 3 and 4) was applied on a 4 m × 1m plot area and replicated twice (Tables 4).

Table 4. Details of treatments in the runoff trials.

Trial	Treatment	Timing of application	Adjuvant type	Adjuvant name and application rate	Herbicide and rate of application
1 and 2	T1	3 weeks before rainfall sim	Oil-based	Grounded® at 3%	Bobcat®i-MAXX at 3.8 L/ha equivalent to imazapic at 95 g/ha + hexazinone at 475 g/ha + Balance®750WG at 0.2 kg/ha equivalent to isoxaflutole at 150 g/ha
	T2			Atpolan® soil Maxx at 0.4%	
	T3			Ad-Here™ at 1%	
	T4		None		
	T5	48 h before rainfall sim	Oil-based	Grounded® at 3%	
	T6			Atpolan® soil Maxx at 0.4%	
	T7			Ad-Here™ at 1%	
	T8		none		
3 and 4	T1	3 weeks before rainfall sim	Resin-based	Flextend® at 1.2 L/ha	Bobcat®i-MAXX at 3.8 L/ha equivalent to imazapic at 95 g/ha + hexazinone at 475 g/ha + Balance®750WG at 0.2 kg/ha equivalent to isoxaflutole at 150 g/ha + AmiTron® at 1 kg/ha equivalent to amicarbazone at 700 g/ha
	T2	48 h before rainfall sim	Polyol-based	Watermaxx®2 at 9.35 L/ha	
	T3		none		
	T4		Resin-based	Flextend® at 1.2 L/ha	
	T5		Polyol-based	Watermaxx®2 at 9.35 L/ha	
	T6		None		

Rainfall was applied 48 h or 3 weeks 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). Four rainfall simulation events were necessary to collect runoff from the two replicates for each timing of application (48 h and 3 weeks) for trials 1 and 2, totalling to eight events carried out over a couple of days for each trial. Three rainfall simulation events were necessary for each timing of application for trials 3 and 4, totalling six events carried out over a couple of days for each trial. Runoff water samples from each quadrat (plot) were collected every 5 minutes. Cane trash samples (when present) and topsoil samples (2 cm depth) were taken from six randomised positions in each plot (12 cm × 8 cm area) just after rainfall. Soil and trash samples for trial 1 only were analysed. Water, sediment, trash and soil samples were kept between 0 to 4˚C, protected from light and sent to Sugar Research Australia laboratories at Indooroopilly for pesticide analysis. Some blind samples were also sent to ACS laboratories, Melbourne and confirmed the accuracy and reliability of SRA laboratories. Herbicide runoff loss data are presented as the mean with standard deviation of the replicated treatments. Runoff load losses per hectare were calculated by multiplying the total volume of runoff from each plot by the event mean concentration

RESULTS

Oil-based adjuvants

Efficacy of weed control

Trial 1 on trash blanket. The weed population was composed of broadleaves and sedges and reached 38% ground coverage in the control plot after 5 months. The main broadleaves were rattlepod, blue top, square weed, praxelis and white eclipta. The main sedges were navua sedge and fimbristyle.

For the variable “total percentage reduction”, the analysis showed a significant difference for the interaction Treatment*Date (p 0.0156), although there was no significant difference among treatments within each date. Atpolan® soil Maxx tended to increase imazapic efficacy, while Grounded® seemed to shorten the herbicide efficacy (Figure 1, left graph). The average percentage weed reduction throughout the assessment period was 58% for Grounded®, 69% for Atpolan® soil Maxx and 63% for Ad-Here™ versus 61% for imazapic without adjuvant.

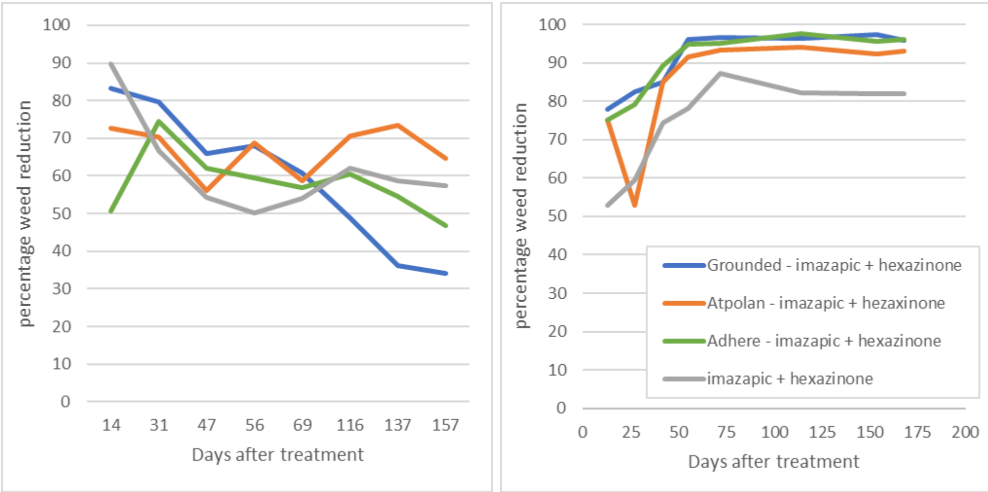

Figure 1. Percentage weed reduction in efficacy trial 1 on trash (left) and trial 2 on bare soil (right).

Trial 2 on bare soil. The weed population in this trial reached 55% soil coverage after 8 months and consisted mainly of broadleaves (mexican clover, willow primrose, blue top, praxelis and phyllantus).

The results of the ANOVA on the efficacy data on the total weed population showed no significant differences for the interaction treatment*date and among treatments (P = 0.46). However, all adjuvants tended to improve the efficacy of Bobcat imax alone throughout the assessment period (Figure 1, right graph). Grounded® and Ad-Here™ seemed to be the most efficient products as they maintained efficacy above 90% for 200 days after product application. The average percentage weed reduction throughout the assessment period was 91% for Grounded®, 85% for Atpolan® soil Maxx and 90% for Ad-Here™ versus 75% for imazapic + hexazinone without adjuvant.

Herbicide loss via runoff

Trial 1 on trash blanket. Herbicide concentrations in runoff from trial 1 on trash blanket are given in Figure 2 for the active ingredients imazapic, hexazinone and isoxaflutole (including metabolites DKN and BA). The variability between the two replicates was minimal, as illustrated by the small error bars. Herbicide concentrations without adjuvants are consistent with results from previous rainfall-simulated trials on trash blanket (Fillols *et al.* 2017).

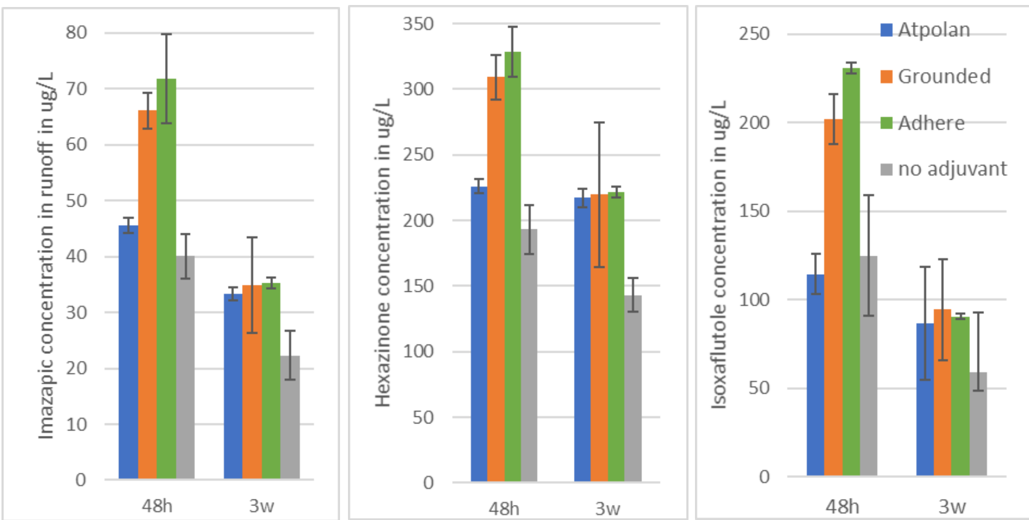

Figure 2. Imazapic, hexazinone and isoxaflutole concentrations in runoff water at 48 h and 3 weeks after application in trial 1.

Results showed that the runoff concentrations for each herbicide significantly increased with the addition of the adjuvants, especially for Ad-Here™ and Grounded® adjuvants where concentration nearly doubled when the rainfall occurred 48h after spraying. Herbicide loads followed the same pattern with Grounded® and Ad-Here™, resulting in losses of about 30 g/ha for imazapic, 150 g/ha for hexazinone and 100 g/ha for isoxaflutole when the runoff occurred 48h after spraying (data not shown). These load losses were 34 to 45% higher than the active herbicides being applied without these adjuvants.

The load losses of the tested herbicides applied with Atpolan® soil Maxx were slightly reduced (by 17%, 12% and 31% for imazapic, hexazinone and isoxaflutole respectively) compared to the herbicides applied without adjuvant, when runoff occurred after 48h (data not shown).

Figure 3 shows partitioning of the herbicide in the trash, soil, sediment and water fraction after 80 mm runoff for imazapic, hexazinone and isoxaflutole total, respectively. All adjuvants seem to have facilitated binding of all tested herbicides to the soil and trash fractions. Very little was bound to the sediment fractions.

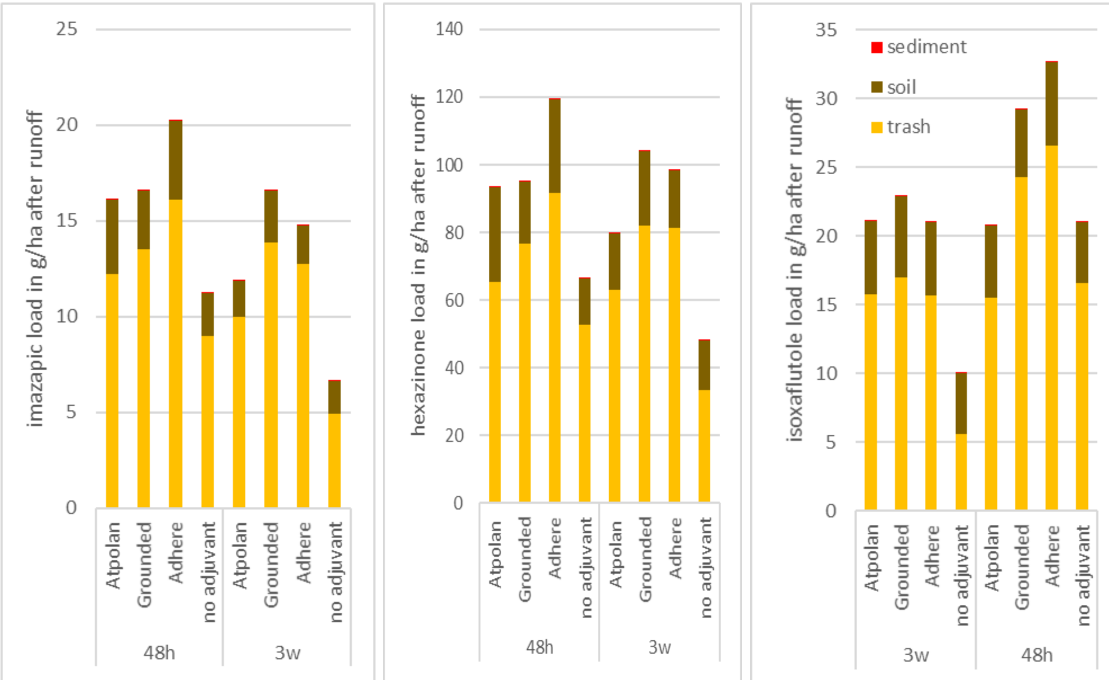

Figure 3. Imazapic, hexazinone and isoxaflutole concentrations in sediment, trash and soil after the 80 mm rainfall event in trial 1.

Trial 2 on bare soil. Herbicide concentrations in runoff for trial 2 on bare soil are given in Figure 4 for the active ingredients imazapic, hexazinone and isoxaflutole (including metabolites), respectively. Herbicide concentrations without adjuvants are consistent with results from previous rainfall simulated trials in plant cane on bare soil. Very low concentrations and loads are characteristic of losses on a freshly tilled ground with small soil aggregates prone to herbicide binding (Fillols *et al.* 2017).

All tested adjuvants reduced herbicide concentrations in runoff when runoff occurred 48h after spraying. These reductions were only significant for Grounded®, which reduced by about 35% the runoff concentration for the three tested herbicides after 48 h. Grounded® also generated significant reductions for imazapic and isoxaflutole concentrations after 3 weeks.

Load losses followed the same pattern, with Grounded® significantly reducing load losses for the three herbicides at 48 h and 3 weeks. Load losses with Grounded® at 48h after spraying were 0.8, 4.0 and 1.0 g/ha for imazapic, hexazinone and isoxaflutole, respectively, which represented a load reduction of 68%, 69% and 70%, respectively, when compared to the herbicides applied without adjuvant (data not shown). Even greater load reductions (77 to 84%) were measured with Grounded® at the 3 weeks runoff event.

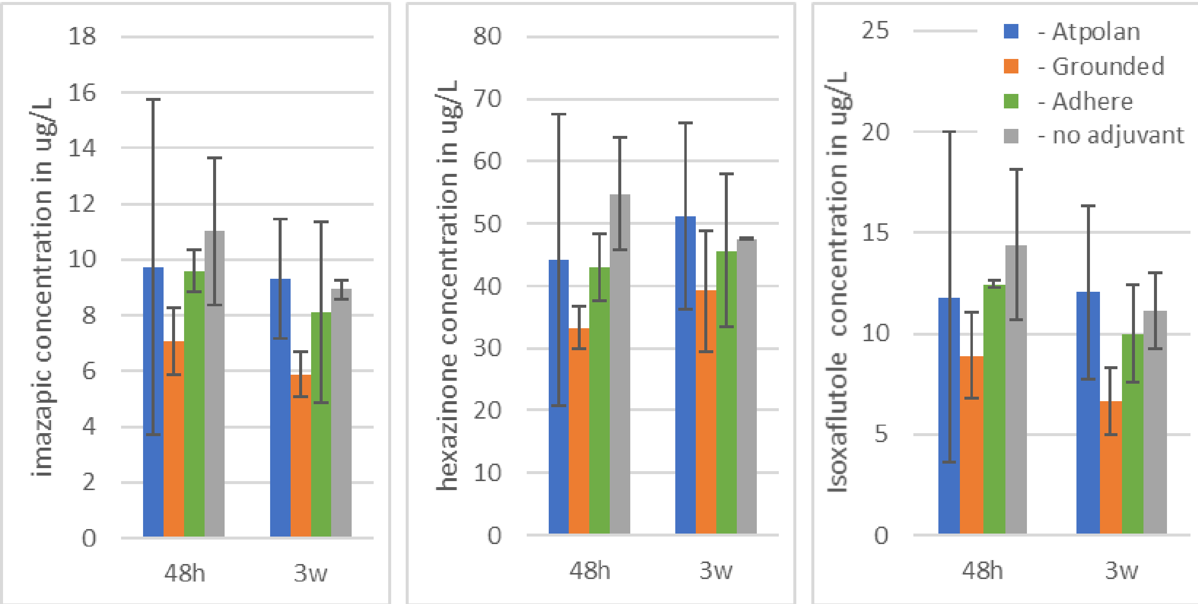

Figure 4. Imazapic, hexazinone and isoxaflutole concentrations in runoff water at 48 h and 3 weeks after application in trial 2.

Pinene-based and polyol-based adjuvants

Efficacy of weed control

Trial 3 on trash blanket. The weed population in this trial reached 80% soil coverage after 5 months and consisted mainly of broadleaves (sensitive weed, spiny spider flower, praxelis, willow primrose, rattlepod and square weed) and some sedges and rushes (mainly navua sedge). There were no significant efficacy differences for the interaction treatment * date or among treatments (P>0.05). Slightly better control was obtained with isoxaflutole + amicarbazone to control the weed population in this trial (Figure 5, left graph). This result was expected, as imazapic does not control legume species and the main weed species in the trial was sensitive weed. Both tested adjuvants seemed to have slightly increased the performance of the isoxaflutole + amicarbazone mix. The average percentage weed reduction throughout the assessment period was 74% for Watermaxx®2 and Flextend® versus 64% for isoxaflutole + amicarbazone without adjuvant.

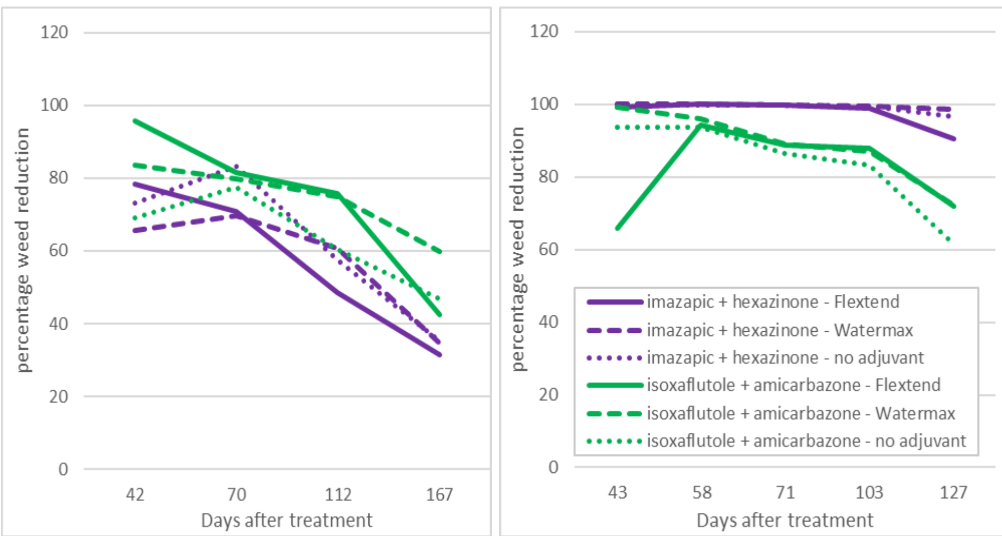

Figure 5. Percentage weed reduction in efficacy trial 3 on trash (left) and trial 4 on bare soil (right).

Trial 4 on bare soil. The weed population reached 90% ground coverage after 4months. In the first 2 months, sedges (mainly navua sedge), rushes and grasses (mainly awnless barnyard grass) dominated. For the last 2 months, broadleaves (willow primrose, Chinese violet, praxelis and Budda pea) became the dominant species. There were no significant efficacy differences for the interaction treatment*date or among treatments (P>0.05).

The imazapic + hexazinone tended to provide better control of the weed population, likely due to the presence of sedges that are well controlled by imazapic and not by any other of the tested herbicides (Figure 5, right graph). This trial received around 2,000 mm of rainfall during the assessment period, without impeding on the efficacy of imazapic + hexazinone.

Watermaxx®2 seemed to slightly increase herbicide performance for both tested herbicide mixes. The average percentage weed reduction throughout the assessment period was 92% for Watermaxx®2 added to isoxaflutole + amicarbazone versus 83% without the adjuvant.

Herbicide loss via runoff

Trial 3 on trash blanket. The results of the trial on trash blanket are given in Figure 6 for imazapic, hexazinone, amicarbazone and isoxaflutole. Watermaxx®2 reduced all tested herbicides concentrations in runoff when the event occurred 48 h after herbicide application. These reductions ranged between 13% and 25% and were significant for amicarbazone and isoxaflutole. Flextend® did not alter the herbicide concentration in runoff.

Loads losses follow the same trend, but the differences were not significant (data not shown). Watermaxx®2 reduced imazapic losses to 22 g/ha at 48 h (20% reduction compared to imazapic without adjuvant). At 48 h, load losses of 106, 157 and 16.5 g/ha were calculated for hexazinone, amicarbazone and isoxaflutole, respectively, equivalent to 20%, 28% and 31% reductions, respectively.

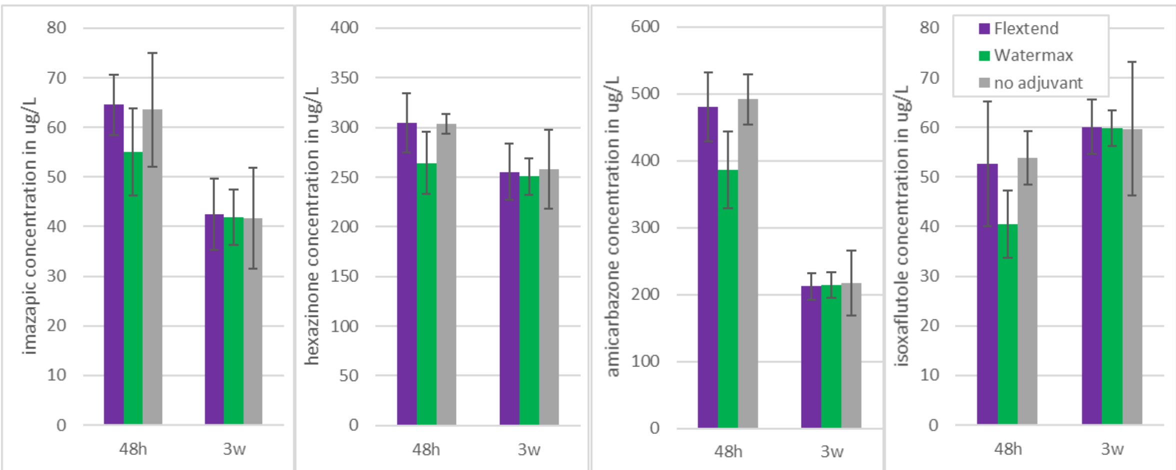

Figure 6. Imazapic, hexazinone, amicarbazone and isoxaflutole concentrations in runoff water when the runoff event occurred 48h and 3 weeks after herbicide application in trial 3.

Trial 4 on bare soil. The results of the trial on bare soil are given in Figure 7 for imazapic, hexazinone, amicarbazone and isoxaflutole. Watermaxx®2 slightly reduced the concentration of herbicides in runoff water when the event occurred 48h and 3 weeks after application. Reductions were only significant for imazapic (18% reduction) and isoxaflutole (26% reduction) when runoff occurred 48 h after product application. Flextend® tended to slightly increased herbicide concentration in runoff, but differences were not significant.

Load losses followed the same trend with Watermaxx®2 reducing imazapic load losses to 1.2 g/ha at 48 h (36% reduction compared to imazapic applied without adjuvant). At 48 h, load losses of 4.3, 7.4 and 1.2 g/ha were calculated for hexazinone, amicarbazone and isoxaflutole, respectively, equivalent to 30%, 34% and 42% reductions, respectively.

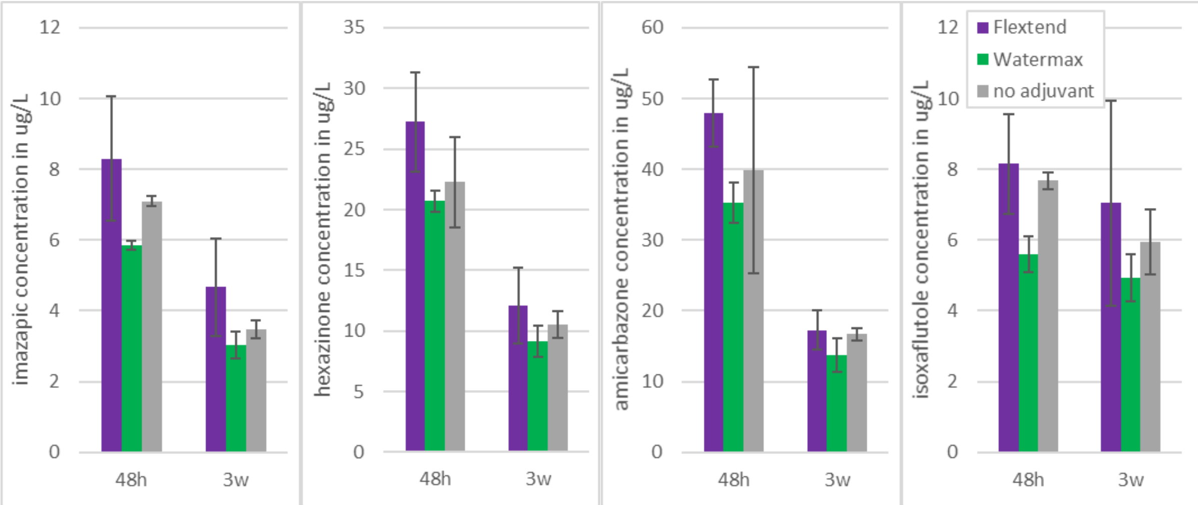

Figure 7. Imazapic, hexazinone, amicarbazone and isoxaflutole concentrations in runoff water when the runoff event occurred 48h and 3 weeks after herbicide application in trial 4.

DISCUSSION

None of the five adjuvants tested in this study was developed to perform in reducing herbicide runoff losses in a tropical climate, yet some of these adjuvants performed relatively well in specific situations.

In a freshly tilled bare soil scenario, Grounded® was the most efficient of the three tested oil-based adjuvants to reduce herbicide in runoff (up to 84% herbicide load reduction). Grounded® is promoted to improve herbicide adsorption in the soil, which translated in this trial into a reduction in herbicide losses *via* runoff. In terms of weed management, all oil-based adjuvants increased the percentage of weed controlled, (+15% herbicide efficacy for Grounded® and Ad-Here™, +10% for Atpolan® soil Maxx). Kierzek *et al.* (2017) also noted that Grounded® at 0.4 L/ha added to flufenacet and diflufenican or flufenacet and metribuzine increased their efficacy to control weeds in winter wheat. Woznica *et al.* (2016) also noted an enhanced efficacy of herbicides metazachlor and clomazone when Atpolan® soil Maxx was added to the spraying mix. Grounded at 3% added to the pre-emergent herbicide mix increases the treatment cost per hectare by $72 (2019 retail price). The water-quality and efficacy benefits of the product may justify this cost in some situations.

When applied on trash blanket, all oil-based adjuvants improved adsorption on soil and trash blanket. Kočárek *et al.* (2018) also observed better soil sorption with the adjuvant Grounded®. The impact of these products on herbicide leaching was not studied in this trial, but our results may suggest these products could have had a positive impact to reduce herbicide leaching. Woznica *et al.* (2016) measured a decrease in herbicide leaching when adding Atpolan® soil Maxx. In our trial, herbicides were absorbed more on the trash blanket than the soil when oil-based adjuvants were added to the spray mix compared to the herbicides alone. It is possible the adjuvants bound the herbicide onto the trash layer and reduced its movement downwards to the soil, positioning the herbicides above the soil surface which would increase their potential to be lost via runoff water. Grounded® significantly increased the runoff losses on trash blanket by nearly two-fold.

Watermaxx®2 was the other type of adjuvant with encouraging runoff results both in bare soil (42% herbicide load reduction) and trash blanket (31% herbicide load reduction) scenarios and slight herbicide efficacy improvements. These results are likely explained by Watermaxx®2's property to enhance water infiltration into the soil resulting in a better placement of the herbicides into the soil layer. Adding Watermaxx®2 at 9.35 L/ha to the herbicide mix increases the treatment cost by $144 per hectare (retail price 2018). The small water-quality and efficacy benefits will unlikely justify this additional cost.

CONCLUSIONS

Encouraging results in freshly tilled bare soil were found with the oil-based adjuvant Grounded®: It reduced herbicide concentration and loads in runoff while maintaining or slightly improving weed control. This product is currently under further investigation in other soil types and in bare soil ratoon. Poor results in GCTB in our trials may need to be confirmed with additional trials.

Slight improvements in runoff off water quality and herbicidal control were found with the adjuvant Watermaxx®2, but they are unlikely to justify the additional cost of the adjuvant.

ACKNOWLEDGEMENTS

We thank the following product manufacturers or distributors for supplying the adjuvants compared in this study: Agromix (Atpolan® soil Maxx), Agspec (Flextend®), RCR Agri Pty Ltd (Grounded®) and Vichem (Ad-Here™). We thank Tim Staier, Lisa Derby and Andrew Lynch from SRA for their technical assistance in the field and in the laboratory, and Sugar Research Australia Limited for funding the project that generated these data.

REFERENCES

Azania AAPM, Azania CAM, Gravena R, Pavani MCMD, Pitelli RA (2002) Sugar cane (*Saccharum* spp.) straw interference in emergence of weed species of the Convolvulaceae family. *Planta Daninha* 20: 207–212.

Correia NM, Durigan JC (2004) Weed emergence in soil covered with sugarcane harvest straw residue. *Planta Daninha* 22: 11–17.

Fillols E (2012) Weedicide properties of trash blankets and timing of application of pre-emergent herbicides on trash. *Proceedings of the Australian Society of Sugar Cane Technologists* 34: 17 pp.

Fillols E, Callow B (2010) Efficacy of pre-emergent herbicides on fresh trash blankets – results on late-harvested ratoons. *Proceedings of the Australian Society of Sugar Cane Technologists* 32: 460–473.

Fillols E, Callow B (2011) Efficacy of pre-emergent herbicides on fresh trash blankets – results on early-harvested ratoons. *Proceedings of the Australian Society of Sugar Cane Technologists* 33: 23–36.

Fillols E, Lewis S, Davis A (2018) Efficacy and environmental runoff impact of alternative pre-emergent herbicides to diuron applied on trash blanketed ratoons. *Proceedings of the Australian Society of Sugar Cane Technologists* 40: 282–292.

Kierzek R, Grychowski R, Ratajkiewicz H, Miklaszewska K (2017) The activity of selected herbicides with addition of soil adjuvants in winter wheat. *Progress in Plant Protection* 57: 312–318.

Kočárek M, Kodešová R, Sharipov U, Jursík M (2018) Effect of adjuvant on pendimethalin and dimethenamid-P behaviour in soil, *Journal of Hazardous Materials* 354, 266–274.

Loch RJ, Robotham BG, Zeller L, *et al.* (2001) A multi-purpose rainfall simulator for field infiltration and erosion studies. *Australian Journal of Soil Research* 39: 599–610.

Manechini CA, Junior Ricci, Donzelli JL (2005) An overview of controlled and non-controlled weeds as influenced by sugarcane trash blankets. *Sugar Cane International* 23: 11–14.

Perez HB, Chao TR (2004) Herbicida isoxaflutol (Merlin GD 75) en retoños verdes de caña de azúcar en la provincia de Cienfuegos. III Congreso 2004 Sociedad Cubana de Malezología, Memorias, Jardín Botánico Nacional, Ciudad Habana, 28, 29 y 30 de abril del 2004, pp.35–37.

Sampietro DA, Vattuone MA (2006) Sugarcane straw and its phytochemicals as growth regulators of weed and crop plants. *Plant Growth Regulation* 48: 21–27.

Selim HM, Bengtson RL, Griffin JL, Zhou L, Zhu H (2001) Effect of mulch residue on the use of alternative herbicides and sugarcane yield. In *Sugarcane research annual progress report, Louisiana State University Agricultural Center,* pp. 257–265.

Shaw M, Furnas MJ, Fabricius K, Haynes D, Carter S (2010) Monitoring pesticides in the Great Barrier Reef. *Marine Pollution Bulletin* 60: 113–122.

Shaw M, Müller JF (2005) Preliminary evaluation of the occurrence of herbicides and PAHs in the Wet Tropics region of the Great Barrier Reef, Australia, using passive samplers. *Marine Pollution Bulletin* 51: 876–881.

Singh D, Tomar PK (2005) Studies on critical period of weed removal in sugarcane ratoon. *Cooperative Sugar* 36: 911–914.

Villegas F, Torres JS, Larrahondo JE, Restrepo DF (2007) Allelopathic effects of sugarcane postharvest residue. *Proceedings of the International Society of Sugar Cane Technologists* 26: 374–379.

Woznica Z, Kucharski M, Szewczyk R, Sip M (2016) Optimising efficacy of herbicides with multifunctional adjuvant formulations (371). In *Proceedings of 7th International Weed Science Congress*, Prague.