Proceedings of the Australian Society of Sugar Cane Technologists, volume 42, 555–562, 2021

Peer-reviewed paper

Effect of the soil-binding adjuvant Grounded® on herbicide efficacy and runoff losses in bare soil in ratoons

EF Fillols[1] and A Davis[2]

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

Abstract To reduce the impact of pesticides, in particular pre-emergent herbicides, on fresh and estuarine water bodies of the Great Barrier Reef catchment, while maintaining productivity, the sugar industry is exploring innovative options to reduce the movement of herbicides off site. Previous research work has shown the oil-based adjuvant Grounded® added at 3 L/ha to the herbicide tank reduced runoff losses by 17 to 40% across all tested herbicides at 48 h and 3 weeks after product application, when applied on bare soil in a tilled plant cane in far northern Queensland. Herbicide efficacy was maintained above 90% for 200 days after product application with or without the addition of the adjuvant. Conversely, Grounded® did not reduce runoff loss when added to herbicides applied in trash blanketed ratoon. This paper presents additional research work carried out to assess the impact of Grounded® on pre-emergent herbicide efficacy and on runoff losses when applied to ratoon cane on bare soil. This scenario is typical of the Burdekin and New South Wales regions. Two trials were conducted in untilled ratoons after burning the trash blanket in far northern Queensland. Grounded® was added to six registered pre-emergent herbicides: imazapic (94.5 g/ha), hexazinone (472.5 g/ha), isoxaflutole (150 g/ha), amicarbazone (700 g/ha), atrazine (1350 g/ha) and pendimethalin (1001 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. Both runoff trials generated similar herbicide concentrations in runoff. As expected, higher concentrations for all herbicides were found in runoff 48 h after spraying compared to 3 weeks after spraying. The adjuvant Grounded® added to the spray tank did not decrease herbicide loss via runoff in both trials. Topsoil samples taken before and after rainfall, generally showed higher percentage herbicide in topsoil after rainfall when Grounded® was added to the tank mix compared to no added adjuvant. However, this slight binding improvement to the soil did not result in lower herbicide loss in runoff. These runoff and soil results mirrored previous research results when Grounded® was applied on trash blanketed ratoons. In both efficacy trials, weed control varied at each site between herbicide treatments depending on the environmental conditions and the weed species. However, the addition of Grounded® to each herbicide treatment did not affect the efficacy of any herbicide treatment in both trials. These results show that the oil-based adjuvant Grounded® is unlikely to improve the quality of runoff water leaving sugarcane paddocks when applied to untilled ratoon cane on bare soil.

Key words Grounded®, pre-emergent herbicide, runoff, water quality, soil-binding adjuvant

INTRODUCTION

Weeds actively compete with the sugarcane crop for light, water and nutrients. An effective weed-management program is essential to maintain sugarcane productivity.

Herbicides are commonly detected in key Great Barrier Reef (GBR) rivers by the GBRF Catchment Loads Monitoring Program. Herbicides that inhibit electron transport at photosystem II (PSII) in plants are particularly disruptive to the ecosystem. They include diuron, atrazine, hexazinone, ametryn, simazine and tebuthiuron (Haynes *et al.* 2000; Shaw and Müller 2005; Shaw *et al.* 2010), which are commonly detected at concentrations that at times exceed GBR ecological water quality protection guideline trigger values for up to several weeks.

Extension messages have focused on encouraging growers to reduce the amount of surface area sprayed (i.e. band spraying) with these PSII herbicides, to time the spraying well in advance to any predicted runoff inducing rain event and the use of alternative herbicides. The Queensland sugar industry is progressively minimising their reliance on PSII herbicides and adopting 'alternative' herbicides for weed control (Davis *et al.* 2014; Fillols *et al.* 2018, 2020). However, considerable uncertainty subsists on the most appropriate herbicide mix and application that provides suitable weed control while also achieving desirable water quality outcomes.

Since 2017, SRA has been investigating a different approach consisting of adding soil-binding adjuvants to the spray tank to assist in reducing herbicide losses via runoff, while maintaining or increasing the pre-emergent herbicides efficacies. Previous research work showed that three of the tested adjuvants significantly reduced herbicide runoff losses in bare soil in tilled plant cane. In this situation, Grounded® (an oil-based adjuvant) was the most effective adjuvant which reduced herbicide concentrations by 35% in average when runoff occurred 48 h after spraying. Most of the tested products did not significantly increase herbicide efficacy on weeds in the efficacy trials. In tilled plant cane, the use of Grounded® could assist in improving the quality of runoff water leaving sugarcane paddocks and, therefore, reduce the canegrower's impact on freshwater water and marine ecosystems. Conversely, when applied in green-cane trash-blanketed ratoons, all tested oil-based adjuvants significantly increased the runoff of the tested herbicides (Fillols and Davis 2020).

Some adjuvants are promoted by the manufacturer for their soil-binding properties, mostly regarding reduction of leaching. Kocarek *et al.* (2018) showed that Grounded® increased soil sorption of herbicides, with significant results for pendimethalin. It is to be noted Grounded® has not been specifically developed to sustain tropical climate and heavy rainfalls. Grounded® is commercially available in Australia.

Here, we present the results of further research work with the adjuvant Grounded® when sprayed in combination with pre-emergent herbicides in ratoon cane on bare soil. This scenario is common to the Burdekin and New South Wales regions who harvest burnt cane or burn the trash after harvest, but the trials were conducted in far northern Queensland where technical resource was readily available.

Table 1. Details of trial sites.

Trial site	1	2
Ground cover	Bare soil (burnt trash)	Bare soil (burnt trash)
Area	Moderate rainfall (annual average 1,900 mm), well drained	High rainfall (annual average 3,300 mm), poorly drained
Location	Mount Peter	Fishery Falls
GPS coordinates	17.068123°S, 145.749854°E	17.164499°S, 145.883598°E
Cane variety and ratoon number	Q240$^{\phi}$ First ratoon	Q232$^{\phi}$ Second ratoon
Soil type	Edmonton-Mission: Clay loam, ferrosol	Malbon-Thorpe: Grey loam
Date product applied	Runoff trial: 28/08/2019 (3 weeks), 16/09/2019 (48 h) Efficacy trial: 20/08/2019	Runoff trial: 4/09/2019 (3 weeks), 23/09/2019 (48 h), Efficacy trial: 23/8/2019
Weather conditions at application	20/08/2019: Temp 21.4°C, H% 72.1, Delta T 4.1, Wind SSW, average 2.1 km/h, max 3.7 km/h 28/08/2019: Temp 24.8°C, H% 68, Delta T 5, Wind SE, average 0.2 km/h, max 1.2 km/h 16/09/2019: Temp 24.4 °C, H% 57.5, Delta T 6.1, Wind SSE, average 1.7 km/h, max 10 km/h	23/08/2019: Temp 22.6°C, H% 55.4, Delta T 5.4, Wind SSE, average 4.6 km/h, max 7.6 km/h 4/09/2019: Temp 20.5°C, H% 54.5, Delta T 6.3, Wind SE, average 0.2 km/h, max 1.5 km/h 23/09/2019: Temp 25.5°C, H% 77.3, Delta T 3, Wind SE, average 6.5 km/h, max 15.9 km/h
Spray equipment	6-tank sprayer with boom Runoff trial (plot size: 0.75 m * 3 m): 3 brown air-inducted nozzles, tarps used to cover adjacent plots to avoid drift Efficacy trial (plot size: 2 interrow * 15m) : 6 brown air-inducted nozzles	
Rainfall simulation dates	18/09/2019 (48 h), 19/09/2019 (3 weeks)	25/09/2019 (48 h), 26/09/2019 (3 weeks)

METHODS

Two trials in ratoon cane compared the efficacy on weeds of herbicide treatments with and without the tested adjuvants boom-sprayed just after harvest. In both trials, the trash blanket was burnt after harvest, leaving only some ash residues on the ground. The trials (Table 1) were located in far northern Queensland in moderate and 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 the oil-based adjuvant Grounded® from Helena (USA, now retailed in Australia by Relyon) added to the herbicidal active ingredients imazapic, hexazinone, isoxaflutole, amicarbazone, atrazine and pendimethalin.

Each herbicide efficacy trial was designed as a randomised complete-block (RCB) design with adjacent controls and four replicates. Details of the treatments are given 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. Six subsequent assessment dates in each trial were done at 2-weekly intervals. Weed species present in the trials are shown in Table 3.

Table 2. Details of treatments in Trials 1 and 2.

Treatment	Adjuvant and rate	Herbicide and rate of application	Herbicide rate in kg/ha	Active ingredient (a.i.)	a.i. rate in g/ha
T1	Grounded® at 3%	Bobcat i-maxx SG	0.63	Imazapic Hexazinone	94.5 472.5
T2	None	Bobcat i-maxx SG	0.63	Imazapic Hexazinone	94.5 472.5
T3	Grounded® at 3%	Amitron Balance	1 0.2	Amicarbazone Isoxaflutole	700 150
T4	None	Amitron Balance	1 0.2	Amicarbazone Isoxaflutole	700 150
T5	Grounded® at 3%	Stomp Xtra Gesaprim	2.2 1.5	Pendimethalin Atrazine	1001 1350
T6	None	Stomp Xtra Gesaprim	2.2 1.5	Pendimethalin Atrazine	1001 1350

Table 3. Weed species in Trials 1 and 2.

Weed		Present in trial
Awnless barnyard grass	*Echinochloa colona*	1,2
Crowsfoot	*Eleusine indica*	1,2
Green summer grass	*Urochloa subquadripara*	1
Summer grass	*Digitaria ciliaris*	1
Blue top	*Ageratum conizoides*	2
Sensitive weed	*Mimosa pudica*	2
Prickly spider flower	*Cleome aculeata*	2
Red convolvulus	*Ipomoea hederifolia*	2
Pink convolvulus	*Ipomoea triloba*	2

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 in the adjacent control fitted as a covariate.

In the same cane blocks as the efficacy trials, ee used adjacent areas to carry out runoff experiments. We used a rainfall simulator (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 North Queensland, Figure 1). Each herbicide treatment (T1 to T4) was applied to a 4 m by 1 m and replicated three times (Table 4).

Figure 1. Runoff collection at Trial 1.

Table 4. Details of treatments in the runoff trials.

Treatment	Timing of application	Adjuvant and application rate	Active ingredient	a.i. rate in g/ha
T1	48 h before rainfall	Grounded® at 3%	Imazapic	94.5
T2		None	Hexazinone	472.5
T3	3 weeks before rainfall	Grounded® at 3%	Isoxaflutole	150
T4		None	Amicarbazone	700
			Pendimethalin	1001
			Atrazine	1350

Rainfall was applied 48 h or 3 weeks after herbicide application. For each rainfall simulation event, two 0.75 by 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 for each timing of application (48 h and 3 weeks) for trials 1 and 2, totalling to six events carried out over 2 days for each trial. Runoff water samples from each quadrat (plot) were collected every 5 minutes. Topsoil samples (2 cm depth) were taken from six randomised positions in each plot (12 cm by 8 cm area) before and just after rainfall. Water, sediment 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. Herbicide runoff-loss data are presented as the mean runoff concentrations with standard deviation of the replicated treatments. Herbicide concentration in soil after rainfall is presented in percentage of measured in soil before rainfall.

RESULTS

Efficacy in controlling weeds

Trial 1

The weed population was mainly composed of grasses and only reached 28% ground coverage in the control plots after 7 months. The main grasses were green summer grass, summer grass, awnless Barnyard grass and crowsfoot.

The first rainfall event that allowed the herbicides to be incorporated and activated, occurred on 4 October (10 mm rainfall), more than 7 weeks after spraying.

The means for T5 and T6 were not estimable due to absence of weeds in the untreated controls on those treatments for the first two assessment dates. The date-by-treatment interaction was excluded from the model as it was not significant and estimates for all the treatment effects could be obtained. For the variable "total percentage reduction", the analysis revealed significant differences among treatments ($p < 0.0001$). Stomp Xtra + Gesaprim was a less effective herbicide treatment (average T5 and T6: 40% efficacy) than Bobcat imax (average T1 and T2: 90% efficacy) or Balance + Amitron (average T3 and T4: 69% efficacy) for the 8-month assessment period. The lack of efficacy of Stomp + Gesaprim is linked to the delayed incorporation which exposed the treatment to UV light for weeks. Other tested herbicides are more UV stable and not as susceptible to delayed incorporation. The addition of Grounded® did not result in any significant changes in herbicide efficacy (Figure 2, left).

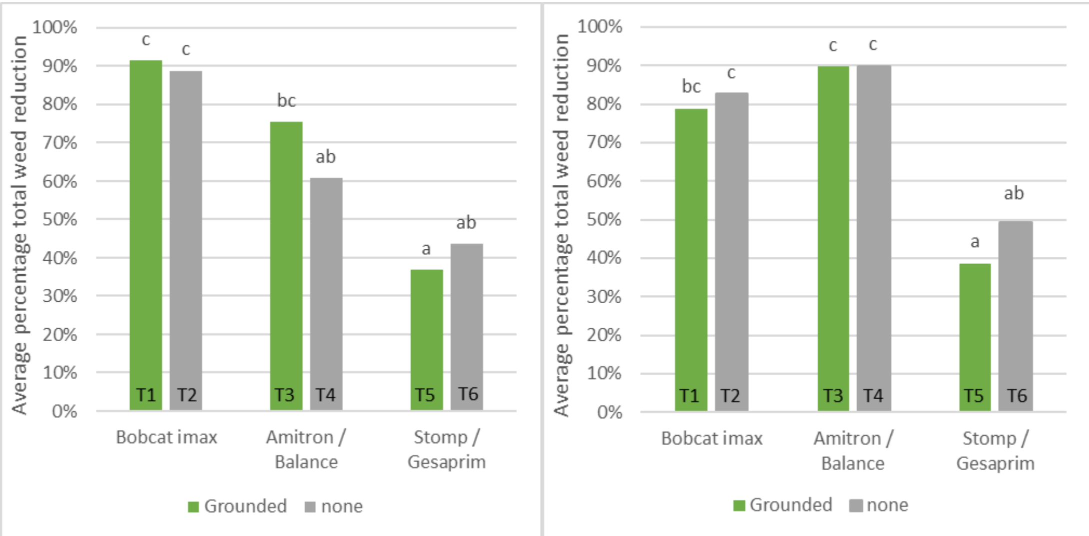

Figure 2. Percentage weed reduction in efficacy Trial 1 (left) and Trial 2 (right).

Trial 2

The weed population in this trial reached 92% soil coverage after 5 months and consisted mainly of broadleaves (sensitive weed, blue top, pricky spider flower) and grasses (awnless Barnyard grass, crowsfoot). Some red and pink convolvulus vines were also present.

The first incorporating rainfall event occurred on 4 and 5 October (17 mm and 13 mm rainfall, respectively), more than 5 weeks after spraying.

For the variable "total percentage reduction", the analysis revealed no significant difference for the interaction Treatment*Date ($p = 0.129$), however there were significant differences among treatments ($p = 0.0002$). Stomp Xtra + Gesaprim was a less effective herbicide treatment (average T5 and T6: 42% weed reduction) than Balance + Amitron with efficacies above 90% for the 5-month assessment period and Bobcat imax (average T1 and T2: 80% weed reduction). Again, the delayed incorporation by rainfall impeded the efficacy of Stomp + Gesaprim. The addition of Grounded® did not result in any significant changes in herbicide efficacy (Figure 2, right).

Herbicide loss through runoff

Herbicide concentrations in runoff are presented in Figure 3 (Trial 1: left; Trial 2: right) for the active ingredients imazapic, hexazinone, isoxaflutole (including metabolites DKN and BA), amicarbazone, pendimethalin and atrazine. The variability between the three replicates is illustrated by the error bars.

Herbicide concentrations without adjuvants are consistent with results from previous rainfall simulated trials on untilled ratoons (Fillols *et al.* 2020).

Results showed that the runoff concentrations for each herbicide was similar or slightly increased (not significantly) with the addition of Grounded® adjuvant, especially when runoff occurred 48 h after spraying.

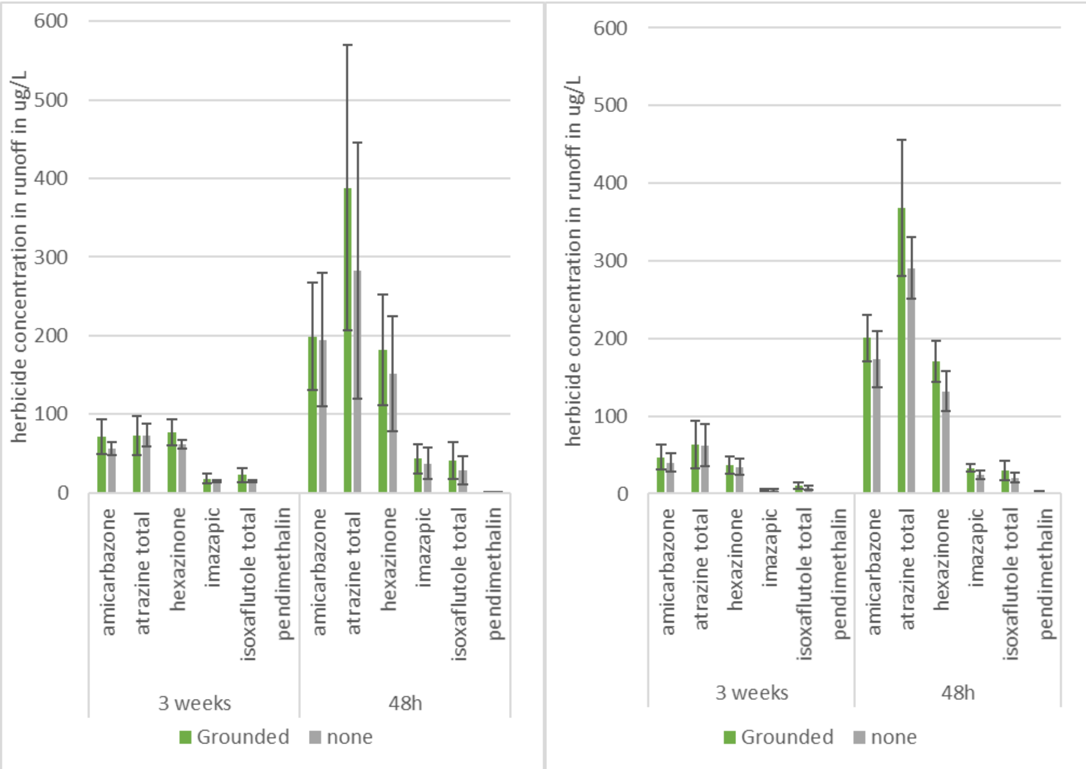

Figure 3. Herbicide concentrations in runoff water at 48 h and 3 weeks after application in Trial 1 (left) and Trial 2 (right). Error bars represent the standard deviation of the replicated treatments.

Figure 4 shows the concentration of herbicide in the topsoil after 80 mm runoff in percentage of the herbicide concentration in the topsoil before rainfall for amicarbazone, atrazine, hexazinone, imazapic, isoxaflutole and pendimethalin.

As a general rule, a larger percentage of herbicide was found in the topsoil after rainfall when the rain event occurred 3 weeks after spraying compared to 48 h. Better binding to the soil particles and less runoff occurred when herbicides had 3 weeks to bind to the soil versus 48 h. We observed that Grounded® further improved binding to the soil, especially when longer duration before rainfall (3 weeks versus 48 h) occurred. The error bars indicate significant differences in trial 1 (ferrosol) where Grounded® facilitated binding of isoxaflutole at both rainfall timing and of hexazinone and pendimethalin when 3 weeks elapsed between spraying and rainfall (Figure 4). In trial 2 on the grey loam, Grounded® seemed to have slightly increased binding all tested herbicides to the soil, when 3 weeks elapsed between application and rainfall. However, Grounded® seemed to have slightly decreased binding of all tested herbicides when only 48 h elapsed between spraying and rainfall (significant difference for imazapic). Very little amounts were bound to the sediment fraction (data not shown). The soil characteristics seemed to have influenced the binding speed of the adjuvant Grounded®.

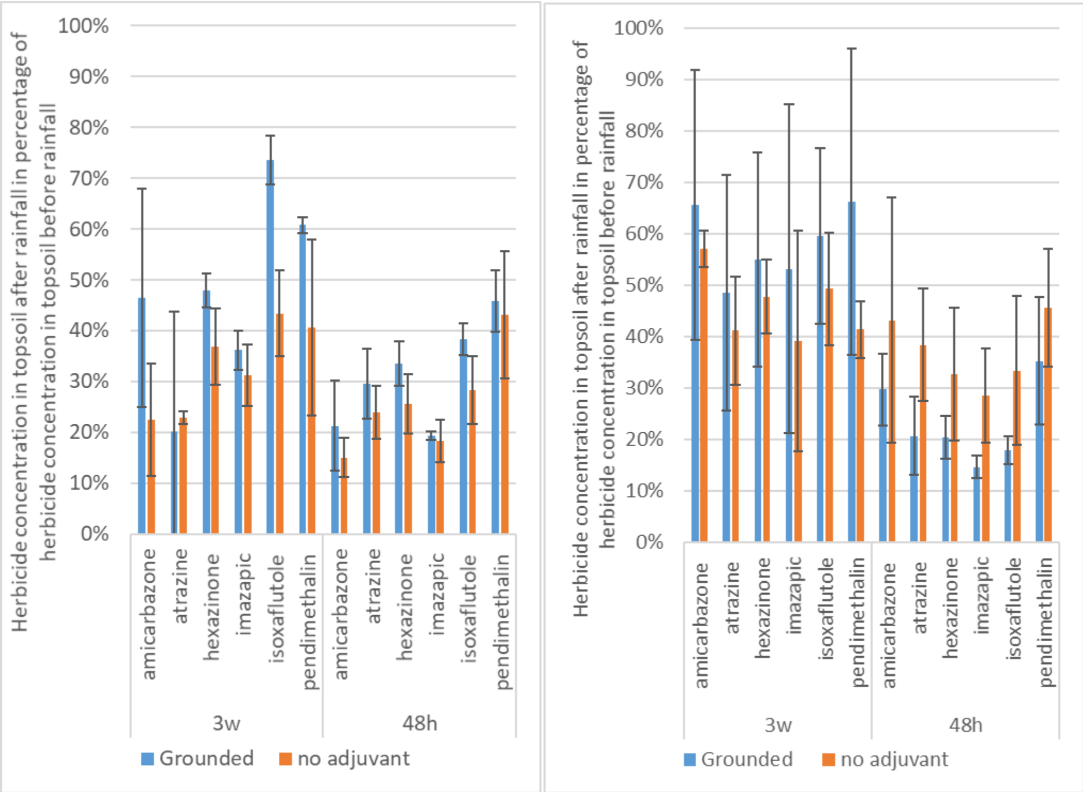

Figure 4. Percentage of active ingredient remaining in the topsoil after an 80 mm rainfall event in Trial 1 (left) and Trial 2 (right).

DISCUSSION

When Grounded® was added to herbicide tank mixes in freshly tilled bare-soil plant cane in a previous trial, it was the most efficient of the tested oil-based adjuvants to reduce herbicide in runoff (up to 84% herbicide load reduction, Fillols and Davis 2020). Grounded® is promoted to improve herbicide adsorption in the soil, which translated in this previous trial into a reduction in herbicide losses via runoff. In terms of weed management in this previous trial, Grounded® increased the percentage of weed controlled by 15%, which confirmed findings from Kierzek *et al.* (2017) who 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.

Here, Grounded® applied to untilled bare soil ratoon cane did not result in herbicide reductions in runoff nor in significant increase in herbicide efficacy to control the weeds. These results are similar to those obtained in a previous trial in trash-blanketed ratoon, when the tested herbicides were found in higher concentrations in the trash blanket when Grounded® was added to the tank mix, suggesting better binding to organic matter (Fillols and Davis 2020). Here, the percentage of herbicide concentrations remaining in topsoil were generally slightly higher for the treatment Grounded® in the topsoils at both trial sites when the runoff event occurred 3 weeks after spraying and at one site when runoff occurred 48 h after spraying. The slight additional herbicide binding in the topsoil (or in the trash blanket in a previous trial) did not result in runoff reduction suggesting the binding is not tight enough to prevent the herbicide to return to the soil water during a runoff event.

Interestingly the herbicide concentrations in the topsoil after runoff in the previous trial in freshly tilled plant cane on a grey loam (soil type similar to trial 2) were 2 to10-fold lower than the two trials shown here (compare Fillols and Davis 2020). It seems like the dynamic of herbicide binding is a complex process where timing and soil compaction (tilled/ untilled) interact with soil type and herbicide / adjuvant properties. In the previous trial on freshly tilled soil, herbicide concentrations in runoff were greatly reduced in presence of the adjuvant Grounded® at both runoff event date, suggesting that in loose soil, Grounded® could have assisted in better binding of herbicides lower in the soil profile (Fillols and Davis 2020). Here, on bare soil in untilled ratoons, the water infiltration was insufficient to allow rapid movement of active ingredient down the profile within the 1-hour rainfall event, which could have limited herbicide sorption into deeper soil layer and resulted in less opportunities for Grounded® to facilitate herbicide binding to soil particles.

When adding Grounded® at 3% to the pre-emergent herbicide mix, treatment cost per hectare increases by AU$72 (2019 retail price). The water quality and efficacy benefits of the product may only be justified in freshly tilled plant cane; however, herbicide losses in plant cane are already very low (less than 5% of herbicide applied get lost via runoff) due to inherent better binding to soil particles and better water infiltration, and the use of soil-binding adjuvant in this situation would be of little value.

CONCLUSIONS

Encouraging results previously obtained with the oil-based adjuvant Grounded® in freshly tilled bare soil (reduction in herbicide concentration and loads in runoff while maintaining or slightly improving weed control) were not confirmed in ratoon cane. Poor runoff water quality outcomes and efficacy results were obtained when using Grounded® in compacted ratoon cane on bare soil in two soil types.

ACKNOWLEDGEMENTS

We thank Tim Staier, Lisa Derby and Andrew Lynch from Sugar Research Australia for their technical assistance in the field and in the laboratory and Muyiwa Olayemi for the statistical analysis. We also thank Sugar Research Australia for funding the project that generated these data.

REFERENCES

Davis AM, Lewis SE, O'Brien DS, Bainbridge ZT, Bentley C, Mueller JF, Brodie JE (2014) Water resource development and high value coastal wetlands on the Lower Burdekin floodplain, Australia. In *Estuaries of Australia in 2050 and beyond* (Ed. W Eric) pp. 223–245. Springer, Dordrecht.

Fillols E, Davis A (2020) Soil-binding adjuvants can reduce herbicide loss via runoff. *Proceedings of the Australian Society of Sugar Cane Technologists* 42: 433–443.

Fillols E, Davis AM, Lewis SE (2020) Combining weed efficacy, economics and environmental considerations for improved herbicide management in the Great Barrier Reef catchment area. *Science of the Total Environment* 720: 137481.

Fillols E, Lewis S, Davis A, Ward 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.

Haynes D, Muller J, Carter S (2000) Pesticide and herbicide residues in sediments and seagrasses from the Great Barrier Reef World Heritage Area and Queensland coast. *Marine Pollution Bulletin* 41: 279–287.

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, Masterman N, Orange DN, Bridge BJ, Sheridan G, Bourke JJ (2001) A multi-purpose rainfall simulator for field infiltration and erosion studies. *Australian Journal of Soil Research* 39: 599–610.

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.