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Impact of application depth and slot closure on runoff losses of imidacloprid

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Abstract Imidacloprid represents the Australian sugar industry's best canegrub-management tool, but it has been detected in many water bodies, including groundwater, creeks, rivers and marine environments, posing a potential risk to the health of the Great Barrier Reef. In ratoon cane, it is commonly applied in liquid form with coulters within the cane row. Imidacloprid product labels state that, when applied in ratoons, the product must be placed at 100–125 mm depth and the slot must be covered; however, it is not uncommon to observe application equipment that does not maintain the desired depth or fails to close the slot appropriately. To investigate the best application methods to reduce imidacloprid runoff, two rainfall-simulation trials were established in the Burdekin and in the Wet Tropics to assess the impact of depth and slot coverage on imidacloprid runoff when the liquid formulation is applied with a stool-splitter tine implement. An additional runoff trial under overhead irrigation was set up in the Wet Tropics to test the efficacy of the StoolZippa™ to close the slot and reduce imidacloprid runoff losses when the product is applied at the correct depth of 100 mm. Results from the rainfall-simulation trials showed higher imidacloprid concentration in runoff from a shallow application at 50 mm compared to the recommended minimum 100 mm application depth. A press wheel reduced the imidacloprid concentration to nil when the product was applied at the correct depth of 100 mm; however, it slightly increased the concentration in the case of the shallow application. In the overhead-irrigation trial, the StoolZippa™ increased the imidacloprid concentrations in runoff versus the slot left open, but these concentrations were still extremely low and not of environmental concern. These trials indicate that ensuring the product is consistently applied at 100 mm depth is the best way to reduce imidacloprid loss via runoff when the product is applied with a stool-splitter tine implement. As trials were only conducted in loam soils at two locations, further trials are recommended over a range of soil types and geographic locations.

Key words Imidacloprid, stool splitter, application, depth, slot

INTRODUCTION

Imidacloprid is a neonicotinoid insecticide that is water soluble and readily absorbed by plants via their root system. This provides a significant advantage for controlling root-feeding insects such as canegrubs (larvae of scarab beetles) and imidacloprid has proven to be a reliable and cost-effective protection for the Australian sugarcane industry. The estimated field half-life in soil ranges from 104 to 228 days (Pesticide Properties Database, University of Hertfordshire 2019); this persistence provides good pest control throughout a cropping season. Liquid forms of imidacloprid (e.g. Confidor® Guard) can be used strategically in response to emergent canegrub damage at any point in the crop and are a very affordable control method.

Imidacloprid is highly soluble in water (610 mg/L) and moderately mobile in soil (Kfoc range 109–411 mL/g; Pesticide Properties Database). Therefore, imidacloprid may ultimately end up in aquatic environments as a result of spray drift or via run-off after application (Tišler *et al.* 2009). Losses in surface runoff were first studied in tobacco by Triantafyllidis *et al.* (2006) who reported imidacloprid losses ranging from 2 to 12 µg/L for slope gradients varying between 0 to 10% when rainfall occurred 24 hours after product application at 55 g a.i./ha. Thuyet *et al.* (2011) also reported imidacloprid runoff losses of 91 and 75 µg/L when rainfall occurred 24 h and 7 days, respectively, after product application at 278 g a.i./ha. In both of these studies, the imidacloprid was surface applied, unlike in sugarcane where imidacloprid is applied under the soil surface either sprayed in the furrow and followed by immediate soil coverage in plant cane or with coulters in ratoon cane.

The Great Barrier Reef (GBR) Catchment Loads Monitoring Program monitors concentrations of pesticides in key GBR rivers. Between 2011 and 2015, imidacloprid was detected in approximately 50% of surface-water samples in waterways that drain agricultural land and discharge to the Great Barrier Reef (Turner *et al.* 2013a, 2013b; Wallace *et al.* 2014, 2015, 2016; Garzon-Garcia *et al.* 2015).

Imidacloprid were also detected in more than half of the deployed marine passive samplers in 2016–17 (Grant *et al.* 2018). End-of-catchment annual pesticide loads were calculated and annual loads of imidacloprid were comparable with those for the PSII herbicides in some catchments (i.e. 230 kg imidacloprid annual load for both the Tully and Proserpine rivers and 170 kg for the Pioneer river) (Grant *et al.* 2018). Masters *et al.* 2014 also detected imidacloprid in leachate approximately 2.5 years after the time of application.

Many studies have proven the toxicity of imidacloprid to the aquatic environment. Single-species laboratory tests (Alexander *et al.* 2007; Stoughton *et al.* 2008; Roessink *et al.* 2013; Cavallaro *et al.* 2017; Van den Brink *et al.* 2016) and model ecosystem studies (Hayasaka *et al.* 2012; Mohr *et al.* 2012; Colombo *et al.* 2013) showed the susceptibility of a wide range of species in temperate climate.

Sumon *et al.* (2018) also indicated that (sub-)tropical aquatic ecosystems could be more sensitive to imidacloprid compared to temperate ones with significant effects of imidacloprid on the zooplankton and macroinvertebrate community, and on some individual phytoplankton taxa, with *Cloeon* sp., *Diaptomus* sp. and *Keratella* sp. being the most affected species.

In response to these detections of imidacloprid in water, and in view of its toxicity to the aquatic ecosystem, the Queensland Government proposed a new aquatic-ecosystem protection-guideline value for imidacloprid in 2017. The new value for imidacloprid to protect 95% of freshwater species in Australia is 0.11 µg/L (King *et al.* 2017). Exceedances of this new guideline have already occurred in some catchments (i.e. Johnstone River, Tully River, Pioneer River and Sandy Creek) (Great Barrier Reef Catchment Loads Monitoring program, Queensland Department of Environment and Science, 2015).

These imidacloprid exceedances are not unique to Australia. Starner and Goh (2012) detected imidacloprid in 89% of water samples taken from rivers, creeks and drains in California, with 19% of samples exceeding the US Environmental Protection Agency guideline concentration of 1.05 µg/L. In the Netherlands, their maximum permissible risk guideline value of 0.013 µg/L was exceeded in almost half of their 9037 water samples, with the highest exceedance value of 320 µg/L measured in 2005 (Van Dijk *et al.* 2013). Bonmatin *et al.* 2015 also quoted exceedances of imidacloprid in water in the Canadian Prairie Pothole region, in Almeria (Spain), in Sweden, Quebec, New York State and Wisconsin.

Despite imidacloprid application in sugarcane under the soil surface, contamination of the surrounding waterways still occurs and exceedances are recorded. As imidacloprid represents the sugar industry's best canegrub management tool, proper stewardship of this chemical is vital for the ongoing viability of cane farming in the soils where canegrub damage is common. s previous runoff work (Triantafyllidis *et al.* 2006; Thuyet *et al.* 2011) indicated imidacloprid losses via runoff when the product was surface applied, a study of the impact of product placement in sugarcane was necessary to identify the main contributing factors to runoff losses. Imidacloprid product labels state that, when applied in ratoons, the product must be placed at 100–125 mm depth and the slot must be covered with soil. We have frequently noticed that a range of application equipment do not consistently maintain depth along the row and across the implement coulter assemblies and do not close the slot appropriately.

METHODOLOGY

Two rainfall simulation trials (trial 1 and trial 2) compared the impact of depth and slot coverage on imidacloprid runoff when the liquid formulation was applied in ratoons, with a stool-splitter tine implement. The slot was closed using a normal press wheel (e.g. Figure 1). The trials were in the Burdekin (Dry Tropics) and at Meringa (Wet Tropics), in soils favourable to greyback canegrubs (*Dermolepida albohirtum*) (Table 1). Trial 3 was established under sprinkler irrigation and compared the impact of slot closure using the StoolZippa™ versus an open slot (Figure 2). StoolZippa™ is a spiked closing wheel (EHS design, QDAF funding) designed to close the slot on a wide range of soil types, especially on clay soils that are hard to close with a normal press wheel. Details of the treatments for trial 3 are given in Table 2.

Table 1. Details of the trial sites.

Trial site	1	2	3
Trial type	Rainfall simulation	Rainfall simulation	Irrigated with flumes
Ground cover	Trash blanket	Bare soil	Trash blanket
Area	Moderate rainfall, well drained	Low rainfall, moderately drained	Moderate rainfall, well drained
Location	Meringa Sugar Research Australia (SRA) station	Brandon SRA station	Meringa SRA station,
Catchment area	Mulgrave	Burdekin	Mulgrave
GPS coordinates	17.072022°E 145.779424°S	19.565610°E 147.322735°S	17.072080°E 145.779446°S
Cane variety and ratoon number	Mixed varieties, 3R	Mixed varieties, 2R	Mixed varieties, 2R
Soil type	Clifton[1] Red loamy sand – Kandosols[2]	BUfc[1] Clay loam soils – Dermosols, Ferrosols[2]	Clifton[1] Grey loam – Kandosols[2]
Soil texture 0–200 mm	Clay 7%, Fine sand 64%, Coarse sand 18%, Silt 11%	Clay 20%, Fine sand 56%, Coarse sand 1%, Silt 22%	Clay 15%, Fine sand 49%, Coarse sand 18%, Silt 19%
Soil texture 200–400 mm	Clay 10%, Fine sand 59%, Coarse sand 19%, Silt 13%	Clay 23%, Fine sand 56%, Coarse sand 1%, Silt 20%	Clay 14%, Fine sand 48%, Coarse sand 17%, Silt 21%
Date product applied	14–15–16/08/2017	9–10–11/10/2017	30/07/2018
Weather at application	Fine weather, sunny.	Fine weather, sunny.	Fine weather, sunny.
Equipment used	Stool splitter with tine, fitted with depth wheel. Nozzle spraying downwards at the bottom of the slot.	Stool splitter with tine, no depth wheel. Nozzle spraying backwards in the slot.	Stool splitter with tine, fitted with depth wheel. Nozzle spraying downwards at the bottom of the slot.
Runoff dates	16–21–22/08/2017*	11–12–13/10/2017	8/08/2018, 27/08/2018, 13/09/2018
Comments	Many stones	Very dry soil	Dry soil

[1] Soil mapping unit name

[2] Australian soil classification

* Technical issue with the rainfall simulator delayed rainfall on replicate 2 and 3 (by four days)

Figure 1. Press-wheel assembly (behind a double-disk opener in this picture). Credit : Hodge Industries.

Figure 2. StoolZippa™ behind a stool-splitter tine assembly.

Table 2. Details of treatments in the runoff trials.

Trial	Number of replicates	Treatment	Timing of rainfall	Depth of application	Slot coverage	Product application rate
1 and 2	3	T1	48h after product application	50 mm	Open slot	Confidor® Guard at 22 mL/100 m Water rate 1.6 L/100 m Nozzle delivering 0.8 L/min, speed 3 km/h
		T2		50 mm	Closed with press wheel	
		T3		100 mm	Open slot	
		T4		100 mm	Closed with press wheel	
		Untreated				None
3	3	T1	9, 28 and 44 days after product application	100 mm	Open slot	Confidor® Guard at 22 mL/100 m Water rate 1.6 L/100 m Nozzle delivering 0.8 L/min, speed 3 km/h
		T2		100 mm	Closed with StoolZippa™	

In trials 1 and 2, a rainfall simulator (built according to Loch *et al.* 2001) was used to apply rainfall to small field plots (1.6 m wide × 3 m long) two days after the application of imidacloprid to maximize the risk of imidacloprid loss in runoff (Figure 3). Plot edges were bound by a metal frame driven 30–50 mm into the soil. Runoff was routed through metal spouts for collection. Simulated rainfall was applied at rates (70–80 mm/h) representing a one-in-two-year average recurrence interval for the region (Melland *et al.* 2016). Three rain gauges located in the plot recorded the rainfall amount applied during each simulation. Runoff water was collected every 5 minutes and composited as one sample for each plot (plot runoff collected for 4–5 seconds every 5 minutes, depending on the flow rates at each site), starting when runoff commenced and continuing until plot runoff ceased. The runoff flow volume for each plot was also measured at the same 5-minute sample collection periods by timing the duration for plot runoff to fill a 500 mL jug.

Figure 3. Rainfall simulator and small field plot.

In trial 3, a network of 20 overhead sprinklers was installed to irrigate six 60-meter-long strips (three rows each). Strips were separated by a minimum of two untreated guard rows. Six flumes channelling water coming from the two interrows of each plot were installed to measure flow and collect water samples. Three runoff-inducing irrigation events were applied: 100 mm of overhead irrigation was applied in 5 hours for each event. A total of 26 mm of irrigation was applied in four separate irrigation events (not enough to generate runoff) after product application and before the first runoff event. This “conditioning” of the soil was intended to displace imidacloprid bound to soil particles into the soil solution and make it more prone to runoff. The runoff flow volume for each plot was measured every 10 minutes by timing the duration for plot runoff to fill a 3 L jug. 100 mL of runoff water was collected from every 400 L that flowed through the flume and combined in a composite sample for each runoff event. Sampling started when runoff commenced and continued until plot runoff ceased.

The composite sample was used to analyse the concentration of imidacloprid in the water and sediment fractions. Samples were collected directly into 1 L glass bottles that were covered in aluminium foil. Samples were stored in ice boxes (on site) or in the fridge (4°C overnight) prior to transport by refrigerated road freight to the receiving laboratory. Sugar Research Australia (SRA) laboratories at Indooroopilly was used for imidacloprid analysis. Some blind samples were also sent to ACS laboratories, Melbourne, and confirmed the accuracy and reliability of SRA laboratories.

For the statistical analysis, concentrations and loads were considered continuous variables. The explanatory factors are qualitative, therefore, a linear mixed model using ASeml-R (Butler 2009) in R (R Core Team 2016) was fitted to the data. Data from trial 1 and 2 were combined. The analyses were conducted on the natural logarithmic scale for all variables.

RESULTS

Trials 1 and 2

Individual imidacloprid concentrations for each plot and calculated loads for trials 1 and 2 are reported in Table 3. High variabilities among replicates were measured, unlike runoff results traditionally obtained during rainfall simulation with surface-applied herbicides (Fillols *et al.* 2018). Imidacloprid concentrations obtained in trials 1 and 2 were very low. The value for plot 7, trial 2 was removed from the statistical analysis as it reflected only an issue at application.

Table 3. Imidacloprid concentrations in runoff and calculated loads in trial 1 and 2.

Trial	Plot	Depth in mm	Closure[1]	Rep	Concentration in µg/L	Concentration minus untreated in µg/L	Volume runoff in plot in L	Calculated load in g/ha[2]
1	1	50	PW	1	1.85	1.79	200	0.74
	2	100	PW	1	[0.08]	0.02	192	0.01
	3	50	OS	1	0.18	0.12	243	0.06
	4	100	OS	1	0.12	0.06	280	0.04
	5	100	OS	2	2.43	2.37	266	1.31
	6	50	OS	2	0.23	0.17	298	0.11
	7	100	PW	2	0.16	0.10	212	0.04
	8	50	PW	2	9.98	9.92	283	5.85
	9	50	OS	3	2.22	2.16	167	0.75
	10	100	PW	3	0.14	0.08	286	0.05
	11	50	PW	3	1.00	0.94	311	0.61
	12	100	OS	3	0.44	0.38	177	0.14
	Untreated				[0.06]	0.00	180	0
	Irrigation bore water				0.27			
2	1	50	PW	1	0.25	–0.06	119	NA
	2	100	PW	1	1.05	0.74	129	0.20
	3	50	OS	1	0.49	0.18	148	0.06
	4	100	OS	1	0.47	0.16	171	0.06
	5	100	OS	2	0.25	–0.06	83	NA
	6	50	OS	2	0.53	0.22	151	0.07
	7	100	PW	2	51.58*	51.27*	213	22.80*
	8	50	PW	2	0.16	–0.15	163	NA
	9	50	OS	3	[0.09]	–0.22	171	NA
	10	100	PW	3	0.20	–0.11	189	NA
	11	50	PW	3	0.24	–0.07	159	NA
	12	100	OS	3	0.16	–0.15	166	NA
	Untreated				0.31	0.00	159	0.10
	Irrigation bore water				<LOD			

[ ] Bracketed results are less than LOQ and greater than the LOD of 0.05 µg/L

[1] PW: Press wheel; OS: Open slot

[2] Loads = concentration minus untreated * volume of runoff * 10000 / plot surface area

* Technical application issue (pump was left on while the nozzle was off the ground, contaminating the surface).

In trial 1, an application depth of 50 mm resulted in imidacloprid concentrations of 0.8 to 9.98 µg/L versus 0 to 2.43 µg/L for an application depth of 100 mm. The background contamination was minimal as shown by the imidacloprid concentration measured in the untreated control plot (below the limit of quantification) despite the irrigation bore water containing 0.27 µg/L of imidacloprid.

In trial 2, imidacloprid concentrations were 0.16 to 1.05 µg/L for application at 50 mm versus 0.09 to 0.049 µg/L for the deep application. The background soil contamination in the untreated plot resulted in 0.31 µg/L of imidacloprid found in the runoff water. Imidacloprid losses due to this background contamination were similar or higher than losses coming from 5 of 10 of the treated plots, invalidating the load calculation for those plots. No detectable imidacloprid was found in the irrigation bore water at this site.

In both trials, an extremely small amount of imidacloprid were found bound to the sediment fraction of the runoff (0 to 0.06 mg/kg in trial 1, 0 to 0.13 mg/kg in trial 2) and their values for each plot mirrored the concentrations measured in the water fraction.

Despite high variability among the three replicates, the statistical analysis on the combined data for trials 1 and 2 showed there was a significant effect due to Trial (P 0.029) and Depth (P 0.039) on the variable "concentration minus untreated". The back-transformed predicted values for the main effect of depth are found in Table 4. There was no significant effect due to Closure (P 0.651).

Table 4. Predicted concentration minus untreated for the main effect Depth (trial 1 and 2 combined).

Depth in mm	Predicted value in µg/L	Standard error	Back-transformed predicted concentration minus untreated in µg/L	Ranking
50	0.435	0.127	2.546	B
100	0.199	0.126	2.220	A

In terms of loads, there was a significant effect due to Trial (P 0.031) on the variable "load minus untreated" but no significant effect due to Depth (P 0.085) or Closure (P 0.548); however, loads data followed the same trends as the concentrations data.

The analysis showed that higher imidacloprid concentrations were found from application at 50 mm versus 100 mm. The slot closure did not have a significant effect on imidacloprid loss, but the press wheel seemed to reduce the imidacloprid concentration to nearly zero (concentration minus untreated) when the product was applied at the correct depth of 100 mm, whereas it seemed to increase imidacloprid concentration in the case of the shallow application (Figure 4). However, there was no significant effect due to Interaction depth*slot closure (P 0.15).

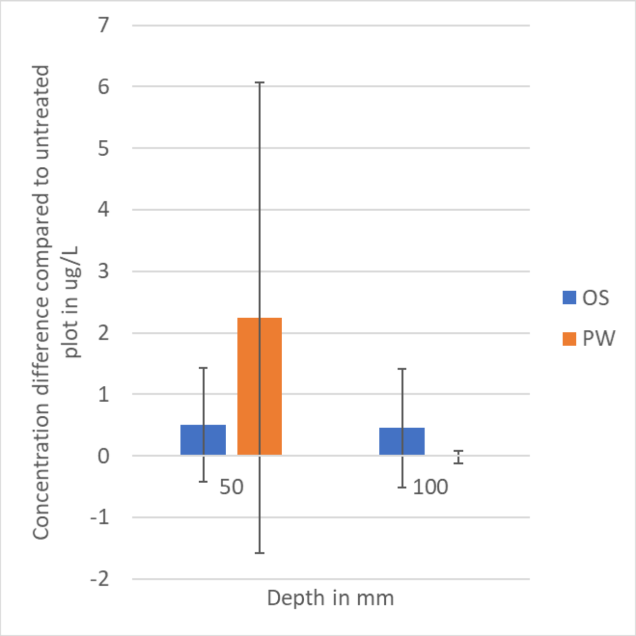

Figure 4. Concentration differences to the untreated control (combined data for trial 1 and 2). PW: Press wheel; OS: Open slot.

Trial 3

Individual imidacloprid concentrations for each plot and calculated loads for trial 3 are shown in Table 5. In this trial, no untreated control plot was added to the design, so the loads were calculated from the raw imidacloprid concentrations in runoff measured in each plot. The irrigation water used in this trial was pumped from the same bore as trial 1. Again, relatively high concentrations of imidacloprid were found in the bore water for each event (0.24, 0.18 and 0.19 µg/L). Most of the imidacloprid concentrations measured in the treated plots in trial 3 were below the concentration found in the bore. A similar phenomenon was observed in trial 1, where the runoff of the untreated plot and most of the treated plots had lower concentration of imidacloprid than the irrigation water.

In this trial, we measured low variability among the three replicates, indicating this large-scale rainfall simulation was a more suitable methodology than small plots rainfall simulation to study runoff losses from products applied under the soil surface.

The statistical analysis showed there was a significant effect due to Closure (P 0.022) and due to Event (P 0.017) on the variable "concentration". The back-transformed predicted values for the main effect of Closure are found in Table 6.

In terms of loads, there were no significant terms in the model (P>0.05); however, loads followed the same trends as the concentrations.

The analysis showed very low imidacloprid concentrations in runoff for both tested treatments. The application with the StoolZippa™ resulted in higher imidacloprid losses via runoff compared to the slot left open.

Table 5. Imidacloprid concentrations in runoff and calculated loads in trial 3.

Event	Plot	Treatment[1]	Slot depth in mm	Rep	Concentration in µg/L	Runoff volume L/ha	Load in g/ha
1	1	OS	100	1	0.18	189369	0.034
	2	ZIP	100	1	0.175	317928	0.056
	3	ZIP	100	2	0.15	218146	0.033
	4	OS	100	2	0.1	453756	0.045
	5	ZIP	100	3	0.12	317697	0.038
	6	OS	100	3	0.115	271040	0.031
	Irrigation bore water				0.24		
2	1	OS	100	1	0.11	142539	0.015
	2	ZIP	100	1	0.16	230695	0.037
	3	ZIP	100	2	0.14	156321	0.022
	4	OS	100	2	0.12	403348	0.046
	5	ZIP	100	3	0.13	213246	0.028
	6	OS	100	3	0.10	215137	0.022
	Irrigation bore water				0.18		
3	1	OS	100	1	0.125	129760	0.016
	2	ZIP	100	1	0.195	236410	0.046
	3	ZIP	100	2	0.255	123784	0.032
	4	OS	100	2	0.165	450987	0.074
	5	ZIP	100	3	0.175	215045	0.038
	6	OS	100	3	0.17	241799	0.041
	Irrigation bore water				0.19		

[1] OS: Open slot, ZIP: StoolZippa™

Table 6. Predicted concentration for main effect Closure in trial 3.

Closure	Predicted value in µg/L	Standard error	Back-transformed predicted concentration minus untreated in µg/L	Ranking
OS	0.122	0.008	2.130	A
ZIP	0.154	0.008	2.166	B

DISCUSSION

Trials 1 and 2 showed that application at a depth of 100 mm significantly reduced imidacloprid losses via runoff versus a shallower depth of 50 mm. A minimum depth of 100mm as recommended by the label significantly contributed to minimise the impact of the product on water quality. In our three trials, imidacloprid application at 100 mm depth led to very low imidacloprid losses via runoff, often below 1 µg/L, resulting in load losses below 1 g per hectare.

The press wheel reduced the imidacloprid losses when the product was applied at the correct depth of 100 mm; however, it increased the concentration in the case of the shallow application (probably because the wheel was occasionally in direct contact with treated soil). Press wheels need to be used behind implements that apply imidacloprid at the correct depth or they may aggravate imidacloprid loss from a shallow application. Unexpectedly, the StoolZippa™, used to close the slot in trial 3 behind a correct application at 100 mm depth, increased the imidacloprid concentration in runoff, when it was meant to reduce it. It is possible that the spike wheel, designed to crumble the soil, could have been in contact with the product applied in the slot and rotated it back towards the surface. However, imidacloprid losses measured in the StoolZippa™ treatment remained very low and without real consequence to water quality. The StoolZippa™ was designed to solve the closure issue on clay soil, where a press wheel is inefficient. Hughes and Gonzalez (2019) showed that imidacloprid concentrations were reduced by two folds when using the StoolZippa™ to close the slot in their trial carried out on a clay soil. Our trials were set up on grub-prone, loamy soils where the use of the StoolZippa™ was not especially required and a traditional press wheel would have worked successfully, potentially without increasing imidacloprid runoff losses (as in trials 1 and 2).

Some imidacloprid background soil contamination was expected, as the paddocks were treated with imidacloprid 2 years before the trial and imidacloprid half-life in soil ranges from 130 to 191 days. Bonmatin *et al.* (2015) found detectable imidacloprid in 62 out of the 67 sampled soil on conventional farming, with some of these positive samples not being treated within the last 2 years.

In trial 2, the background contamination resulted in similar or higher loss from the untreated plot than 50% of the plots that were treated with imidacloprid 48 hours before runoff. This unexpected outcome may be explained by a heterogenous distribution of imidacloprid in the soil across the paddock from previous applications. As we only had one untreated control plot in our trial design, we could not have captured this potential variability.

The very low imidacloprid concentrations recorded in the three trials were not anticipated as they cannot explain the exceedances measured in the rivers by the Great Barrier Reef Catchment Loads Monitoring Program (The Great Barrier Reef Catchment Loads Monitoring program, Queensland Department of Environment and Science 2015). Our runoff concentrations were below some observed peak river concentrations and following any dilution would be presumed to present low ecological risk. Further robust research in each area is still necessary to fully understand the potential causes of contamination. However, a range of hypotheses to explain these differences can be formulated:

- These trials were undertaken in grub-prone soil types. Application of imidacloprid in heavier soil types may result in higher losses via runoff; however, heavier soil types are likely not to be prone to canegrub and may not justify imidacloprid application.
- These trials have all been applied using a single-tine stool splitter. Other types of equipment, such as a side dresser or a double-disk opener may result in higher imidacloprid losses via runoff.
- We applied imidacloprid at the set depth of 100 mm or 50 mm. Shallower application may result in much higher runoff losses (as indicated by the technical issue in plot 7, trial 2). The runoff from very shallow imidacloprid application is being assessed by SRA in 2019–2020.
- These trials only investigated the runoff loss pathway. No leachate measurements were taken but the imidacloprid concentrations in the bore water at Meringa is intriguing and above the Australian freshwater-water quality environmental guideline of 0.11 µg/L. However, high contamination of rivers via a leaching pathway is unlikely: data from the Great Barrier Reef Catchment Loads Monitoring Program seem to indicate imidacloprid is mainly lost via runoff. High readings in bore water appear localized and are likely slow to feed the river streams, which does not align well with the spikes of imidacloprid typically measured in conjunction with river flow peaks (Ryan Turner, pers. comm.). At the Meringa site, the runoff from the untreated plots and most of the treated plots even had lower concentration of imidacloprid than the irrigation water. This phenomenon can be possibly explained by the sorption of imidacloprid to the soil particles, therefore “filtering” the contaminated irrigation water. Imidacloprid sorption depends on soil type and has been found to increase proportionally with organic matter and clay content (Capri *et al.* 2001).

CONCLUSIONS

We have shown that higher imidacloprid concentrations in runoff are more likely to occur from shallow (50 mm) than deep (100 mm) applications. Coulter slots should be filled with soil after imidacloprid application, in line with the label requirement. Our results suggest that the use of a press wheel further reduces imidacloprid runoff losses when the product is applied at the correct depth of 100 mm, but the press wheel may increase losses when the product is applied too shallow (probably because the wheel is occasionally in direct contact with treated soil).

Using the StoolZippa™ to close the slot on a loamy soil type behind application of imidacloprid at 100 mm did not reduce imidacloprid runoff. The StoolZippa™ still needs to be adequately assessed for its impact on imidacloprid runoff in paddocks with variable soil types (featuring both “hard to close” clay soils and lighter “grub prone” soils), which are found in the Central region.

Results from our trials need to be confirmed in other soil types and using other application implement like a double-disk opener or a side dresser, which are more prevalent in other cane growing districts (i.e. Central and the Burdekin). The water-quality impacts of poor applications (variation in sub-surface application depths, slot closure etc.) in relation to label-compliant press wheel and StoolZippa™ applications would also be informative.

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