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Non-shielded dual-spray technology for application of herbicides in sugarcane production systems

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Abstract In 2009 the Queensland Government introduced a suite of environmental regulations aimed at reducing the amount of herbicides, fertilizers and sediment entering the Great Barrier Reef Lagoon. Staff from the Queensland Government were conducting spray-drift management workshops throughout the Wet Tropics region of far-northern Queensland when growers attending the workshops asked if it was possible to design a spray system for existing Irvin-type booms that could apply glyphosate to the interrow of sugarcane using air-induction nozzles, eliminating the need for shields or hoods. They thought that this would assist them to comply with the new regulations, as well as generally reduce use of residual herbicides. Early design and static testing commenced in October 2010 with various combinations of spray nozzles and spray bar angles tested. Prototype engineering drawings were also completed. No evidence of glyphosate toxicity to sugarcane was detected in replicated trials using the 'Dual Herbicide Sprayer' (DHS) in the 2012-2013 growing season. Yield data were not significantly different between plots where glyphosate was applied in the interrow and the standard grower practice of a mixture of diuron and paraquat applied over the entire paddock. Other indicators of phytotoxicity used in the trials, including stalks per metre of row, Brix, CCS, stalk diameter and height, showed no significant differences among treatments. A user manual for the DHS has been developed and is available free-of-charge to equipment manufacturers and growers. Based on sales of spray bars and new sprayers, approximately 11,000 ha are now being sprayed using DHS technology.

Key words Dual Herbicide Sprayer, glyphosate, Irvin-type booms, Great Barrier Reef water quality, residual herbicides, sugarcane production

INTRODUCTION

Catchments adjacent to the World Heritage-listed Great Barrier Reef (GBR) have been exhibiting declining water quality over the last two decades and more. This is due to several factors; one of which is the increase in intensive agricultural production activities with associated with risks to GBR ecosystems (Bohnet *et al.* 2008; Brodie *et al.* 2013). In 2009 the Queensland Government introduced a suite of environmental regulations aimed at reducing the amount of herbicides, fertilizers and sediment entering the GBR lagoon (RWQPP 2009). Staff from several departments within the Queensland Government were appointed to assist Reef Protection Officers work with sugarcane growers to implement this new legislation.

One aim of the legislation was to reduce the amount of photosystem II (PSII) mode-of-action residual herbicides being used within the GBR catchments. The four most common PSII chemicals used in sugarcane production in Australia are atrazine, diuron, hexazinone and ametryn. In response to the new regulations, AB, an Extension Officer with the Department of Agriculture and Fisheries (DAF), was tasked with delivering grower workshops in the Wet Tropics region of far-northern Queensland.

During these workshops AB demonstrated different spray nozzles and ultraviolet tracers to visually assess drift and off-target application. Sugarcane growers showed a keen interest in these demonstrations and asked if a spraying system could be designed to apply herbicides such as glyphosate to the interrow without causing a phytotoxic effect on the sugarcane crop. At that time, shielded or hooded sprayers, which apply glyphosate to the interrow in bands, were being used as a way of reducing the use of PSII and other residual herbicides applied to sugarcane. However, growers thought they were expensive and too heavy to adapt to their existing sprayers. They asked if a non-shielded spraying system could be developed as an alternative. Requests were for a spray system that could deliver a band of non-residual herbicide to the interrow and a band of residual pre-emergent herbicide mixture with paraquat to the row.

BAND SPRAYING TO REDUCE PSII HERBICIDES

Band spraying (applying herbicides to specific areas of paddocks) is increasingly emerging as an alternative tool in more sustainable pesticide-use strategies (Davis and Pradolin 2016). Dual spray-line systems have been developed using shields to simultaneously apply two tank mixes. The environmental advantages of band or strip spraying herbicides in flood-irrigated sugarcane are well documented (Oliver *et al.* 2013; Davis and Pradolin 2016; Masters *et al*. 2013), with off-site pesticide load reductions of >80%. Under rainfall simulations, the load reductions in surface-water runoff of several PSII herbicides ranged from 48 to 57% in banded applications compared to broadcast applications in sugarcane (equating closely to the reductions in paddock herbicide application area associated with banding). Band-spraying technologies can, however, be expensive in terms of construction and components, and issues with their effective uptake remain in the GBR sugarcane industry (discussed subsequently).

The increased integration of knockdown herbicides into weed management is seen as vital in the GBR sugar industry's sustainability as it shifts away from the traditional reliance on pre-emergent PSII herbicides. Glyphosate (the world's most widely used herbicide), in particular, is seen as a valuable weed-control tool in moves to new farming systems and precision agriculture approaches such as band-shield spraying. Glyphosate is, however, phytotoxic to sugarcane, and application to the crop interrow without shields has traditionally caused concern. Some anecdotal, non-published data also indicate that even the use of shielded-sprayer technologies can cause cane yield reductions (which may be due to incorrect nozzle configuration under the shield or hood, or perhaps by attempting to use shields wider than that intended for the given row spacing). These concerns have been associated with a reduction in stool growth caused by off-target application onto the lower leaves.

The amount of glyphosate that young plant or ratooning cane can tolerate is unclear. Chedzey and Findlay (1985) demonstrated that rates of 6.0 to 10.0 L/ha of Roundup® (glyphosate 359 g/L) killed sugarcane where foliage height was 0.1-0.7 m. They stressed that the spray coverage over the whole plant was very important. These rates equate to 2.15 to 3.59 kg active constituent per hectare. Regrowth from treatments below 2.15 kg active constituent per hectare was variable depending on the time of year and the cane growth rates. Richard (1991) found that rates of glyphosate of 0.2 kg active ingredient per hectare and above resulted in a significant reduction in yield when compared to the control. This rate caused a significant reduction in yield that varied throughout the season with earlier applications having greater effect. While these data were not directly applicable to our situation, it demonstrated that low rates of glyphosate not directly applied over the plant may not be as toxic as first thought.

Both shields/hoods and our non-shielded Dual Herbicide Sprayer (DHS) are band-spraying machines. Here, we provide an overview of the design process and field testing (phytotoxicity and yield reductions) of the DAF DHS.

DESIGN PROCESS

DAF responded to growers' requests and feedback regarding practical needs and commenced work on some early designs for a lower cost, but effective, dual herbicide sprayer. IB, an aeronautical engineer, considered the required angles and overlap from nozzle technical data and field experiments to develop the original spray bar design. The original drawings were based on 1.5 m row spacing, with subsequent drawings incorporated 1.5, 1.65 and 1.8 to 2.0 m row spacing.

Initally, it was envisaged that the Irvin-type boom spray, relatively common in the sugar industry in Queensland, would be used as the platform for the development work. The critical component is the parallelogram and tracking leg arrangement that allows the spray bar to maintain a constant height above the ground (Figure 1). Growers also supported utilising this type of sprayer as they saw retrofitting an existing Irvin-type boom as an inexpensive alternative to purchasing a new sprayer. A commercially available 12 V spray pump and tank was added to the existing boom sprays. A simple pressure regulator was attached, and the glyphosate delivery hose routed alongside the existing spray lines that were used for the wing nozzles. Several prototypes were manufactured; one of the final prototypes is shown in Figure 2. Engineering drawings were developed and published in a user manual, available free-of-charge from DAF.

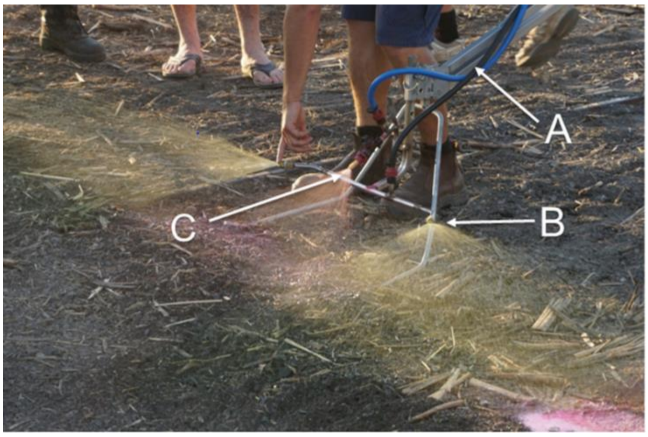

Figure 1. The parallelogram component of an Irvin-type boom spray (A), the wing nozzle (B), and the central low-drift air-induction nozzle (C).

Figure 2. Final prototype being statically tested with water.

Final adjustments to the prototypes were done using ultraviolet dyes. Nozzle angles were fine tuned to minimise the potential for glyphosate application from the central nozzle onto the lower leaves of the sugarcane stool. Ultraviolet qualitative dye tests were done on plants in the field ranging from 0.4 to 0.9 m high. In Figures 3 and 4 yellow deposits show interrow application of glyphosate and red represents industry standard pre-emergent and paraquat herbicide mix applied to the row.

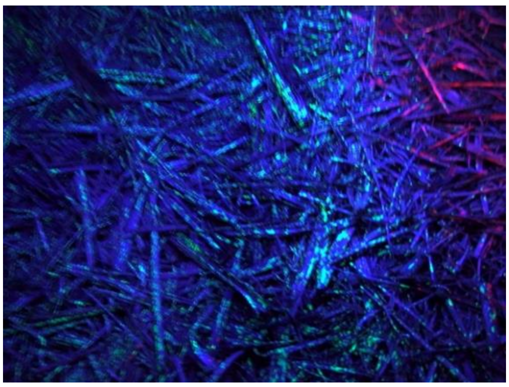

Figure 3: Ultra-violet dye. Note the distinct 'line' and absence of drift between the red (row) application and yellow (interrow) herbicide application.

Figure 4. Final production version spraying dye in 1.8 m sugarcane rows. Yellow represents interrow glyphosate application and red row-spray application.

PHYTOTOXICITY

GBR canegrowers have always been concerned that band-spraying technologies have the potential for glyphosate phytotoxicity to sugarcane. Within the sugarcane industry, glyphosate is used to chemically eradicate the ratoon (Azania *et al.* 2013). Hence, glyphosate applied to sugarcane in the correct dose and at certain growth stages can also cause significant injury to inadvertently treated crops (Richard 1991).

Our early development tests on several varieties at different locations using the DHS showed no measurable or visible signs of phytotoxicity to crops over 20 cm high (top visible dewlap). These tests were conducted under normal spraying conditions and winds up to 15 knots at 1.5 m above ground level. This was equal to a range of 2-5 knots at the droplet release point on the spray bar.

TESTING

After development, it became clear that the new spray bar had potential to become a useful weed-management tool in sugarcane production in the Wet Tropics region and it could also assist growers to both comply with the Reef Regulations and usage changes proposed under the APVMA diuron review. We carried out several sets of testing and then established experiments at three sites to test the efficacy of the spray bar compared to standard spraying practice. The aim was to test the spray bars under a commercial situation by collecting growth, CCS and cane yield data for each plot.

Initial testing

To determine the distribution of spray droplets produced by the central air-induction nozzle at different ground speeds and wind strengths and directions, we fitted cameras to the legs of the spray. Fine adjustments were then made to the prototypes and tested with small plots of about 0.5 ha. Varieties included Q186$^{\Phi}$, Q228$^{\Phi}$, Q200$^{\Phi}$ and Q208$^{\Phi}$. Different nozzle outputs were tested, and results were assessed visually by using ultraviolet dye. The crop was also monitored for any sign of glyphosate toxicity to the sugarcane. The plots were checked for symptoms of glyphosate toxicity using Azania *et al.* (2013) as a guide.

Expanded trials

During 2011, observation plots were established at Cairns, Innisfail, Tully and Ingham. The varieties trialled were Q200$^{\Phi}$, Q228$^{\Phi}$ and Q186$^{\Phi}$, all of which demonstrated no visual reduction in yield when sprayed with the dual herbicide sprayer. Here, diuron was applied through the wing nozzles at the rate of 900 g active constituent per sprayed hectare combined with paraquat at 312 mL active constituent per hectare. Glyphosate was applied through the central interrow nozzle at rates from 855 g to 2.28 kg active constituent per hectare.

At a series of grower workshops during August-December 2012, growers saw the results of the observation plots and some early economic analysis that showed the DHS halved the cost of the newer non-PSII herbicides.

Growers were enthusiastic about the spray system that would allow them to economically use more expensive non-PSII herbicides through the wing nozzles and apply low-cost glyphosate simultaneously to the interrow. This was seen as an important innovation, particularly since a planned APVMA review was likely to place restrictions on diuron use.

Continued testing

In 2011 and 2012 we undertook collaborative sprayer development work with growers including Ray Zamora from Tully, Adrian Darveniza from South Johnstone and Mark Savina from Cairns. Final design work was completed on the now named 'Dual Herbicide Spray Bars'. The original angles and nozzle intersects remained largely unchanged, but modifications were made with the central interrow nozzle, which was relocated on a bracket, allowing for more height adjustment on the spray bar. This was a requirement for controlled-traffic layouts where the cane is grown on permanent beds and the interrow is significantly lower than in conventional layouts.

While different brands of nozzles could be used, we tested Hardi® and Teejet® products - these brands are the most commonly used in far-northern Queensland. We configured them as low-drift 110° fans in the wing nozzle bodies and 95-100° air-inclusion or air-induction spray nozzles in the central interrow position. The angles presented by the wing nozzles in the spray bar gave a spray pattern similar to that from an even fan on the side of the drill.

Replicated trials

We established an experiment of four treatments (Table 1) with three replicates of each in a randomised complete-block design at each of Cairns and South Johnstone. A single replicate of each treatment was established in Tully; this site was too narrow to establish a replicated trial. We selected sites with plots large enough to be mechanically harvested to give meaningful yield and we obtained CCS figures from the sugar mill. Plot sizes ranged from 0.18 to 0.35 ha.

Table 1. Treatments used in replicated trials.

Treatment	Herbicide details		Nozzle details	
	Wing nozzles	Central interrow	Wing nozzle	Central interrow
1 Standard practice. Broadcast spray	Diuron 900 WG at 1.0 kg/ha sprayed area plus paraquat 250 at 1.25 L/ha sprayed area	Diuron 900 WG at 1.0 kg/ha sprayed area plus paraquat 250 at 1.25 L/ha sprayed area	Hardi® ISO Minidrift 04 Std spray 2.0 bar pressure	Hardi® LD-1100-04 Std spray 2.0 bar pressure
2 DHS	Diuron 900 WG at 1.0 kg/ha sprayed area plus paraquat 250 at 1.25 L/ha sprayed area	Glyphosate 570 at 5.0 L/ha (actual applied 5.02 L/ha)	Hardi® ISO Minidrift 04 2.0 bar pressure	Teejet® AI950 02 air induction even spray tip 2.0 bar pressure
3 DHS	Diuron 900 WG at 1.0 kg/ha sprayed area plus paraquat 250 at 1.25 L/ha sprayed area	Glyphosate 570 at 5.0 L/ha (actual applied 4.96 L/ha)	Hardi® ® ISO Minidrift 04 2.0 bar pressure	Hardi® Injet 014 nozzle 3.0 bar pressure
4 Glyphosate to interrow only	Blocked off	Glyphosate 570 at 5.0 L/ha (actual applied 5.02 L/ha)	Blocked off	Teejet® AI950 02 air induction even spray tip 2.0 bar pressure

Growth data were collected during the growing season through a combination of cane stalk counts, top visible dewlap measurements and diameter measurements. Analysis of variance (ANOVA) was used to compare the effect of treatment on the various harvest measurements at each of the replicated trial sites. Significance testing was at the 0.05 level and pairwise comparisons were performed using Fisher's protected 95% least-significant difference (LSD). The two replicated sites and the single replicate at Tully were combined into a multi-site analysis using residual maximum likelihood (REML). The dewlap measurements at each replicated site were modelled using non-linear regression to investigate the response over time. All analyses were conducted in GenStat for Windows 14th edition (VSN International).

The three trials were harvested during the 2013 season by the harvesting contractor contracted for that farm and cane was processed by the local mill.

Results - South Johnstone replicated trial

The South Johnstone replicated trial was harvested on 6 July 2013 by Greko Harvesting and processed by South Johnstone Mill (Maryborough Sugar Factory). An ANOVA of sugars, stalk diameters and harvest data found no significant differences in each among the treatments at the 0.05 level of significance (Table 2).

A logistic curve was used to model the dewlap measurements throughout the season and the best fitting model for each treatment is shown in Figure 5 (adjusted R^2=99.7; p<0.001). Comparison of the fitted models showed no significant differences among the treatments.

Table 2. Statistical analysis of cane yield, CCS, stalk diameter and Brix for the South Johnstone trial.

Treatment	Cane yield (t/ha)	CCS	Stalk diameter (mm)	Brix (Bx)
1	114.5	10.60	22.1	20.25
2	119.3	10.90	22.3	21.08
3	114.8	10.57	21.3	19.83
4	119.4	10.46	21.9	20.08
p-value	0.735	0.430	0.578	0.554
SED	5.81	0.256	0.71	0.876
95% LSD	14.21	0.658	1.73	2.143

SED = standard error of the difference; LSD = least significant difference

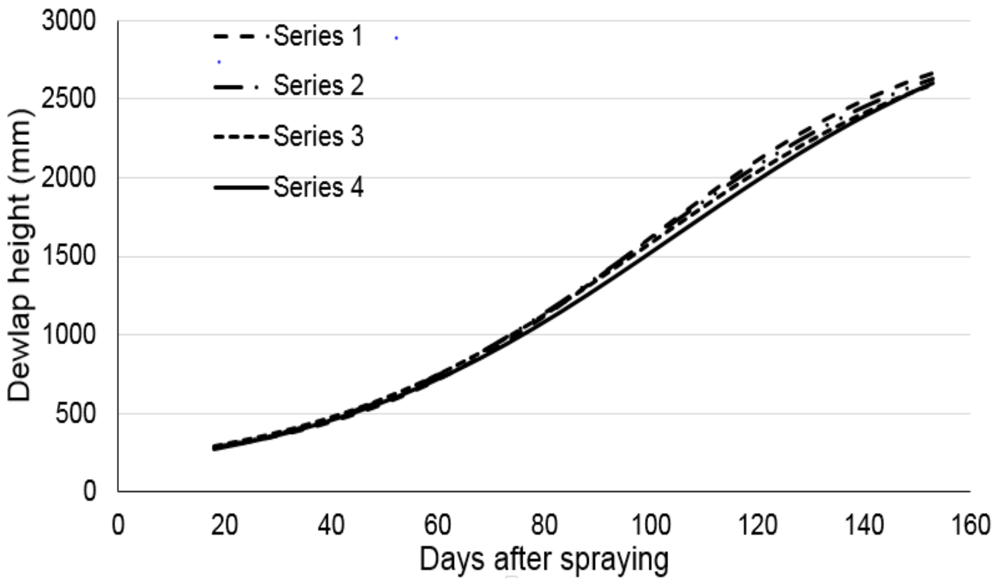

Figure 5. Fitted non-linear models to top-visible-dewlap height over time for each treatment in the South Johnstone trial.

Results - Cairns replicated trial

The Cairns replicated trial was harvested on 19 July 2013 by Selmac Harvesting and processed by Mulgrave Mill (Maryborough Sugar Factory). An ANOVA of sugars, stalk diameters and harvest data found no significant differences in each among the treatments at the 0.05 level of significance (Table 3).

A logistic curve was used to model the dewlap measurements throughout the season and the best fitting model for each treatment is shown in Figure 6 (adjusted R^2=96.8; p<0.001). Comparison of the fitted models showed no significant differences among the treatments.

Table 3. Statistical analysis of cane yield, CCS, stalk diameter, Brix and stalk counts for the Cairns trial.

Treatment	Cane yield (t/ha)	CCS	Stalk diameter (mm)	Brix (Bx)	Stalk count (m^{-1})
1	81.2	10.28	24.3	17.23	9.8
2	84.4	10.07	22.9	17.48	10.9
3	82.8	10.29	23.0	17.93	10.4
4	84.5	10.16	23.1	19.30	10.9
p-value	0.106	0.577	0.438	0.745	0.283
SED	1.25	0.167	0.91	2.010	0.57
95% LSD	3.05	0.464	2.23	4.919	1.41

SED = standard error of the difference; LSD = least significant difference

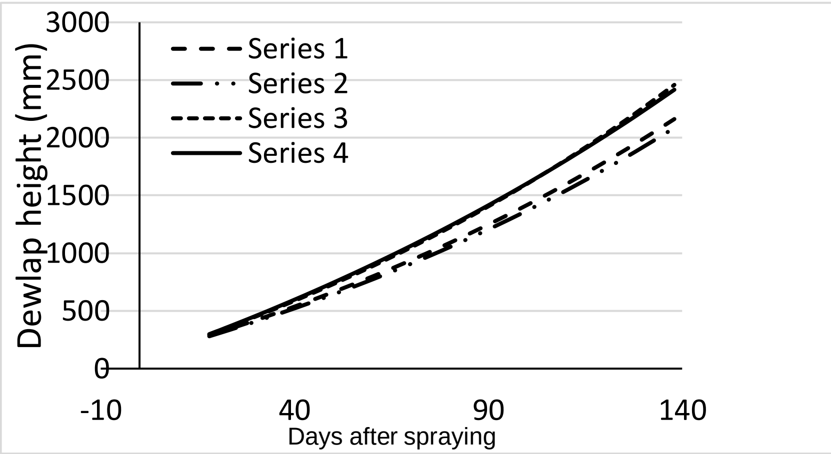

Figure 6. Fitted non-linear models to top-visible-dewlap height over time for each treatment in the Cairns trial.

Combined analysis of South Johnstone, Cairns and Tully trials

The Tully trial was harvested on 4 November 2013 and yielded an average of 100 t/ ha.

Across the three trials there were no significant differences for each of cane yields, CCS, stalk diameters or Brix among the treatments (Table 4).

Table 4. Cane yield, CCS, stalk diameter and Brix statistical analysis for the combined trials.

Treatment	Cane yield (t/ha)	CCS	Stalk diameter (mm)	Brix (Bx)
1	98.0	10.42	23.0	19.1
2	101.3	10.44	22.7	19.8
3	99.6	10.45	22.1	18.8
4	101.4	10.35	22.5	19.2
p-value	0.072	0.903	0.340	0.551
SED	1.19	0.161	0.50	0.72
95% LSD	2.83	0.988	1.06	1.57

SED = standard error of the difference; LSD = least significant difference

Discussion

We saw no reduction in yield or crop vigour over the 4 months after application with the DHS in any of the field tests. Some plants at the ends of the row showed an initial yellowing followed by some necrosis that was caused by the spray bar being dragged over the row as the tractor was repositioned to commence the next rows. Further field tests in 2011 with variety Q200⁽ᴰ⁾ showed almost no visual signs of cane damage, except for the occasional stool located at the end of rows where the drag bars had been incorrectly aligned. To prevent this damage, the operator ensured that the boom legs were lined up with the rows prior to commencing to spray. This involved dropping the 3-point linkage further away from the start of the rows so that the legs would track correctly.

In the replicated trials, we expected some reduction in yields in glyphosate treatments, but this was not the case with none of the yield or growth measurements significantly different to those in the other treatments. We presume that paraquat, a desiccant herbicide, prevented uptake of any non-target glyphosate applied to the row. In commercial applications, we recommended that a suitable desiccant herbicide such as paraquat be used as an uptake barrier in row application through the wing nozzles.

DEVELOPMENTS

Three commercial DHSs have been funded through the Queensland Government Reef Water Quality Program (Figure 7). These machines are used for further testing by cane growers and research staff. Several commercial sprayers have been produced and are operating in the sugarcane industry in Queensland. The most recent estimate (July 2016) from sales data is that about 11,000 ha of cane are being sprayed using DHS technology.

Figure 7. One of the three trial sprayers being used by northern cane growers.

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