Evaluating commercially available precision weed spraying technology for detecting weeds in sugarcane farming systems

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Evaluating commercially available precision weed spraying technology for detecting weeds in sugarcane farming systems

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Executive Summary

Competition from weeds in the sugar industry causes significant loss in production and profitability. Precision spray technologies that are target orientated have the potential to revolutionise weed management by more effective and efficient control of weeds. As a consequence the development of more precise spray and weed management will lead to i) reduced herbicide usage, ii) reduced potential for offsite impacts, iii) relief of traditional chemicals, iv) reinforcement of minimum tillage and the new farming system while v) maximising production.

To realise these benefits research was undertaken to develop and evaluate precision weed spot spraying technologies for inter-row and fallow weed control (i.e. green from brown) and for the discrimination of grass weeds from sugarcane within the row (i.e. green from green). The green from brown investigations evaluated commercial weed spot spraying technologies for the sugar industry while green from green investigations developed a new weed detection technology for in-crop weed control and focused on the discrimination of guinea grass from sugar cane.

Green from brown investigations consisted of evaluating commercially available precision weed spraying technology for detecting weeds from bare soil / trash blanket. An inter-row shield sprayer was developed in consultation with growers and spray contractors. The shield sprayer was instrumented with commercially available Weedseeker sensors and was trialed in various field conditions to compare with traditional weed management strategies and to evaluate the environmental impact of the technology. Establishing the field sites and field program involved inputs from farming collaborators, extension personnel and scientists to implement a plan that was highly rigorous and relevant to industry.

The Weedseeker sensors were found to be sensitive to background soil and stubble conditions, which led to variable performance ranging from very good to very poor. Sprayed area was found to have a poor relationship with weed coverage due to the distribution and type of weeds in the field and the large footprint of a single nozzle. In some instances, with a scattered weed distribution, 30% weed coverage led to greater than 90% spray coverage. A guideline for use of Weedseeker based on these investigations will be made available to the sugar industry in 2013.

The environmental impact of new herbicide management practices using weed spot spray technologies was measured in runoff studies. The runoff studies established that the runoff concentrations of herbicides were directly proportional to the percent spray coverage and that glyphosate and fluroxypyr typically ran off less than older residuals.

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1. **Background**

Competition from weeds in the sugar industry causes significant loss in production and profitability. At the same time there is increasing pressure on the Industry in relation to nutrient and pesticide runoff given the close proximity to the Great Barrier Reef Marine Park (GBRMP). As a result two main residual herbicides (Diuron and Atrazine) are under continual review due to their potential off-site impacts to water ways and the environment. This pressure is somewhat increased as the industry moves towards farming systems based on minimum tillage and an increasing dependance on herbicides. Despite these pressures the industry has an opportunity to proactively respond by developing new strategies for weed management based on precision weed spraying technologies.

There is a need to develop both new weedspraying technologies and guidelines to assist with the implementation of existing technologies to more finely manage herbicide use. Through greater control and precision of spraying operations, precision spray technologies have the potential to improve weed management by targeting the weed not the crop. The application of these technologies will improve productivity (by reducing weed competition), reduce off site movement of herbicides and impacts (by targeted herbicide application and use), reinforce minimum tillage (soften herbicide dependence) and provide greater flexibility in weed management strategies (by enabling alternate herbicide options).

The development and implementation of precision weed spraying technologies also relates to the arena strategy for improved farming and harvesting systems by developing and implementing better weed management systems for sugarcane farmers to manage weeds, reduce inputs, improve the timing of operations and reduce labour and capital costs.
2. Objectives

The aim of this project is to develop precision spray technologies that are target orientated and have the potential to revolutionise weed management by more effective and efficient control of weeds. The specific objectives and their achievement in this project are detailed in the following subsections.

2.1. Evaluate commercially available precision weed spraying technology (green from brown)

The project has undertaken significant evaluation of commercially available precision weed spraying technology

The project has put significant effort into establishing field sites in Bundaberg and Mackay and BSES will undertake trials which will fine tune machine settings and compare traditional weed control strategies with those based on the use of commercially available Burdekin regions and has commenced implementing a runoff study (which is currently being undertaken) in Mackay and Bundaberg to both evaluate precision weed spraying technology and to further define the environmental benefits. This work has involved inputs from farming collaborators, extension personnel and scientists to implement a plan of attack that is highly rigorous and relevant to industry.

2.2. Develop strategies to apply precision weed spraying technology in the Sugar Industry

iii) The performance of the commercial (Weedseeker) system was sensitive to background soil conditions and other factors resulting in very good to very poor performance in some instances;

2.3. Identify / quantify potential benefits of precision weed spraying technology

The project has also investigated the potential of reduced herbicide runoff through precision weed spraying technology via rainfall simulator runoff studies

The BSES teams will also undertake runoff studies to assess the potential reduction in herbicide runoff from precision weed spraying technologies

Key findings from the project include:

i) Runoff concentrations of herbicides are directly proportional to the percent spray coverage.

ii) The spray footprint of a single nozzle is significantly large; where 30% weed coverage in some instances may lead to 90% - 100% spray coverage, limiting the opportunity of reduced herbicide use (as associated environmental benefits).
3. Review of commercial technologies that detect green from brown

Several commercial systems using photo sensors for weed detection have been developed. Photo sensors are sensitive to a specific spectral band and are used to calculate spectral indices that discriminate vegetation and soil matter. One of the first commercial systems to be developed was the Weed Activated Spraying Process (WASP) by Warwick Felton and Paul Nash from the NSW Department of Agriculture. Currently there are four main technologies commercially available for weed spot spraying which are:

- Weed Control Australia (WCA)
- Rees Technology
- Weedit
- Weedseeker (formerly Patchen)

3.1. Weed Control Australia (WCA)

WCA are based in Western Australia and have developed a precision spray system based on assessing the spectral differences between weeds and the bare ground. Green vegetation has a high reflectance in the near infrared and green wavebands whereas soil has a relatively low near infrared reflectance. The WCA sensor calculates a vegetation index similar to NDVI to discriminate vegetation and soil based on spectral differences. The product was initially developed for the determination of skeleton weed in wheat and operated on an open boom. Subsequent improvements included the incorporation of a light source in a semi-controlled area (i.e. a hood) which improved accuracy. The WCA product also discriminates different plant sizes.

The current WCA unit is pictured in Figure 3-1. The ground is illuminated by visible and infrared radiation and onboard electronic equipment processes the reflectances detected by the photo sensors. A ‘positive strike’ signal is generated if the detected vegetation matches predefined weed colour and size parameters.

Currently the company has no commercial representation.

3.2. Rees Technology

Rees Technology developed a system based on video image analysis. The system determined weeds based on colour and shape/size properties. If the detected colour and shape matched an
operator-defined prescription the vegetation was identified as weed and sprayed. The product was
designed to spray weeds in a fallow situation and hence, had limited applicability to cropped areas.
Technologies patented by Rees included the real-time method of analysis for colour and basic shape/size. The system used a hood and artificial light source to improve accuracy.

The product is currently being redeveloped and is due out soon.

3.3. Weedit

The Weedit uses red light colour technology that is partially shifted to Near Infrared when
passed over live plant chlorophyll (Figure 3-2). The system requires no ongoing manual calibration
and allows the operator to change the sensitivity of the sensor via one touch button in the cab.
Sensors are spaced at 1m on the boom and operated at a height of 1m off the ground. One sensor
can control five solenoids each at 20cm spacings.

The product is represented in Australia by GPS-AG and was also developed into broadacre
operations in conjunction with GPS-AG. The original technology was developed in the Netherlands.

3.4. Weedseeker®

The Weedseeker® was developed in the 1990s by Patchen in California and sold to John
Deere who marketed the system into row crops. John Deere found that the product needed more
specialised attention than its standard product line and that the sales were not sufficient to command
the extra investment. Weedseeker® was subsequently sold to Rainbow Agricultural Services owned
by Mayfield in California who were a dealer of the Weedseeker® product, specifically servicing the
horticulture market. Rainbow Agricultural Services joined with the Oklahoma State University to
form a joint venture company, Ntech which now handles the technology. The technology has been
further developed to be able to detect differing shades of green for fertiliser deficiencies. Ntech
incorporates patents developed by Patchen as well as patents developed by the NSW Department of
Agriculture and the Oklahoma State University (Figure 3-3).
The Weedseeker® product works in a similar way to the WCA product by assessing the ratio difference of red and near infrared reflectances of vegetation and background. The Weedseeker® features red and near infrared LEDs to improve accuracy.

The Weedseeker® is commercially represented in Australia by Crop Optics

Weedseeker® technology has been applied in various horticultural circumstances including and not limited to vineyards, tree crops and broadacre fallow spraying. For use in sugarcane, this technology is to be used in conjunction with shielded sprayers as opposed to broadacre boom application (Figure 3-4). The Weedseeker® technology is also currently being trialed on shielded sprayers for inter-row spraying of broadacre crops, such as sorghum and other broadacre row crops such as cotton where up to 80% savings in herbicide use have been reported.
Current shield designs available commercially (Red Ball and GC Shields) have limitations when used with Weedseeker® to control weeds in sugarcane, particularly leaf interference with sensor optics and turbulence within the shield. Early adopters of this technology in Mackay and the Burdekin have used commercially available shields and have observed these turbulence issues. Modifications of the commercial shields have met with limited success. The modifications of the Red Ball shield (Burdekin grower) consisted of attaching Weedseeker® sensors externally to the front of the shield. This resulted in severe cane leaf interference which led to ‘misfire’ of the nozzles. Following this limitation, a solid metal plate was attached to act as a protective device for the sensors. This in turn created low pressure turbulence which led to leaf interference of the sensor optics (Figure 3-5). To avoid leaf suction, a mesh grate has been installed.

The GC Shield (Mackay) has been designed to be carried very close to the ground. This shield had nozzle height limitations which negatively effects spot spray swath within the inter-row (Figure 3-6). The nozzles were placed externally on top of the shield firing through holes made in the shield to try and address the height limitation. Spray efficiency against tall weeds will be limited for this shield design. Black plastic panels have been added to the front of the Weedseeker® sensors to reduce cane leaf interference which would lead to misfires.
3.5. **Suitability of these technologies for sugarcane**

From this review the Weedseeker and Weedit technologies seemed the best candidates to adapt to the cane industry because they both are commercially available. With the Weedseeker, three sensors could cover 1.14 m width in the inter row, whereas the Weedit technology was covering only 1 m wide. It was decided to purchase and create a prototype shield using the Weedseeker sensors that would trigger the weeds in one cane inter row. The shield would be tailored to match the Weedseeker specifications.

3.6. **Assessment of VRC to achieve precision weed spraying**

Variable rate controller (VRC) can allow the grower to spray selected areas of the paddock. There are no detection sensors involved in this technology. The spray operator can program the integrated display to spray areas of the paddock that were previously identified as weedy. This system implies the existence of a weed map for the block. The weed maps could be generated by a Weedseeker system that logged the weed location at a point in time. However, without identifying the type of weeds (e.g. annual or perennial), it is difficult to predict if the weed patches will be at the same location in the future. It would be more sensible if the grower manually logs the position of a perennial problem weed (e.g. guinea grass) and generates a weed map of the paddock.

Two growers in the Mackay district equipped with a variable rate controller (VRC) system were interviewed about the potential benefits of this technology in terms of precision weed spraying.

3.6.1 **David Ellwood. Sugarcane grower, Victoria Plains (04/2012)**

David owns a 3 year old VRC system he bought from Croplands : Spraymate II. The system allows the driver to select the volume rate to apply. The main application of the system is to keep a...
constant water and chemical rate regardless of the speed driven. The system also informs the operator of the area covered by the spraying job.

The changes are done manually from the cabin by the operator while spraying. The grower manually increases the water rate according to the weed density. The range of variation can also been pre-determined (example +/−10L). In our case the grower goes from label rate down to nearly nothing while spraying Velpar®, Soccer® or Balance®. A reduction of water rate is achieved by diminishing the pressure, which poses the problem of nozzle spray pattern at low pressure or even spray width.

In May 2012 he installed a new unit with a screen (Integra verso) that draws a map where the spraying is done at each rate. This information could be used by DERM inspectors to precisely check the amount of herbicide used.

He uses it to fertilise and spray herbicide. He intends to install it on a dual tank sprayer. He is not interested in automatic steering.

EM Mapping has been done at the grower’s farm so he has a detailed map of his soil type and the precise boundaries. The grower is thinking of using the new unit to vary the application rate according to the soil map (example: lower rate of the pre-emergent herbicide Flame or Balance on lighter soil).

For Flame the VRC could also be used to control sections of the boom in order to insure the buffer zone within 50 m of water ways is respected.

He is also thinking of using the first year as a weed infestation mapping exercise which locates where the problem weeds and patches are, record them and automatically spray the following year these areas at label rate (e.g. guinea grass stools, couch grass, Johnson grass), assuming the weeds will be recurrent at the same spot.

He also wants to see if there is any relationship between his soil layer and some weed species.

Future research needs: check the resulted map determining the Flame area rate depending on the soil map and assess the efficacy results.

3.6.2 Phil Deguara, sugarcane grower, Eton (06/2012)

Phil owns a variable rate controller Raven Viper Pro and is looking to get a newer model Integra. He has automatic steering.

The system allows him to vary the rate of suSCon and fertiliser while planting. EM mapping has been done on his farm and he has three different soil types represented.

He created his own maps with the paddock boundaries by driving around the blocks. The map has a 2 cm precision.

He draws on the home computer the boundaries where he wants to apply the insecticide to control the grubs according to the soil maps and the infestation patches and then the variable rate controller does it automatically.

He uses the VRC to have a constant planting rate (number of billets/m) regardless of the speed he drives.

He does not use the VRC for spraying weeds because the nozzles are not adapted to handle variable rate (e.g. from 200 L to 300 L/ha). The only way to make the system work at this stage is to move to manual mode when reaching an area with a different water rate and adjust the speed to stay within the capacity of the nozzles on the boom.

He doesn’t like to change the water volume and chemical rate at the same time, because it isn’t a recommended practice.

The grower could buy an extension package so sections of the boom can be turned off when reaching an area of the map that shouldn’t be sprayed. It is not part of his current package.

The grower uses the VRC on the boom sprayer only. He uses it to spray fallows and pre emergence in cane. The VRC has the advantage of maintaining a constant rate even if the speed varies. He doesn’t use it on the high rise. He is not interested in varying the rate of Roundup on the
hoods because he reckons he can’t vary the water rate without affecting the efficacy of the chemical.

Future research needs: investigate variable rate nozzles that would maintain the correct spray pattern at different pressure and water rate.

From these discussions it seems that variable rate technology is not quite adapted to herbicide spraying yet as it cannot modify the rate of herbicide /ha without affecting the water rate and the nozzle spray pattern. Future investigation on variable rate nozzles that would maintain the correct spray pattern at different pressure and water rate is necessary.

4. Development and refinement of a shield adapted to the Weedseeker® system

Operating the Weedseeker® technology in conjunction with the inter-row shield required a number of considerations. The main operating specifications provided by Crop Optics Australia were: field of vision for each sensor – 380mm; sensor spacing – 380mm; sensor height above ground – 610- 760mm. Other technical aspects that were considered included nozzle height from the ground, nozzle size (0.02, 0.01 and 0.015) and type.

In 2011 an aluminium inter-row shield was designed according to these specifications and built to protect the Weedseeker® sensors from leaf interference and avoid spray drift for inter-row use in sugarcane. A light single spray tank was mounted on an inter-row tractor. This spray tank was connected to the shield, sensors and the spray rig. Brushes were added to the sides of the shield as a precaution against spray drift and both LED extension cables and a tank level gauge were installed to help monitor rapidity of spot spraying (Figure 4-1).

Figure 4-1 Shield showing brushes to reduce spray drift
Initial testing using 65° flat fan nozzles, size 02 at a sensitivity rating of between 6 and 7, with an optimal sensor height above ground of 620mm, operating at 2-3 bars with a tractor speed of 8 km/h showed that the sensors successfully detected green weeds larger than 60mm in size (Figure 4-2). However, refinement of equipment was necessary as:

- the boom was mounted too high and needed to be lowered by 12 cm
- the nozzle spray beams overlapped (5 cm) which made it unsuitable for even-jet nozzles
- dripping was also observed to occur from each side of the shield
- solenoids and nozzle brackets (U bolt) were not adequate for the purpose (the fitting was too loose and prone to twisting). These were replaced with the appropriate brackets that were sourced from Crop Optic
- the laser beam was intercepted by an aluminium edge on each side of the shield

The spraying coverage was perfect when the bottom of the brushes was set 13 cm above the ground level. The total spray width was exactly 1.25m. No drift could be detected outside the shield and absolutely no cane damage was recorded when spraying glyphosate inter-row even in windy conditions (tested up to 9.5 km/h).

Eight km/h was the most adequate speed for the equipment (tractor and Weedseeker sprayer) to spray inter-row in ratoon or in fallow on soft ground so it was the only speed tested.

The Weedseeker unit was initially setup on the prototype shield sprayer to spot spray weeds without any logging or totalising functionality. Modifications in 2012 included the development of equipment to totalise the amount of spray applied to the field to determine potential herbicide savings. For this, four timer units were purchased and retrofitted to the machine so that every time the Weedseeker solenoid valve was triggered a totalised value was recorded. At the end of a particular spray application, the total amount of time that each solenoid valve was activated (relative to that required for a full blanket spray) was used to determine the percentage of the field sprayed.
Through further developments a Leica GPS unit was integrated with the Weedseeker so that each time a solenoid valve is activated a spray / weed map of the field can be generated. This will enhance weed scouting at each of the trial sites and provide the ability to map the persistence of weed populations over time. The GPS data logging system records the location of the Weedseeker unit every 0.2 seconds and logs how many times the solenoid has been triggered in that time. The data from this can be mapped in ARC GIS for evaluation.

In 2013, to increase the economic benefit, the water rate was decreased by changing to 02 65 even nozzles. The efficacy of the sprayer was maintained and no visible drift damage was recorded (yield data 2013 will confirm that no phytotoxicity occurred on cane).

The Weedseeker shield sprayer was fitted with a second tank and one nozzle each side of the shield to be able to direct spray in the row (Figure 4-3). It was wrapped into black plastic to rule out any light interference (Figure 4-4). Figure 4-5 shows the Weedseeker set up for a wide row spacing of 1.8m (four sensors).
The Weedseeker Shield Sprayer prototype performed adequately in its final set up. However, a problem arose due to the inter-row tractor on which the system was mounted by the 3-point linkage. In some situations the tractor wheels drove on the edge of cane stools and flattened some cane stalks which got detected by the sensors under the shield. To solve the issue a similar shield unit (without the tanks) with a different centre of gravity would need to be build and mounted on legs of a high-rise sprayer. We suspect that the Weedseeker shield sprayer hanging from legs in a commercial situation would have better performance. Some modifications to reinforce the front of the shield may be needed.

5. Assessment of the Weedseeker technology in sugarcane

The evaluation of the Weedseeker technology involved:

- To determine the capacity of the sensors to be triggered by weeds in various situations common in sugarcane farming systems in order to inform the future potential user of the likelihood of success/failure of the technology depending on the environmental conditions. We determined that the soil type (trash, no trash) and its colour could be the main factor impacting on the efficacy of the sensors. For the assessment, creeping weeds (eg bacopa, paspalum, vines…) were measured in diameter whereas erect weeds (awnless barnyard grass, ludwigia…) were measured in height. Weeds like blue tops or nutgrass have similar diameter and height during their vegetative stage.
- To determine if the technology was economically competitive in bare fallow.
- To determine if the technology was economically competitive in sugarcane ratoon on green cane trash blanket.

5.1. Efficacy of the Weedseeker technology to detect and spray weeds in a sugarcane cropping system

5.1.3 Preliminary trials

Early tests were undertaken on a uniform background in 2010-2011 as soon as the sprayer was put together.

In 2011, early tests were carried out in fallow with brown background and all weeds more than 6 cm were detected at sensitivity 4 and 6 (Table 5-1). It could be noted that tall weeds located where the spray overlapped may only had their base sprayed, which may not be sufficient to kill them. This was a drawback of using even nozzles. At setting 10, the sensors were not sensitive enough to detect weeds that were only 6 cm in size.
### Table 5-1 Preliminary results of Weedseeker testing (Green from Brown) at 8 km/h

<table>
<thead>
<tr>
<th>Round</th>
<th>Sensitivity No.</th>
<th>Hits &gt;6cm diameter</th>
<th>Misses &gt;6cm diameter</th>
<th>False Positives</th>
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<tr>
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<td>1</td>
<td>10</td>
<td>7</td>
<td>10*</td>
<td>0</td>
</tr>
</tbody>
</table>

* # missed weeds caused by weeds being above spray overlap; * sensitivity rating targeting larger weeds

Later in 2011, a wider range of situations were tested: a brown-soil fallow with nutgrass, a brown-soil fallow with broadleaf weeds, and a trash blanketed cane field with grass.

#### 5.1.4 Trial on nutgrass on brown soil

The trial was carried out on a bare fallow with nutgrass patches on the Mackay BSES farm. Paraquat at 1.6 L/ha + activator 0.1% was sprayed on 13/07/2011 and the assessments were done the next day.

The speed was limited to 8 km/h because the ground was too soft to drive faster. To achieve this speed the tractor was run at 2300 RPM. The tractor bar height was on setting number 5.

Sensitivity 1, 2, 3, 4, 6 and 8 were tested in a RCB design with 5 repetitions. Plots were 7 m long and 1.25 m wide.

To determine the % detection we counted the number of nutgrass plants hit and missed in a 2 m * 1.25 m quadrat within each plot. This assessment method did not allow us to determine if the system was misfiring (i.e. spraying onto bare soil).

The nutgrass plants were not particularly well detected by the sensors. The best results were achieved on sensitivity 1 (the more precise setting) but still with only 43% detection (Figure 5-1 Capacity of the sensors to detect nutgrass in a fallow (uniform color)). Low numerical settings for sensitivity are adapted to small weeds or, in the case of nutgrass, weeds that are hard to detect because of their leaf shape.
The nutgrass plants seemed to be better detected when they were in clusters instead of isolated.

The graphs in Figures 5-2 show the percentage detection depending on the nutgrass density (recalculated per square meter) for each sensitivity setting.

The line is an extrapolation of the observed data (regression) and the $R^2$ show the reliability of the extrapolation. $R^2$ for sensitivity 1 wasn’t good but the other $R^2$ for other sensitivity settings were acceptable.

If we take a set density we can see a downward trend in the % detection as the sensitivity number increases from 1 to 8.

A density of 30 nutgrass/m² has 55% chance to be detected at sensitivity 1, 33% at sensitivity 2, 17% at sensitivity 3, 20% at sensitivity 4, 10% at sensitivity 6 and no chance at sensitivity 8.

A density of 15 nutgrass/m² has 35% chance to be detected at sensitivity 1, 17% at sensitivity 2, 7% at sensitivity 3, 3% at sensitivity 4, 2% at sensitivity 6 and no chance at sensitivity 8.

As expected, the more dense the nutgrass was, the more reliable the detection by the sensors at all sensitivity settings.
Sensitivity 1

\[ y = 1.3461x + 15.272 \]
\[ R^2 = 0.3384 \]

Sensitivity 2

\[ y = 1.0805x + 0.224 \]
\[ R^2 = 0.8265 \]

Sensitivity 3

\[ y = 0.8336x - 8.5044 \]
\[ R^2 = 0.6882 \]
Conclusion: Nutgrass plants were poorly detected on brown soil except when they were grouped in clusters.

5.1.5 Trial on broadleaf weeds on brown soil

The trial was carried out on a bare fallow with broadleaf weeds (mainly Blackberry nightshade and bluetop) and a few grasses on the Mackay BSES farm on 14/07/2011. Unlike previous trials on nutgrass, we tried to use red dye as a marker so an assessment could be done straight away without waiting for the herbicide to work. Unfortunately the coloured hits were not obvious making the assessment near impossible. We sprayed Gypsum as an
alternative marker on reps 1, 2 and 3. Gypsum drops were visible on weed leaves but some fine gypsum drift within the shield created some false positives and also made the assessment difficult. So we decided to revert to Paraquat at 1.6 L/ha + activator 0.1% for reps 4 and 5. In that case the assessments were done on 18/07/2011. Again the misfires could not be assessed.

The speed was only 8 km/h because the ground was too soft to drive faster. To achieve this speed the tractor was run at 2300 RPM. The tractor bar height was on setting number 5.

Sensitivity 1, 2, 3, 4, 6 and 8 were tested in a RCB design with 5 repetitions. Plots were 7 m long and 1.25 m wide.

To determine the percentage detection we counted the number of weeds hit and missed in a 2 m * 1.25 m quadrat within each plot.

Figure 5-3 shows that bigger weeds were better detected than smaller weeds.

For smaller weeds the lowest numerical sensitivity settings gave the best detection rates; 50% detection rate for very small broadleaf weeds (<3 cm diameter) and 70 % for small broadleaf weeds (3 to 6 cm diameter) at sensitivity 1, and 75% detection rate for small grass (<6 cm diameter) at sensitivity 1.

For bigger broadleaf weeds (more than 6 cm diameter) sensitivity 1 to 6 gave similar detection rates of 80% or more.

For bigger grasses (more than 6 cm diameter) sensitivity 1 to 4 gave similar results (close to 100% detection).

These results were quite logical and consistent with the manufacturer recommendations. Around 40% detection must be expected for weeds smaller than 3cm in diameter at low sensitivity settings.

Figure 5-3 Capacity of the sensors to detect broadleaf and grasses on brown soil

Conclusion: Broadleaves and grasses on brown soil were well detected by the sensors, especially when their size was more than 6 cm diameter.

5.1.6 Trial on grasses in ratoon cane on fresh trash blanket

The trial was carried out in the inter-row of a ratoon cane on trash blanket at a grower’s farm (Victoria Plains). We chose to apply Roundup Powermax so we could also visually assess if there was no drift issue on the cane. Roundup was applied at 2.3 L/ha on the 11/08/2011. The assessments were done on 29/08/2011.
The speed was 8 km/h. To achieve this speed the tractor was run at 2300 RPM. The tractor bar height was on setting number 5.

Sensitivity 1, 2, 3, 4, 6 and 8 were tested in a RCB design with 5 repetitions. Plots were 7 m long and 1.25 m wide.

To determine the % detection we counted the number of grasses/broadleaf weeds hit and missed in a 2 m * 1.25 m quadrat within each plot. Again we couldn’t record the misfires using this method.

At the time of spraying and assessing, most grasses were mature and quite tall. Some were flowering and their colour started to turn yellow. The results represented in Figure 5-4 sometimes seem like they do not follow the logic of the sensitivity settings, but they can be explained:

- As expected the detection rates for nutgrass were quite low. Sensitivity 2 seemed the best setting; however the average number of nutgrass/m² in these plots was only 62% of the total weed number and the sensors would have detected the adjacent big weeds/grasses and the nutgrass got sprayed. The results must be considered more reliable for sensitivity 1, 3 and 4 where the nutgrass represented more than 80% of the weeds present.
- For large grasses with relatively broad leaves like Paspalum the detection rate reached 100% for sensitivity 1, 4, 6 and 8. Lowest detection rates were obtained for sensitivity 2 and 3 because the Paspalum were a bit smaller (10 cm diameter) in these plots. The density of Paspalum /m² was very low but each plant was large.
- For Bacopa weed, perfect detection was achieved for sensitivity 1 and 3. The poor detection value obtained at sensitivity 2 was due to small Bacopa plants (less than 2 cm diameter) in these plots being missed. The same sized plants were detected on sensitivity 1.
- Purpletop and Rhodes are two similar grasses (both Chloris sp.) and their detection rate was quite similar: more than 80% detection at sensitivity 1 and between 60 and 80% detection at sensitivities 2,3,4. Poor detection of purpletop on sensitivity 2 was due to small plants (around 10 cm high) in these plots. The results on these two species were particularly good since the grasses were really mature and turning a reddish-yellowish color.
- Only one big patch of couch grass was present on a plot on sensitivity setting 8 and it was obviously detected.

Note: the density of weed species in the trial can be found in Annexe 1.2, table 1

No visual impact from drift on cane was recorded.
Conclusion: Mature grasses were well detected on fresh trash blanket by the sensors even when some grasses were really mature and turning a reddish-yellowish color.
Further tests were carried out in 2012 – 2013 to cover a wider range of situations: white, grey, black and red soils and a weathered trash blanket. For these experiments, the efficiency of the sensors was measured by spraying blue dye on the weeds and counting the number of weeds sprayed, missed and also the misfires (the area of bare soil without any weeds that got sprayed). The blue dye was sufficiently visible on plants and soil to allow accurate measurement.

Each fallow site hosting these test trials was also used to carry out a demonstration. With these demonstrations we assessed the relevance of the Weedseeker technology for fallow management (efficacy, economic impact). The demonstrations were composed of four 20 m long strips that were sprayed with dye using the best sensitivity setting determined in the test trial.

The weed coverage was visually assessed and timers and GPS recorder were used to measure and identify the area sprayed.

5.1.7 Trials on light coloured soil

5.1.7.1 Efficiency of the sensors on light coloured soil

Preliminary work consisted of calibrating the sensors using three 20 m long strips. As expected, more area was sprayed at lower numerical sensitivity settings (including a lot of misfires) but no weeds were missed. As the sensitivity number increased the percentage area sprayed decreased (fewer misfires) but more weeds didn’t get detected (Figure 5-5). The best outcomes were obtained for sensitivity 2 and 3. As the 2 sensitivity gave very similar output we chose to use only sensitivity 2 for the trial.

![Figure 5-5 Area sprayed and number of misses for different sensitivity settings- calibration exercise](image)

![Figure 5-6 Plot in trial on white soil sprayed at sensitivity 2](image)
The trial consisted of 5 repetitions of strips 1.3 m wide (the width of the Weedseeker shield sprayer) by 10 m long. We measured only 3% misfire at sensitivity 2 (Table 5-2). Dead plant materials (stubble) triggered the sensors. The trial location was quite free of stubble which explains the good results (Figure 5-6). Misfires increased where the density of dead plants increased. Recalibrating on dead stubble was unsuccessful because the sensors would not detect the weeds anymore.

The trial site was mainly composed of small broadleaves (less than 10 cm tall) (figure 1 in Annexe 1). The sensors detected weeds bigger than 5 cm significantly better than the weeds less than 5 cm (P = 0.022). More than 80% of the broadleaves (bigger than 5 cm diameter) and the grasses (bigger than 10 cm diameter) were detected (Figure 5-7). Only 55% of the broadleaves smaller than 5 cm were detected which is in accordance with previous test trials and manufacturer specifications.

There were only a very small number of sedges taller than 10 cm that were 100% detected. It was also difficult to conclude anything about the sensor efficiency on the vines as their density was very low; however, they seemed well detected especially when their size was more than 10 cm diameter.

![Figure 5-7 Detection capacity of sensors in trial on light coloured soil, sensitivity 2](image)

**Figure 5-7**: Detection capacity of sensors in trial on light coloured soil, sensitivity 2

<table>
<thead>
<tr>
<th>Sensitivity</th>
<th>Number of misfires in 200m</th>
<th>Area sprayed by misfires</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>206</td>
<td>3%</td>
</tr>
</tbody>
</table>

**Table 5-2**: Misfires in trial 1 on white soil

Conclusion: the capacity of the sensors to detect broadleaf weeds and grasses on a light coloured soil was acceptable (more than 80% detection for weeds taller than 5 cm).
5.1.7.2 Suitability of the technology for fallow management on light-coloured soil

Four 20 m strips (1.3 m wide: width of the Weedseeker shield sprayer) representative of the paddock were chosen for the demonstration on a light coloured-soil fallow (Figure 5-8). A lot of dead stubble creating darker shades was present in this paddock and calibration was a difficult task (Figure 5-9, Figure 5-10). As per manufacturer’s instruction, the calibration must be done in the lighter coloured area but this created misfires in every dark area as well as on the green weeds. Calibrating on darker patches of dead stubble diminished the misfires but decreased dramatically the capacity to detect green weeds. After several attempts to calibrate the device, no acceptable compromise was found.

Figure 5-8 Fallow used as demonstration site in light coloured soil. Soil colour variability and dead plant material are big issues in fallow management

Figure 5-9 Area sprayed at sensitivity 2: most weeds got sprayed but stubble also triggered the sensors

Figure 5-10 Sensitivity 4 didn’t solve the issue: fewer weeds detected but most of the stubble and darker areas still triggered the sensors
The following results were obtained when spraying at sensitivity 2 after calibrating on soil without stubble. The percentage detection of weeds was the same as in the trial however 70% of soil without any weeds also got sprayed due to:

- misfires on the dead stubble
- many small scattered broadleaves less than 5 cm diameter got detected and areas of 0.38 m * 0.1 m (nozzle footprint) got sprayed (Figure 5-11, Figure 5-12, Figure 5-13). Refer to paragraph 5.1.10 explaining the nozzle footprint.

![Figure 5-11 Area covered by weeds and area sprayed in demonstration on a light-coloured-soil fallow](image-url)
A map generated by the GPS recorder fitted to the Weedseeker sensors also highlights that most of the area was sprayed (Annexe 1, Figure 2).

Poor results were obtained by using the Weedseeker technology on a light-coloured soil fallow in the presence of dead stubble as 70% of the area free of weeds was sprayed by misfires or because of the large nozzle footprint. Savings up to 80% would have been expected in this fallow; however the technology wasn’t accurate enough nor able to discriminate between live weeds and dead plants.

In this paddock, soil colour changed and the calibration process of the sensor needed to be carried out every time a different colour was recognised.

Conclusion: light-coloured fallow blocks with several colour changes or dead stubble were not optimal candidates for Weedseeker applications.

5.1.8 Trials on black soil

5.1.8.1 Efficiency of the sensors on black soil

Two identical trials were carried out on black soil in two close locations with different weed species. The trials were designed as RCBs with 3 sensitivity treatments and 5 repetitions. Each plot was 1.3 m wide (the width of the Weedseeker shield sprayer) by 10 m...
long. The calibration process on this site was quite straightforward with sensitivity 3, 4 and 5 giving acceptable preliminary observations.

Trial 1 was mainly composed of medium size (5 to 10 cm) sedges and broadleaves (Annexe 1, figure 3). Sensitivity set on 3 gave the best outcomes with more than 80% detection for broadleaf plants bigger than 5 cm and grasses of all sizes. Sedges were detected 70% of the time as well as 50% of small broadleaves (charts in Figure 5-14). Less than 1% of the area was sprayed by misfires without much difference for the 3 tested sensitivity settings (Table 5-3). These misfires were only triggered by the cracking texture of some areas of the paddock (these areas got wet and the soil surface peeled, Figure 5-15).

When the sensitivity number increased the medium size detection rate for broadleaves dropped to 60% and for nutgrass to 45%. At sensitivity 5, more than 20% of the largest broadleaves were not detected.

**sensitivity 3**

![Graph showing sensitivity 3 results]

**sensitivity 4**

![Graph showing sensitivity 4 results]
Figure 5-14 Percentage detection of the sensors at sensitivity 3, 4 and 5 in trial 1 on black soil

Table 5-3 Misfires in trial 1 on black soil

<table>
<thead>
<tr>
<th>Sensitivity</th>
<th>Number of misfires in 50 m</th>
<th>Area sprayed by misfires</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>6</td>
<td>0.4%</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>0.6%</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>0.5%</td>
</tr>
<tr>
<td>P</td>
<td>0.81</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5-15 Only cracking peeled surface triggered the sensors by mistake in the trial on black soil.
Trial 2 on black soil was mainly composed of small broadleaves and grasses of all size (Annexe 1, figure 4).

Three was again the best sensitivity setting and more than 80% of all weed types and sizes were detected. Only a small number of misfires (less than 1% of the area) were recorded (Table 5-4). When the sensitivity increased to 5 the detection rate dropped to 60% for small broadleaves and grasses and down to 45% for sedges (Figure 5-16, Figure 5-17, Figure 5-18, Figure 5-19).
Figure 5-16 Percentage detection of the sensors at sensitivity 3, 4 and 5 in trial 2 on black soil

Table 5-4 Misfires in trial 2 on black soil

<table>
<thead>
<tr>
<th>Sensitivity</th>
<th>Number of misfires in 50 m</th>
<th>Area sprayed by misfires</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>6</td>
<td>0.4%</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>0.3%</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0.1%</td>
</tr>
<tr>
<td>P</td>
<td>0.83</td>
<td></td>
</tr>
</tbody>
</table>

Conclusion: the sensors were efficient to detect broadleaf weeds and grasses on a black soil. When the 2 trials were combined the interaction weed size by sensitivity was not significant (P = 0.5034)

- The sensors detected weeds bigger than 10 cm significantly better than weeds smaller than 10 cm (P < 0.0001)
- The capacity of the sensors to detect the weeds was significantly better at sensitivity 3 than at sensitivity 4 and 5 (P = 0.0001)
5.1.8.2 Suitability of the technology for fallow management on black soil

The 4 strips of the black-soil fallow were sprayed at sensitivity 3. As in the trial, more than 80% of weeds were detected and only 10% of soil without weeds also got sprayed (where the soil surface was cracking) (Figure 5-20, Figure 5-21, Figure 5-22). Using the Weedseeker in this fallow resulted in 80% herbicide savings and more than 80% of the weeds sprayed (a few misses on small broadleaves and grasses and sedges were recorded).

![Figure 5-20 Area covered by weeds and area sprayed in demonstration on black-coloured fallow](image-url)
Conclusion: black-coloured fallow blocks were suitable for the use of the Weedseeker technology that could potentially generate big herbicide savings as long as the soil surface was not peeling or cracking on large areas.

5.1.9 Trials on grey soil

5.1.9.1 Efficiency of the sensors on grey soil

The trial was designed as RCB with 3 sensitivity treatments and 5 repetitions. Each plot was 1.3m wide (the width of the Weedseeker shield sprayer) by 10 m long.

The calibration process was delicate due to dead plant material sitting on the ground. Darker and lighter areas were also a challenge for calibration (Figure 5-23, Figure 5-24). We observed that calibration on darker areas was more effective than on lighter areas. The potential detection wasn’t affected but fewer misfires were triggered. We can note it goes against manufacturer recommendations. These preliminary observations led us to use sensitivity 4, 5 and 6 as best settings.
Barnyard grass and blue top were the main weeds present. Most weeds were bigger than 5 cm except a few small blue tops and other broadleaves (Annexe 1, figure 5).

Sensitivity 4 tended to produce better detection; however there was no significant difference between sensitivity settings (interaction weed size by sensitivity $P = 0.864$, $P_{sensitivity} = 0.0561$). Sensitivity 4 seemed to be the best compromise to reach as many weeds as possible on this soil colour with dead plant material that triggered 1% of area sprayed by misfire (Table 5-5).

Weeds larger than 20 cm were better detected than weeds between 10 and 20 cm, which were better detected than the weeds smaller than 10 cm ($P < 0.0001$). Sedges, small grasses and tiny broadleaves were the least detected (charts in Figure 5-25).
Figure 5-25 Percentage detection of the sensors at sensitivity 4, 5 and 6 in trial on grey soil
Table 5-5 Misfires in trial on grey soil

<table>
<thead>
<tr>
<th>Sensitivity</th>
<th>Number of misfires in 100 m</th>
<th>Area sprayed by misfires</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>31B</td>
<td>1%</td>
</tr>
<tr>
<td>5</td>
<td>7 A</td>
<td>0.2%</td>
</tr>
<tr>
<td>6</td>
<td>19 B</td>
<td>0.6%</td>
</tr>
<tr>
<td>P</td>
<td>0.0103</td>
<td></td>
</tr>
</tbody>
</table>

Conclusion: the capacity of the sensors to detect weeds on grey soil was acceptable: more than 75% detection of broadleaves bigger than 5 cm and grasses, 60% of sedges detected.

5.1.9.2 Suitability of the technology for fallow management on grey soil

The 4 strips of the grey-coloured fallow were sprayed at sensitivity 4. The percentage detection of weeds was the same as in the trial; however 30% of soil without any weeds also got sprayed (Figure 5-26). Dead stubbles triggered the sensors and many small scattered broadleaves (less than 5 cm diameter) got detected and areas (0.38 m * 0.1 m) larger than the area covered by the weed got sprayed (Figure 5-27, Figure 5-28)

![Figure 5-26 Area covered by weeds and area sprayed in demonstration on grey-coloured fallow](image)

The map generated by the GPS recorder highlights that more than 50% of the area was not sprayed (Annexe 1, figure 6).

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Conclusion: grey-coloured fallow blocks with dead stubble and small scattered weeds may still be suitable for the use of the Weedseeker technology even if 30% of the herbicide was wasted due to the misfires or the large nozzle footprint (versus 85% for broadcast application).

5.1.10 Trials on red soil

5.1.10.1 Efficiency of the sensors on red soil

The trials were designed as RCB with 3 sensitivity treatments and 5 repetitions. Each plot was 1.3 m wide (the width of the Weedseeker shield sprayer) by 10 m long.

Calibration was an easy process as near to no misfires were counted while using sensitivity 1. Very few misses were measured when sensitivity was increased to 3.

Most of the weeds in the trial were small blue tops (less than 5 cm) and medium size blue tops and Leucas (Annexe 1, figure 7). The whole block was covered by weeds so we rotary hoed some zones 2 days before spraying in order to create areas free of weeds (Figure 5-29).
Almost 100% of the weeds present were detected using sensitivity 1, 2 or 3 (graphs in Figure 5-30, Figure 5-31, Figure 5-32, Figure 5-33). Very few misfires were recorded (Table 5-6)
Figure 5-30 Percentage detection of the sensors at sensitivity 1, 2 and 3 in trial on red soil

<table>
<thead>
<tr>
<th>Sensitivity</th>
<th>Number of misfires in 100 m</th>
<th>Area sprayed by misfires</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28 B</td>
<td>0.8%</td>
</tr>
<tr>
<td>2</td>
<td>4 A</td>
<td>0.1%</td>
</tr>
<tr>
<td>3</td>
<td>0 A</td>
<td>0.0%</td>
</tr>
<tr>
<td>P</td>
<td>0.0056</td>
<td></td>
</tr>
</tbody>
</table>
Conclusion: the capacity of the sensors to detect weeds on red soil was excellent with close to 100% detection of broadleaves and grasses all size. No misfires were triggered in this soil type free of dead plants.

5.1.10.2 Suitability of the technology for fallow management on red soil

The 4 strips of the red-coloured fallow were sprayed at sensitivity 2. The percentage detection of weeds was the same as in the trial; however 50% of soil without any weeds also got sprayed because of the amount of small broadleaves (less than 5 cm diameter) that triggered the sensors, causing an area of 0.038 m² to be sprayed on each occasion (Figure 5-34, Error! Reference source not found., Error! Reference source not found.).
Conclusion: red-coloured fallow blocks free of stubble but with small scattered weeds may still be suitable for the use of the Weedseeker technology even if 50% of the herbicide was wasted due to the size and distribution of the weeds (versus 75% for broadcast application).

5.1.11 Trial on weathered trash in ratoon crop

In the trials carried out on trash in 2010-2011, the sensors proved able to adequately detect and spray the weeds. However, the number and position of the misfires was not established due to the lack of a suitable dye and the absence of the GPS logger.

On 29/04/2013, tests on weathered trash were carried out in the same paddock that hosted the Mackay agronomy trial 2012-2013 at Rod Lamb’s.

The trial design was a RCB with 3 sensitivity treatments and 5 repetitions. Each plot was 1.3 m wide (the width of the Weedseeker shield sprayer) by 15 m long.

The calibration process was delicate due to variable colour of the trash sitting on the ground. Darker coloured trash was observed where flood water stagnated in the wet season (Figure 5-38). In some areas the trash was washed away and dark colour soil was visible. As in the previous trials on bare soil, darker and lighter areas were a challenge for calibration. We calibrated the sensors on medium colour tone for the paddock and we compared sensitivity 3, 4 and 5.

Most of the broadleaved weeds in the trial were small and medium size blue tops, ludwigia and white eclipta. The main grass species was awnless barnyard grass (mature and about 20-30 cm tall) and mature sedges and nutgrass were also present (Annexe 1, figure 8).

Almost 100% of the weeds present in this trial were detected using sensitivity 3 or 4. Increasing the sensitivity setting to 5 decreased the detection capacity on smaller broadleaves and sedges; however the variable did not follow a normal distribution and no statistical analysis could be fitted.

Many misfires were recorded especially on sensitivity 3 and 4 due to the detection of darker areas; however there was no statistical difference between the sensitivity settings (Table 5-7, Figure 5-39, Figure 5-40)
sensitivity 3

% detection

% weed coverage

Weed size (cm) per category

<5  >5  >5  >5

Broadleaf  Grass  Sedges

Average of %detection

Average of %weed coverage

sensitivity 4

% detection

% weed coverage

Weed size (cm) per category

<5  >5  >5  >5

Broadleaf  Grass  Sedges

Average of %detection

Average of %weed coverage
Figure 5-37 Percentage detection of the sensors at sensitivity 3, 4 and 5 in trial on weathered trash

Table 5-7 Misfires in trial on weathered trash

<table>
<thead>
<tr>
<th>Sensitivity</th>
<th>Area sprayed by misfires</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>32%</td>
</tr>
<tr>
<td>4</td>
<td>36%</td>
</tr>
<tr>
<td>5</td>
<td>9.6%</td>
</tr>
<tr>
<td>P</td>
<td>0.1255</td>
</tr>
</tbody>
</table>

Figure 5-38 Plot before spraying
Darker areas in the centre of the inter row where water logging occurred triggered misfires

Figure 5-39 Same plot after spraying using sensitivity 3 (image saturation enhanced to improve visibility of blue dye)
Conclusion: the sensors’ capacity to detect weeds on weathered trash was good: more than 90% of weeds were detected at sensitivity 3 and 4; however misfires on dark areas would have made the scenario economically unacceptable (data not logged).

5.1.12 Other technical considerations when using the Weedseeker technology.

Limitations of the Weedseeker technology were identified when it was used in three agronomy trials implemented in cane crops. The details of the trials can be found in chapter 6 “Integration of the Weedseeker technology in weed management programs”. In the trials timers were used to measure the cumulated time each solenoid was switched on (nozzle was spraying). Knowing the travel speed and the width each nozzle covered, these durations were converted into areas. For each plot we calculated the percentage area sprayed = area sprayed / total area screened * 100

5.1.12.1 Mackay trial 2011

In the Mackay trial 2011 in ratoon cane on trash blanket, we expected the percentage area sprayed would be close to the percentage weed coverage (data recorded at the assessment time) but a high percentage of the area was sprayed (80%) whereas the weeds only covered 15 to 30% of the ground (Figure 5-40).

![Figure 5-40 Area covered by weeds before spraying versus area sprayed, Mackay Agronomy trial 2011.](image)

The explanation was the distribution and type of weeds in the trial: weeds were mainly small but scattered and regularly triggered the sensors.
The discrepancy between the area sprayed and the % coverage is linked to the way the sensors / nozzles work. The sensors turn on for a minimum time of 0.045 second for a small weed which corresponds to a band of 10 cm at 8 km/h (Cropoptics confirmed that a 20 cm band minimum is sprayed in broadacre at 16 km/h). The timers could record a minimum of 0.05 sec which was acceptable.

Figure 5-41 shows an inter row that was rated less than 30% coverage but more than 80% of the area was sprayed. The area detected by the sensors and sprayed and the resulting chemical savings are determined by the distribution and size of weeds.

Figure 5-41 Typical weed coverage in the trial and simulation of the expected sprayed area

The percentage of area sprayed was converted into volume of herbicide used for each plot and compared to the percentage weed coverage in the plot. The means of all repetitions and 2 dates for each treatment were used to calculate the percentage of herbicide wasted for each treatment (Figure 5-42). The percentage of herbicide wasted means the percentage herbicide that reached the soil and not the targeted weeds. The calculation is:

\[
\text{% herbicide wasted} = \frac{(\text{% area sprayed} - \text{% area covered by weeds})}{\text{% area sprayed}} \times 100.
\]
As expected T2 (blanket spray) seemed to waste more herbicide than the other 3 treatments using the Weedseeker (T3, T4 and T5); however, the differences between treatments were not significant, $P=0.68$.

![Figure 5-42 Percentage herbicide wasted (sprayed on the soil instead of the weeds) for each treatment (treatments are defined in chapter 6).](image)

We suspected such waste of chemical was linked to the type of weeds present in the trial. Figure 5-43 shows the percentage herbicide wasted in each plot sprayed with the Weedseeker depending on the weed species present in the plot.

In plots where blue top was the dominant species, more herbicide seemed to have been wasted on the ground whereas less herbicide was wasted in plots where sensitive weed was dominant.

Sensitive weed is a perennial that creates big isolated patches whereas blue tops are annual and small germinated seedlings can be scattered all across the plot (but cover only 15% of the area)

![Figure 5-43 Percentage herbicide wasted depending on the weed species present in each plot. Weeds’ initials in upper case: dominant species in the plot. Weeds’ initials in lower case: species present but in small numbers.](image)

Two demonstration strips were also set up at the Mackay site 2011 (1 inter row 300 m long, 2 repetitions). Sensitivity 2 was used to make sure young blue tops were detected and sprayed. For the second application in December, most of the weeds were tall grasses emerging from the side of the
row (Figure 5-44, Figure 5-45). The efficacy of the Weedseeker treatment was optimum; however herbicide savings were only 10 and 40% compared to the blanket spray (Figure 5-46).
If the sensitivity setting had been set up to 4 or 6, the sensors would have missed most of the small scattered blue tops and a lot of chemical could have been saved but another application would have been necessary very shortly to deal with the mature blue tops.

Another alternative would be to use a second boom (as in broadacre) blanket spraying with a low rate of glyphosate (or gramoxone) to kill the young seedlings of blue tops. The first boom carrying the Weedseeker (sensitivity 4 or 6) would spot spray glyphosate high rate to hit big weeds.

5.1.12.2 Burdekin trial 2012

Results for the trial in plant cane in the Burdekin were quite similar: 50% of the area was sprayed when the weed coverage was less than 5% and 90% of the area was sprayed when the weed coverage was close to 20%. Unlike the Mackay trial 2011 where the weed distribution was responsible for the discrepancy between weed coverage and area sprayed, the poor performance of the Weedseeker shield sprayer in the Burdekin trial was mainly caused by:

- cane residues on the ground that would have triggered misfires
- sugarcane leaves that were flattened by the interrow tractor, detected by the sensors under the shield and sprayed (Figure 5-47).

55% of the area was sprayed in plots close to zero weed coverage (Figure 5-48). It means that in average 55% of the area was sprayed in all plots due to cane leaf interference or misfires on residues.
Figure 5-47 Plot before spraying showing cane residues on the ground and cane leaves susceptible to be run over by the tractor. Burdekin trial 2012.

Figure 5-48 Area covered by weeds before spraying versus area sprayed, Burdekin Agronomy trial 2012

T3 and T4 strategies (using the Weedseeker) reduced the amount of herbicides wasted by only 27 to 31% compared to T2 (inter row blanket spray, Figure 5-49).
Herbicide wasted (sprayed on the soil or the cane instead of the weeds) for each treatment, Burdekin Agronomy trial 2012

A map produced from the GPS logger confirms that more than 60% of the area in the plots got sprayed (Annexe 1, figure 9).

5.1.12.3 Mackay trial 2012

Mackay trial 2012 was in ratoon cane on trash blanket. Results were quite similar to the ones obtained the previous year also in Mackay on ratoon cane on trash blanket (Figure 5-50). 70% of the area was sprayed when the weed coverage was around 10% and more than 80% of the area was sprayed when the weed coverage reached 25%. Again scattered small weeds triggered the sensors satisfactorily but the large footprint for each nozzle spray created the discrepancy between area sprayed and percentage weed coverage.

Figure 5-50 Area covered by weeds before spraying versus area sprayed, Mackay trial 2012
Figure 5-51 show that many scattered small weeds triggered the sensors despite a low weed coverage. In some plots darker areas where the trash was absent and the soil was apparent would have created misfires (Figure 5-52).

A combination of these two factors would have been responsible of the high ratio between area sprayed versus percentage coverage.

Figure 5-51 Plot with small scattered weeds before spraying
T3, T4 and T5 strategies (using the Weedseeker) reduce the amount of herbicides wasted by 26 to 41% compared to T2 (inter row blanket spray, Figure 5-53).
A map produced from the GPS logger confirms that more than 60% of the area in the plots got sprayed (Annexe 1, figure 10).

Conclusion: the three agronomy trials show that the sensors were efficient in detecting weeds on trash blanket and bare soil; however the large nozzle footprint when spraying on scattered small weeds, the misfires on cane residues on bare soil or on dark areas on trash blanket are situations that can significantly limit herbicide savings and impact on the economic benefit of the technology.

5.2. Economic assessment of the Weedseeker technology in sugarcane cropping system

5.2.1 Economic study in fallow

The detailed calculation for the economic study of the four fallow demonstrations is presented in Annexe 1 tables 2 and 3. Calculations were made using herbicides (glyphosate + adjuvant) instead of dye. Each fallow situation sprayed with the Weedseeker was compared to a broadcast boom spray. The cost of spraying was set at $30/ha for the broadcast boom and $42 /ha for spraying with the Weedseeker (assumption of 15 sensors placed on a 6 m boom).

At this cost /ha, it was cheaper to use the Weedseeker in the black fallow situation compared to a broadcast spray (Table 5-8). In all other fallow situations tested in 2012, using the Weedseeker was more expensive than broadcasting the herbicide.

It seems that in most fallow situations where the demonstrations were implemented, the conditions were not right for a profitable use of the Weedseeker technology. The following situations were not economically suitable for a Weedseeker application in fallow:

- dead plant material or stubble on the ground,
- variable soil colour within the block,
- small scattered weeds covering a few percentage of the soil but triggering large areas to be sprayed.

Table 5-8 Economic study of Weedseeker used in fallow

<table>
<thead>
<tr>
<th>Treatment</th>
<th>total cost /ha (chemical + application) for grower paying for service</th>
</tr>
</thead>
<tbody>
<tr>
<td>boom spray broadcast all fallows</td>
<td>$49</td>
</tr>
<tr>
<td>Weedseeker white fallow</td>
<td>$59</td>
</tr>
<tr>
<td>Weedseeker black fallow</td>
<td>$46</td>
</tr>
<tr>
<td>Weedseeker grey fallow</td>
<td>$51</td>
</tr>
<tr>
<td>weedseeker red fallow</td>
<td>$56</td>
</tr>
</tbody>
</table>

5.2.2 Economic study in trash blanketed ratoon cane

To set a price for the use of the Weedseeker mounted in shields on a dual tank high-rise sprayer, two spraying contractors were asked for practical details such as volume/ha used, speed driven, cost of application using similar equipment without the Weedseeker technology. It was decided that the Weedseeker system should be paid off within 3 years and a contractor should be able to spray 3000 to 4000 ha within this period.

Using the current settings of our Weedseeker sprayer that are recommended by the manufacturer Crop Optics, there are some limitations:

- The minimum pressure to operate the sprayer is 2 bars.
• The nozzle type must be flat fan non air inducted, non-drift guard even nozzle
• The maximum speed we can drive with the high rise is 8 to 10 km/h
• The recommended droplet size for glyphosate application in a sugarcane crop under shield is coarse

To satisfy these limitations, in 2011 a 03 flat fan even nozzle was used at 2 bars, which resulted in a water rate of 160 to 200 L/ha (at 10 and 8 km/h respectively). This water rate was too high and not appropriate for the application of glyphosate (recommended water rate around 80 L/ha under shield). To address the issue the dose of glyphosate / ha was increased to make sure the concentration of the brew was adequate. The cost of this scenario is reported in Table 5-9, in the columns 3 and 4. In this case the grower paying for service was better off using the Weedseeker only if the area sprayed for weeds is less than 31% of the total sprayed area.

The only parameter that could be modified to make the Weedseeker sprayer more appealing for farmers was the nozzle size. Using 02 nozzles would reduce the water rate down to 160 L/ha at 8 km/h and glyphosate rate was dropped to 3.5 L/ha. The resulting economics are illustrated in column 5 and 6 (Table 5-9). In this new scenario the grower paying for service would be better off using the Weedseeker if the area sprayed for weeds is less than 36% of the total sprayed area. In 2012 trials were sprayed using 02 nozzles that produce fine droplets so potential crop damaged due to drift was assessed. Yield will be measured during 2013 crush to check if any yield loss could be attributed to glyphosate drift.

### Table 5-9 Scenarios for spraying cost using a Weedseeker sprayer

<table>
<thead>
<tr>
<th>Scenarios on 1.6 m row spacing , shield 1.25 m wide</th>
<th>High rise shielded sprayer low water rate</th>
<th>Weedseeker high rise shielded sprayer high water rate</th>
<th>Weedseeker high rise shielded sprayer low water rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weed coverage scenario (% area sprayed)</td>
<td>30%</td>
<td>60%</td>
<td>30%</td>
</tr>
<tr>
<td>Water rate(L sprayed/ha)</td>
<td>80</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Nozzle type at 2 bars</td>
<td>TP6503E</td>
<td>TP6503E</td>
<td>TP6502E</td>
</tr>
<tr>
<td>Speed km/h</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Time to spray 1 ha (including refill time 0.4h)</td>
<td>0.15 h</td>
<td>0.144 h</td>
<td>0.163 h</td>
</tr>
<tr>
<td>Water rate (L sprayed / ha driven)</td>
<td>62.5</td>
<td>4</td>
<td>94</td>
</tr>
<tr>
<td>Rate of chemical (L/ha)</td>
<td>2.5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Base price of contracting equipment</td>
<td>$32</td>
<td>$42</td>
<td>$42</td>
</tr>
<tr>
<td>Cost chemical used (glyphosate at $8/L)</td>
<td>$20</td>
<td>$9.60</td>
<td>$19.20</td>
</tr>
<tr>
<td>Total cost for service</td>
<td>$52</td>
<td>$51.60</td>
<td>$61.20</td>
</tr>
</tbody>
</table>

Conclusion: Situations where the Weedseeker technology would be profitable are limited to cane blocks on bare soil or trash blanket (where the background is relatively uniform to prevent misfires) with isolated clumps of weeds. In most fallow situations, the conditions would not be right for a profitable use of the Weedseeker technology because of the variability of the soil surface triggering the sensors (dead plant material, soil colour change) or the weed distribution (small scattered weeds).
6. Integration of the Weedseeker technology in weed management programs

In order to evaluate the benefits of including the Weedseeker technology in weed management strategy, agronomy trials were carried out. They compared weed management strategies including the use of the Weedseeker technology to different current weed management strategies using other traditional spraying devices (directed spray with droppers, band spray, broadcast spray with a boom). Weed management practices can be classified within the ABCD framework representing the impact of the practice on the environment as well as its profitability for the grower (Table 6-1).

<table>
<thead>
<tr>
<th>Class A practices</th>
<th>Cutting-edge practices that require further validation of environmental, social and economic costs/benefits.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class B practices</td>
<td>Currently promoted practices often referred to as ‘Best Management Practices’.</td>
</tr>
<tr>
<td>Class C practices</td>
<td>Common practices. Often referred to as ‘Code of Practice’. Acceptable practice today but may not be acceptable in medium term.</td>
</tr>
<tr>
<td>Class D practices</td>
<td>Practices that are superseded or unacceptable by industry and community standards.</td>
</tr>
</tbody>
</table>

The use of the Weedseeker technology falls into the class A practices and was compared to practices B and C. Class D practices were not included as they are considered unacceptable. Assessments of the weed population, cane yield and an economical study of the cost of different practices indicated if the use of the Weedseeker technology for managing weeds in sugarcane was more or less profitable and efficient to control the weeds compared with B and C practices.

A growers’ consultative group that included three growers (Lee Blackburn, Rodney Lamb and Allan McLean), BSES Limited Extension and Agriserv staff met in 2011 to discuss the design of the new WeedSeeker® shield sprayer device, ideas for improvement and participation in trials.

The group identified the main application of the technology was to use the Weedseeker sensors under a shield to treat interrows in ratoon cane on trash blanket.

6.1. Agronomy trials 2011

In 2011, field sites were selected in Bundaberg, Mackay and the Burdekin. Unfortunately the Burdekin site was accidently sprayed after the second assessment and was consequently abandoned. Attempts were made to find an alternative site but in each case the crop was already well established and already sprayed.

For Bundaberg and Mackay areas the basic class C practice in terms of weed management would traditionally consist of the broadcast application of a pre-emergent herbicide just after harvest followed by directed knockdown if needed. The Class B practice tested in our trials involved the band application of pre-emergent herbicide over the row just after harvest followed by a directed spray knock-down interrow. The Weedseeker technology was used in 3 identified strategies that would belong to class A practices.

The 5 treatments compared were:
• Treatment 1: Class C - broadcast pre-emergence just after harvest then knockdown directed sprayed if needed.
• Treatment 2: Class B - banded pre-emergence over the row just after harvest then knockdown directed sprayed if needed.
• Treatment 3: Class A - banded pre-emergence over the row just after harvest then Weedseeker shield sprayer with glyphosate.
• Treatment 4: Class A - no pre-emergence then Weedseeker shield sprayer with glyphosate + selective knockdown over the row when needed.
• Treatment 5: Class A - no pre-emergence after harvest then Weedseeker shield sprayer with pre-emergence & glyphosate + selective knockdown over the row when needed.

These treatments are detailed in Annexe 1, table 4.

Both sites were monitored every three weeks. At the Bundaberg site, weed pressures were below the 20% threshold for spraying therefore the November treatments (including Weedseeker) were not applied.

All weed data were analysed by SAS using a mixed-model repeated-measures analysis. The treatments were considered as fixed effects and the correlation between sampling dates (rho) was taken into account assuming an exponential decay model structure. If the sampling dates are one apart, i.e. dates 1&2 or dates 2&3, then the correlation equals rho. If the sampling dates are 2 apart, i.e. dates 1&3 or dates 2&4, then the correlation equals rho2.

Efficacies of all treatments were assessed from the first assessment date and zero efficacy was assigned when no treatment was applied before the assessment date. The efficacy variables were transformed using a logit transformation. Means were compared using the Tukey-Kramer test when the analysis had six or more levels and the LSD test when the analysis had five levels or fewer. In the tables, means followed by the same letter are not significantly different.

Yield and marginal return data were analysed by Statistix using analyses of variances for split-plot designs.

### 6.1.3 Mackay trial 2011

The trial was implemented in Kuttabul, at McLean’s farm (farm number 2044) on Block 34-2. The cane variety was Q208. It was a third ratoon, previously harvested on 28/08/2011 yielding 60-70 t/ha. The block was not irrigated during the period of the trial. The soil type was a soloth (Ossa). The trash level was light due to the variety and low yield.

The trial design was a RCB with adjacent controls and 5 treatments (Annexe 1, figure 11). Each plot was composed of 2 inter rows and 1 central cane row. Each plot was 15 m long and 1.6 *2 = 3.2 m wide.

The details of the spraying treatment rates, water volumes and dates are reported in Table 6-2. The spraying equipment used for each application and the status of the crop at time of spraying are detailed in Annexe 1, table 5. The weather was recorded at time of spraying using a Windmate (Annexe 1, table 6). The rainfall amount was recorded by the grower every day (rain gauge within 5 km of the paddock). (Annexe 1, figure 12)

<table>
<thead>
<tr>
<th>Date/2011</th>
<th>Treatment</th>
<th>Product</th>
<th>Rate/ha</th>
<th>Water /ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>14/09/11</td>
<td>T1 broadcast</td>
<td>Balance</td>
<td>200g</td>
<td>300L/ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gramoxone</td>
<td>1.2L</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Activator</td>
<td>0.1%</td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Treatment</td>
<td>Product</td>
<td>Rate/ha</td>
<td>Water /ha</td>
</tr>
<tr>
<td>----------</td>
<td>----------------------------------------</td>
<td>-----------------</td>
<td>---------</td>
<td>-----------</td>
</tr>
<tr>
<td>T2 banded</td>
<td>Balance</td>
<td>200g</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gramoxone</td>
<td>1.2L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Activator</td>
<td>0.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T3 banded (idem T2)</td>
<td>Balance</td>
<td>200g</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gramoxone</td>
<td>1.2L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Activator</td>
<td>0.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/11/11</td>
<td>T2 with shield</td>
<td>Roundup powermax</td>
<td>4L</td>
<td>150L</td>
</tr>
<tr>
<td></td>
<td>Starane Advanced</td>
<td>780ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Liase</td>
<td>2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2/11/11</td>
<td>T3, T4 with WSS</td>
<td>Roundup powermax</td>
<td>4L</td>
<td>200L</td>
</tr>
<tr>
<td></td>
<td>Starane Advanced</td>
<td>780ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Liase</td>
<td>2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2/11/11</td>
<td>T5 with WSS</td>
<td>Roundup powermax</td>
<td>4L</td>
<td>200L</td>
</tr>
<tr>
<td></td>
<td>Flame</td>
<td>300ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Liase</td>
<td>2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/11/11</td>
<td>T2, T3, T4, T5 to the base of the row</td>
<td>Asulox</td>
<td>8.5L</td>
<td>200L</td>
</tr>
<tr>
<td></td>
<td>Actril</td>
<td>1.5L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Activator</td>
<td>0.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8/12/11</td>
<td>T1 with droppers row+IR</td>
<td>Starane Advanced</td>
<td>780ml</td>
<td>200L</td>
</tr>
<tr>
<td></td>
<td>Amicide 625</td>
<td>800ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Uptake oil</td>
<td>1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned but not needed</td>
<td>T2, T3, T4, T5 to the base of the row</td>
<td>Starane Advanced</td>
<td>780ml</td>
<td>200L</td>
</tr>
<tr>
<td></td>
<td>Amicide 625</td>
<td>800ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Uptake oil</td>
<td>1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20/12/11</td>
<td>T2, T3, T4, T5 With the weedseeker</td>
<td>Roundup powermax</td>
<td>4L</td>
<td>200L</td>
</tr>
<tr>
<td></td>
<td>Liase</td>
<td>2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21/12/11</td>
<td>T1</td>
<td>Daconate</td>
<td>6L</td>
<td>300L</td>
</tr>
<tr>
<td></td>
<td>Activator</td>
<td>0.1%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: WSS stands for Weedseeker Shield Sprayer.

According to previous trials the Weedseeker sensitivity was set up on 2 in order to kill weeds that were small as well as big ones.

A demonstration strip trial consisting of 2 treatments and 2 repetitions was also implemented on an adjacent block with similar soil type. Each strip was 4 rows wide. The treatments were:
- T1: knockdown treatment inter row only using the Weedseeker twice (sprayed exactly at the same time, with the same equipment and chemical as T4 – Agronomy trial)
  - 15/11/2011 and 24/12/2011: the grower used his dual tank sprayer. He sprayed the inter row with Roundup Powermax at 1.25 L/ha + LI 700 at
0.25% in 50 L/ha water using the GC hoods. The row got sprayed with 1 L/ha of Amicide 625 in 100L/ha of water.

- 10/01/2012: the grower used Irvin legs and sprayed 0.75 L/ha Gramoxone + 1 L/ha Amicide 625 in 75L/ha of water to clean new emerging weeds before cane closure.

**Weed coverage in untreated plots**

The untreated plots were the reference in terms of potential weed infestation in the trial (Figure 6-1). The trial was mainly infested by broadleaves and grasses. The main broadleaves in the trial were *Ageratum conyzoides* (blue top) and *Mimosa pudica* (sensitive weed). The main grasses were *Digitaria ciliaris* (summer grass) and *Echinochloa colona* (Awnless Barnyard grass). Sedges like *Cyperus brevifolia* and *C. iria* were also present (Figure 6-2).
**Efficacy of herbicide strategies**

The pre-emergent treatments were applied 14/09/2011 on relatively moist soil (under the trash) and it did not rain until 21/10/2011. In these conditions the seeds can germinate under the trash and the pre-emergent herbicides remains on the trash blanket not incorporated. Consequently efficacies for T1, T2 and T3 were low (maximum 50% efficacy reached 2 months after spraying on T1 broadcast, Figure 6-3). At the second assessment date (26/10/2011), T1 controlled the weeds significantly better than the strategies without pre-emergence (interaction Treatment * date, P<0.0001. A zero efficacy was assigned to T4 and T5 for the first 2 dates in the analysis). The banded pre-emergence T2 and T3 reached only 10 to 20% efficacies (due to the weeds in the inter row) that were not statistically different to the strategies T4 and T5 without pre-emergent herbicides.

Two weeks after the application of the first knock down (2/11/11), efficacies reached 75 to 95% in T2, T3, T4 and T5. For the last three assessments, all strategies were similar in controlling the weeds (no significant difference) except on 12/12/2011: T5 was significantly more efficient than T1 (treatment * interaction, P= 0.037).

- T1 efficacy was low on 12/12/11 because the broadleaf knockdown treatment was applied 2 days earlier and the effect just started to be visible. T1 efficacy increased to 90% after the application of the grass knock down end of December.
- T5 was particularly efficient on 12/12/11 which confirmed the efficacy of Flame applied with glyphosate (2/11/11) to prevent the new germination of weeds. However there was no significant difference from the strategies without Flame (T2, T3, T4 and T5).
The pre-emergence treatments were not very effective in controlling the broadleaves in this trial. Up to November the main broadleaf weed was sensitive weed and blue tops emerged only from November onwards. Sensitive weed is a perennial that was not affected by the pre-emergent herbicide Balance. Blue top emerged 2 months after the application of Balance (similar germination period in the untreated plots), and the pre-emergence treatment had lost its activity by then. All post emergence treatments with glyphosate were 75 to 95% effective to control the broadleaves without any difference amongst them (Figure 6-4).

16/11/11 T1 was significantly less effective in controlling the broadleaved weeds than the other strategies because the post emergence treatments hadn’t been applied for T1 yet (interaction Treatment*date, P=0.0027, Annexe 1, figure 13).

When analysing the efficacy on individual weed species, there was a significant difference between treatments for blue top on 16/11/2011: T4 was a significantly more effective control method than T1 (interaction Treatment*date, P=0.0015, analysis done on the last 3 dates only).

Figure 6-3 Efficacy of herbicide strategies on the total weed population (Agronomy trial Mackay, 2011)
Two month after spraying, T1 reduced the grass coverage by 80% (60% reduction 3 months after spraying, Annexe 1, figure 14). T1 was significantly more efficient than T2 on 26/10/11 (interaction Treatment * date, $P=0.0055$, analysis done for the all period using T1, T2 and T3 only). Banded spray results were inconsistent depending on the location of the grass (inter row or in the row). The first knockdown application in T2, T3, T4 and T5 was 75 to 100% efficient but the grasses quickly grew back (in T5 where Flame was used, the pre-emergence seemed to hold back the grass longer; however there was no significant difference from T4 where Flame wasn’t used). T3, T4 and T5 were significantly more efficient to control the grasses than T2 (interaction Treatment*date, $P=0.91$; Treatment, $P=0.037$, analysis done for the last 3 dates only). Same brew was applied but the mode of application was different: T2 was sprayed at lower water rate, higher pressure, air inducted nozzles and different shield shape. The mode of application was less effective on the tall grasses that grew back. We suspect the shield used in T2 did not flatten the tall grasses as much as the Weedseeker shield did and may have resulted in poorest spray coverage.

When analysing the efficacy on individual weed species, there was a significant difference between treatments for summer grass: T3 and T5 were more effective than T1 and T2 (interaction Treatment*date, $P=0.728$ and Treatment $P=0.0254$, analysis done on the last 3 dates only).

There was a lot of variability in the efficacy of the treatments to control the sedges (Annexe 1, figure 15). The application of Flame and glyphosate in T5 seemed efficient as well as Daconate applied in December in T1; however there was no statistical difference between any treatments.
Glyphosate alone was 50 to 70% effective on the sedges. Most of the sedges were located in the row and no herbicides efficient on sedges was applied in the row.

Strategies using the Weedseeker were more effective to control the weeds than strategies relying on pre-emergence only in this trial. Combining banded pre-emergence and Weedseeker did not add any benefit in terms of weed efficacy.

Economic study of the strategies

Setting the cost of Weedseeker at 42$/ha (not including the cost of herbicide), the strategies tested in the trial were compared in Table 6-3. The most expensive strategy was T1: the systematic pre-emergence broadcast strategy. I was also noted that it wasn’t the best one in terms of weed control and a follow up spray was necessary when the pre-emergent herbicides stopped working.

Strategies T2 and T3 were equivalent in term of cost: the savings due to the reduced area sprayed in T3 didn’t totally compensate for the additional cost of spraying with the Weedseeker. In chapter III.2.9 we demonstrate that due to the type of weed coverage, the area sprayed by the Weedseeker was more than 60% of the total sprayed area in the trial. If the sensors triggered less often, T3 would have been a more profitable option than T2.

Strategies T4 and T5 were the cheapest strategies involving only the use of the Weedseeker twice. They could have been even cheaper if less percentage area was sprayed. The accessibility to the paddock at the beginning of the wet season is the biggest risk taken by adopting these strategies.

The additional cost of Flame in T5 was compensated by the reduced amount of glyphosate used in the second application. The application of Flame reduced the germination of grasses and sedges in particular, resulting in only 46% of the area sprayed at the second application.

Table 6-3 Cost of herbicide application for each strategy, Mackay agronomy trial 2011

<table>
<thead>
<tr>
<th>Table cost/ha of each treatment</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balance</td>
<td>$83.73</td>
<td>$26.16</td>
<td>$26.16</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>Gramoxone</td>
<td>$7.20</td>
<td>$2.25</td>
<td>$2.25</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>Activator</td>
<td>$7.26</td>
<td>$2.04</td>
<td>$2.04</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>Starane adv</td>
<td>$23.47</td>
<td>$16.88</td>
<td>$10.81</td>
<td>$13.34</td>
<td>$0.00</td>
</tr>
<tr>
<td>Amicide</td>
<td>$5.08</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>Uptake oil</td>
<td>$16.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>Daconate</td>
<td>$100.77</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>Roundup powermax</td>
<td>$0.00</td>
<td>$47.99</td>
<td>$40.49</td>
<td>$41.24</td>
<td>$30.99</td>
</tr>
<tr>
<td>Liase</td>
<td>$0.00</td>
<td>$11.35</td>
<td>$10.87</td>
<td>$11.07</td>
<td>$8.32</td>
</tr>
<tr>
<td>Asulox</td>
<td>$0.00</td>
<td>$70.49</td>
<td>$70.49</td>
<td>$70.49</td>
<td>$70.49</td>
</tr>
<tr>
<td>ActrilDS</td>
<td>$0.00</td>
<td>$17.92</td>
<td>$17.92</td>
<td>$17.92</td>
<td>$17.92</td>
</tr>
<tr>
<td>Flame</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$27.93</td>
</tr>
<tr>
<td>spraying pre-emergence</td>
<td>$32</td>
<td>$32</td>
<td>$32</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>spraying post-emergence with high-rise with shields and Weedseeker (assumption we had a dual tank)</td>
<td>$0</td>
<td>$0</td>
<td>$84</td>
<td>$84</td>
<td>$84</td>
</tr>
<tr>
<td>spraying post-emergence with high-rise with shields (assumption we had a dual tank)</td>
<td>$0</td>
<td>$64</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
</tbody>
</table>
The yield data collected in September 2012 and marginal return are reported in Figure 6-5. There was no difference in yield between herbicide treatments. Treated plots yielded 11.8 t/ha more than untreated plots ($P = 0.0084$); however the treatments T3 and T4 that involved the use of the Weedseeker technology seemed to result in slightly higher yield.

There was no statistical difference in benefit between herbicide treatments and control treatments. The cost of herbicide treatments in the treated plots compensated yield loss in untreated plots, especially in T1 that relied on application of pre-emergence.

The treatments using the Weedseeker technology tended to produce a higher benefit in t/ha.

### 6.1.4 Bundaberg trial 2011

The trial was implemented at Fairymead, Bundaberg Sugar, in a trash blanket ratoon and set up with the same treatments and design as the Mackay trial 2011 but with a different randomisation of the plots. Unlike Mackay trial, each plot was composed of 4 inter rows and 3 central cane rows to accommodate the grower spraying equipment. It resulted in a total trial area of 41 rows * 60 m. (1.57 m inter row spacing).
The main weed species was nutgrass. Summer grass, pigweed, sesbania, thistle and bellvine were also present in very small numbers. Only nutgrass in some plots created some weed coverage; however most plots were totally free of any weeds so no knockdown spraying was planned (Figure 6-6). Figure 6-7 illustrates the weed coverage in an untreated plot at the end of March where only a few nutgrass were present.
In this paddock and also in the demonstration strip trial done in an adjacent paddock, no broadcast or banded pre-emergence treatment was necessary. The strategies T4 and T5 counting on knock down only were the most interesting since no knock down was applied at all due to the lack of weeds. Even though this trial couldn’t be used to assess the efficacy of the Weedseeker technology, we can still conclude that knock down strategies were the best economic and environmental options for this trial.

6.2. Agronomy trials 2012

Three trials testing the efficacy and the economic impact of weed management strategies including the Weedseeker technology were planned for 2012-2013. Two trials were implemented in October and November 2012 in plant cane in Mackay and in ratoons in the Burdekin, both on bare soil. Another trial in ratoons on trash was planned for Bundaberg.

Weed data were analysed by SAS using similar model as 2011 trials. Efficacies of treatments were assessed from the date the treatment was applied; which was different from the analysis done in previous trials where zero efficacy was assigned to the treatment before it was applied. After discussion with other scientists, this comparison with zero efficacies did not add much value. The efficacy variables were transformed using a logit transformation. Means were compared using the Tukey-Kramer test when the analysis had six or more levels and the LSD test when the analysis had five levels or fewer.

6.2.1 Mackay trial 2012 plant cane (aborted)

The trial in plant cane was implemented on Rod Lamb’s farm at Eton in cane variety Q208A planted 7/10/2012 in loamy soil. The trial design was a split plot design as illustrated in Annexe 1, figure 16.

Five treatments following ABCD framework adapted for plant cane in the Mackay area were compared:

- Treatment 1: Class C - broadcast pre-emergence just after planting then knockdown blanket sprayed if needed.
- Treatment 2: Class B – tilling for weed control then knockdown directed spray if needed
- Treatment 3: Class A - banded pre-emergence just after harvest then Weedseeker shield sprayer with glyphosate
- Treatment 4 : Class A - banded pre-emergence just after harvest then Weedseeker shield sprayer with glyphosate and Flame

The detailed strategies are reported in Annexe 1, table 8.

The first herbicide treatments and the first two assessments occurred in dur time; however the cane emergence was very poor in the area where the trial was set up (the grower believed he planted the billets too deep) and we were forced to abandon the trial. Because the planting season was finished we decided to implement a trial on ratoon cane cut late and a plant cane trial was planned for Bundaberg instead because they do early autumn planting.

6.2.2 Mackay trial 2012 ratoon cane

The trial on trash blanketed ratoon was implemented on Rod Lamb’s farm at Eton in cane variety Q208A cut on 7/12/2012 . It was a fifth ratoon and the soil type was a black earth (Victoria plains). The trial design and treatments were similar to 2011 trial but randomised differently (Annexe 1, figure 17).

The grower made a mistake and sprayed the trial for vines in February. Consequently the weed management protocol was cut short and the second Weedseeker application did not
happen (Table 6-4). Spraying equipment used for each application and the status of the crop at time of spraying are detailed in Annexe 1, table 9. The Weedseeker sensitivity was calibrated on 2 in order to kill weeds that were small as well as big ones.

The weather was recorded at time of spraying using a Windmate (Annexe 1, table 10)

**Table 6-4 Spraying calendar for Mackay agronomy trial on ratoon, 2012**

<table>
<thead>
<tr>
<th>Date</th>
<th>Treatment</th>
<th>Product</th>
<th>Rate/ha</th>
<th>Water /ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>18/12/2012</td>
<td>T1 broadcast</td>
<td>Flame</td>
<td>400ml</td>
<td>300L/ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gramoxone</td>
<td>1.2L</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Activator</td>
<td>0.1%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T2 banded</td>
<td>Flame</td>
<td>400ml</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gramoxone</td>
<td>1.2L</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Activator</td>
<td>0.1%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T3 banded (idem T2)</td>
<td>Flame</td>
<td>400ml</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gramoxone</td>
<td>1.2L</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Activator</td>
<td>0.1%</td>
<td></td>
</tr>
<tr>
<td>21/01/2013</td>
<td>T2, T3, T4</td>
<td>Round up attack</td>
<td>3L</td>
<td>180L/ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amicide 700</td>
<td>1.6L</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Liase</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>21/01/2013</td>
<td>T5</td>
<td>Round up attack</td>
<td>3L</td>
<td>180L/ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amicide 700</td>
<td>1.6L</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flame</td>
<td>300ml</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Liase</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>10/02/2013</td>
<td>All paddock sprayed by mistake by grower</td>
<td>MCPA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Starane</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

**Weed coverage in untreated plots**

The weed population in this trial was relatively low (maximum 25% coverage in January) which created ideal conditions for spot spraying with the Weedseeker (Figure 6-8). Vines largely represented by *Ipomoea triloba* (Pink convolvulus) were the main species. Bluetop (*Ageratum conizoides*) and awnless Barnyard grass (*Echinochloa colona*) were the most dominant species of broadleaves and grasses respectively.
Efficacy of herbicide strategies

T1 applied broadcast seemed to be more effective to control the weeds than T2 and T3 that were banded, however the statistical analysis done on T1, T2 and T3 showed there was no difference between treatments at each date even if the interaction Treatment*Date was significant $P < 0.0001$ (Figure 6-9). At the last date, the efficacies of the treatments ranged between 50 and 85% with no significant difference between them $P = 0.38$. Once applied the strategies including the Weedseeker were as effective as other strategies.

Similar results were obtained on broadleaved weeds (Annexe 1, figure 18). At the last date, T1 strategy seemed less effective than the others; however the difference was not quite
significant \( P = 0.063 \). T1 strategy involved the use of one pre-emergence application: 6 weeks after application the residual action had expectedly ended when the blue tops emerged. The knockdown application was planned on T1 in February to control the late flush of bluetop.

The broadcast pre-emergence strategy T1 was significantly more effective to control the vines than the banded applications T2 and T3 at the first 2 dates (the interaction Treatment*Date was significant \( P = 0.0001 \), when the analysis was done on T1, T2 and T3 only, Figure 6-10). The pre-emergent herbicide Flame was effective to control the pink convolvulus that emerged soon after harvest. Once the knockdown treatments were applied there was no more difference between strategies (at the last date \( P = 0.31 \)).

Figure 6-10 Efficacy of herbicide strategies on the vines (agronomy trial Mackay 2012)

T1 applied broadcast seemed to be slightly more effective to control nutgrass than T2 and T3 that were banded, however the statistical analysis done on T1, T2 and T3 showed there was no difference between treatments (interaction Treatment * Date was not significant \( P = 0.711 \) and \( P \) Treatment was also not significant \( P = 0.082 \), Annexe 1 figure 19). This trend can be explained because the pre-emergent herbicide Flame has some efficacy on nutgrass. At the last date, there was no difference between treatments \( P = 0.453 \), however T3, T4 and T5 tended to be less effective. This was consistent with previous results using the Weedseeker on nutgrass: the sensors didn’t detect efficiently individual nutgrass unless they were in clumps.

Economic study of the strategies

To improve the outcomes of 2012 trial using 03 nozzles that resulted in 200L/ha of water at 8 km/h, the nozzle size was changed down to 02. Unfortunately the condition of the trial at spraying did not allow us to drive faster than 6 km/h, which resulted in a high water rate of 180 L/ha. Consequently the dose of glyphosate used was maintained quite high (3 L/sprayed ha).

The economic was based on a single herbicide application for T1, T4 and T5 which differs to 2011 trial (Table 6-5). Strategies involving the use of the Weedseeker once were the cheapest strategies. T4 strategy was 34 to 43 % cheaper that the strategies involving pre-emergent herbicides without any significant difference in efficacy (except nutgrass that
seemed less controlled in T4, T5). It was impossible to judge if the herbicide strategy T5 using Flame had a longer term efficacy than the strategy T4 using knockdown only because not enough measurements could be recorded before the grower sprayed the block. T2 and T3 strategies were sensibly more expensive than the pre-emergent broadcast strategy because two applications were made. However a second application was urgently needed on T1 and would have been quite costly. T3 strategy was not more expensive than T2 proving that the Weedseeker strategy was fully cost effective in this trial and the chemical saving compensated the access to the technology.

Table 6-5 Cost of herbicide application for each strategy, Mackay agronomy trial 2012

<table>
<thead>
<tr>
<th>Table cost/ha of each treatment</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gramoxone</td>
<td>$7.20</td>
<td>$2.21</td>
<td>$2.21</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>Activator</td>
<td>$3.63</td>
<td>$1.11</td>
<td>$1.11</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>Roundup attack</td>
<td>$0.00</td>
<td>$18.40</td>
<td>$13.41</td>
<td>$14.61</td>
<td>$13.43</td>
</tr>
<tr>
<td>Liase</td>
<td>$0.00</td>
<td>$5.93</td>
<td>$4.32</td>
<td>$4.71</td>
<td>$4.33</td>
</tr>
<tr>
<td>Amicide Advanced 700</td>
<td>$0.00</td>
<td>$8.77</td>
<td>$6.39</td>
<td>$6.96</td>
<td>$6.40</td>
</tr>
<tr>
<td>Flame</td>
<td>$61.12</td>
<td>$18.75</td>
<td>$18.75</td>
<td>$0.00</td>
<td>$25.66</td>
</tr>
<tr>
<td>spraying PE</td>
<td>$32</td>
<td>$32</td>
<td>$32</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>spraying Post with highrise with WSK assumption we had a dual tank</td>
<td>$0</td>
<td>$0</td>
<td>$42</td>
<td>$42</td>
<td>$42</td>
</tr>
<tr>
<td>spraying Post with high rise with shield assumption dual tank</td>
<td>$0</td>
<td>$32</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>total cost chemical + application</td>
<td>$103.94</td>
<td>$119.17</td>
<td>$120.20</td>
<td>$68.28</td>
<td>$91.82</td>
</tr>
</tbody>
</table>

Note: Table 11 in Annexe 1 illustrates the quantities of herbicides used and the number and type of spraying applications.

Even if the spraying strategies were disturbed by the grower’s broadcast application, trial outcomes were similar to last year trial. Strategies T1, T2 and T3 were relatively effective for the first 2 months but were more costly. Strategies using Weedseeker only were more risky but cheap and effective.

We are planning to harvest this trial during 2013 crush (expected harvest date in November) to check for yield difference and marginal return between strategies and confirm that using 02 nozzles in the Weedseeker application did not impede on yield due to glyphosate drift.

6.2.3 Burdekin trial 2012 plant cane

The trial was implemented on Denis Pozzebon’s farm at Waterview, Burdekin. The cane was a fourth ratoon of the variety Q183A. The site was also used by Rob Bramley (CSIRO) to take NDVI, EC and EM measurements. He generated the maps in 2010 and 2011 (figure 20 in Annexe 1).

The trial design was a RCB with paired control, 4 treatments and 4 repetitions. Each plot was 2 inter row wide and 15 m long. Row spacing was 1.6m (Annexe 1, figure 21).

The four treatments tested can be related to different classes of the ABCD Reef Protection framework adapted for the Burdekin growing region:
- Treatment 1: Class C - broadcast herbicide mix (atrazine + paraquat + 2,4-D) using Irvin legs. (2 applications may be necessary)
- **Treatment 2**: Class B – Shield sprayer with glyphosate inter-row + selective knockdown under the row
- **Treatment 3**: Class A - banded pre-emergence just after harvest then WSS with glyphosate
- **Treatment 4**: Class A - WWS with glyphosate+ selective knockdown under the row when needed

The detailed strategies are reported in Annexe 1, table 12.

At the time of the first knockdown application (28/11/12), the cane was widely tilling in the inter row. As a result the Weedseeker shield sprayer and the inter row tractor were too wide and the edges of the cane stools were run over and cane material was being dragged under the shield. It was decided not to spray with glyphosate because cane damage would have been unacceptable. Krismat was selected as a replacement product because it only has a mild temporary phytotoxic effect on cane and was adequate to control the main weeds in the inter-row (bellvine and nutgrass). The cane was short and bushy and not much weed pressure was affecting the row so the side nozzles (second tank) were not used (Table 6-6).

In January the second Weedseeker treatment was due, but the grower feared potential damage in the cane paddock due to driving the inter row tractor after out of hand stage. He decided to use his high rise to spray all plots with Amicide and Starane to control the vines. Like in Mackay trial 2012, the second knockdown spray of the protocol was not applied.

Spraying equipment used for each application and the status of the crop at time of spraying are detailed in Annexe 1, table 13. The Weedseeker sensitivity was calibrated on 2. The weather was recorded at time of spraying using a Windmate (Annexe 1, table 14).

<table>
<thead>
<tr>
<th>Date</th>
<th>Treatment</th>
<th>Product</th>
<th>Rate / ha</th>
<th>Water / ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>31/10/12</td>
<td>T3 banded</td>
<td>Soccer</td>
<td>2 kg</td>
<td>300</td>
</tr>
<tr>
<td>27/11/2012</td>
<td>T1 Irvin leg</td>
<td>Gramoxone</td>
<td>1.2L</td>
<td>328</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amicide 625</td>
<td>1L</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Atradenex</td>
<td>2.2kg</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Activator</td>
<td>0.1%</td>
<td></td>
</tr>
<tr>
<td>28/11/2012</td>
<td>T2,T3,T4 in main tank</td>
<td>Round up attack</td>
<td>3L</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>T2,T3,T4 in second tank</td>
<td>Amicide 700</td>
<td>1.6L</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amicide 625</td>
<td>0.8L</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Starane Advance</td>
<td>0.78L</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Uptake oil</td>
<td>0.5%</td>
<td></td>
</tr>
<tr>
<td>28/11/12</td>
<td>T2,T3,T4 in main tank</td>
<td>Krismat</td>
<td>2kg</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Activator</td>
<td>0.25%</td>
<td></td>
</tr>
<tr>
<td>January 13</td>
<td>All plots done by grower</td>
<td>Amicide 625</td>
<td>0.8L</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Starane Advanced</td>
<td>0.78L</td>
<td></td>
</tr>
</tbody>
</table>

**Weed coverage in untreated plots**

The weed coverage reached 100% in the untreated plot within two months after harvest (Figure 6-11). Bellvines (*Ipomoea plebeia*) represented 60% of the weed population. Summer grass (*Digitaria ciliaris*) and nutgrass (*Cyperus rotundus*) were the other two main weed species.
Efficacy of herbicide strategies

All strategies were similar in controlling the weeds once the knockdown was applied (Figure 6-12). The interaction Treatment * Date was not significant $P = 0.206$ when the analysis was done on all treatments for the last 2 dates and $P$ Treatment was also not significant $P = 0.359$. Applying banded pre-emergence in T3 strategy resulted in an expected 35% weed control (assessment done in the row + inter row). Once applied the strategies including the Weedseeker were as effective as other strategies.

Similar efficacy results were recorded against the vines (Annexe 1, figure 22). Again there was no significant differences between strategies for the last two assessment dates (interaction Treatment * Date $P = 0.875$ and $P$ Treatment $P = 0.238$). It seems that the strategy T1 using Irvin leg was a bit more effective because of a wider control at the base of the row.
Strategies T4 using the Weedseeker was less efficient to control summer grass than T2 that used blanket sprayed (Figure 6-13). The interaction Treatment * Date was not significant $P = 0.913$ when the analysis was done on all treatments for the last 2 dates but $P$ Treatment was significant $P = 0.024$. Summer grass was small (3-4 leaf stage, Figure 6-14) and not detected by the sensors at time of spraying. T1 strategy relying on blanket spray with Irvin legs was as effective as T2 against summer grass.

Figure 6-13 Efficacy of herbicide strategies on summer grass, agronomy trial Burdekin 2012

Figure 6-14 T4 plot before Weedseeker treatment: Summer grass at 3 leaf stage encircled in red
The knockdown strategies using Weedseeker were not quite as effective as knockdown strategies blanket sprayed because some young grasses were missed.

Economic study of the strategies
As in the Mackay trial, 02 nozzles were used. The driving speed was 8 km/h and the pressure was set at 3 bars to achieve a water rate of 180L/ha (high rate suitable to achieve a good spraying coverage when using Krismat).

The economic results are based on one herbicide application only for T1, T2 and T4 but theoretically a second post-emergent treatment should have been done (Table 6-7). T1 strategy which was the common herbicide management practice using Irvin legs was the cheapest option. If glyphosate +2,4-D had been used as planned instead of Krismat, the cost per ha (herbicide + application) for both T2 and T4 would have been $65 which would have resulted in a similar cost to T1. T3 involving the banded pre-emergent followed by the Weedseekeker was expectedly the most expensive option and did not significantly improve the weed management in the trial. T4 strategy was slightly cheaper than T2 proving again that the chemical savings compensated the access to the Weedseeker technology.

Table 6-7 Cost of herbicide application for each strategy, Burdekin agronomy trial 2012

<table>
<thead>
<tr>
<th>Table cost/ha of each strategy</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gramoxone</td>
<td>$7.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activator</td>
<td>$3.99</td>
<td>$4.25</td>
<td>$3.02</td>
<td>$3.27</td>
</tr>
<tr>
<td>Krismat</td>
<td></td>
<td>$62.38</td>
<td>$44.29</td>
<td>$48.04</td>
</tr>
<tr>
<td>Amicide 625</td>
<td></td>
<td>$6.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atradex</td>
<td></td>
<td>$17.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soccer</td>
<td></td>
<td></td>
<td>$21.51</td>
<td></td>
</tr>
<tr>
<td>spraying PE</td>
<td>$0</td>
<td>$0</td>
<td>$32</td>
<td>$0</td>
</tr>
<tr>
<td>spraying Post with highrise with WSK assumption we had a dual tank</td>
<td>$0</td>
<td>$0</td>
<td>$42</td>
<td>$42</td>
</tr>
<tr>
<td>spraying Post with high rise with shield assumption dual tank</td>
<td>$0</td>
<td>$32</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>spraying Post with high rise without shield</td>
<td>$32</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>total cost chemical + application</td>
<td><strong>$67.34</strong></td>
<td><strong>$98.63</strong></td>
<td><strong>$142.82</strong></td>
<td><strong>$93.31</strong></td>
</tr>
</tbody>
</table>

Note: Table 15 in Annexe 1 illustrates the quantities of herbicides used and the number and type of spraying applications.

Traditional class C strategy was efficient and cost effective but could be replaced by strategies using Wedseekeker at the condition that the shield sprayer could fit in the inter row and spray glyphosate.

We are planning to harvest this trial during 2013 crush (expected harvest date in October) to check for yield difference between strategies and confirm that using 02 nozzles in the Weedseekeker application did not impede on yield due to glyphosate drift.

6.2.4 Bundaberg trial 2012 plant cane
It was decided to implement a trial in plant cane in Bundaberg to replace the failed plant cane in Mackay. The trial design and protocol were described at the beginning of this chapter. Unfortunately the late wet season prevented Fairymead’s farm manager to plant in February-March. He started to plant late April and believed the cane would not be ready for the Weedseekeker to spray until the end of winter after hill up (September to November period). With the final milestone report due in August we decided to cancel this trial.
6.3. Experience of two growers using the Weedseeker technology

6.3.1 Rodney Lamb, Mackay

In 2011 Rod Lamb used the Weedseeker system under 5 GC shields mounted on a highrise.

As previously indicated, the GC shields were not easy to adapt to the Weedseeker technology due to their low profile. Made of heavy solid steel their weight impeded with the operation of the spraying hoods (too much weight on the sides) and made the sprayer not suitable for wet areas. As a result, the grower didn’t get many opportunities to use his Weedseeker shield high rise sprayer. He used it on 20 ha that had a light weed coverage made of different grass species: Paspalum sp., awnless barnyard grass, couch grass, Johnson grass and nutgrass in big patches. He also used it on 6 ha where a few big clumps of Paspalum sp. were the only weed issue.

The 6 ha with Paspalum sp. were ideal scenario for the Weedseeker to achieve economical saving (Table 6-8). The big clumps of paspalum allowed the growers to set the sensitivity on 6 and avoid any misfires. The scenario with mixed grass that were concentrated in zones and not scattered was also favourable to achieve economical savings.

Rod Lamb used 8% to 16% of the herbicide brew he would have used if he was not equipped with the Weedseeker. He was totally satisfied by the savings obtained but admitted he still needed to increase the rate of chemical to 4 L/ha because he didn’t achieve a good kill.

We presented to him the outcomes of our trial and he believed such paddocks with scattered small weeds were not representative of an entire farm. It didn’t matter to him if there was no saving at a paddock scale as long as there were savings at the farm scale.

<table>
<thead>
<tr>
<th>Weed coverage</th>
<th>Mixed grasses on 20 ha</th>
<th>Only Paspalum clumps on 6 ha</th>
<th>Theoretical full inter-row blanket spray for 1 ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>volume of brew used</td>
<td>507</td>
<td>78</td>
<td>92</td>
</tr>
<tr>
<td>surface covered</td>
<td>19.97</td>
<td>5.80</td>
<td>0.57</td>
</tr>
<tr>
<td>volume / ha driven</td>
<td>25</td>
<td>13</td>
<td>160</td>
</tr>
</tbody>
</table>

The volume of brew/ ha driven was 160L/ha, Roundup powermax at 3L / sprayed ha. Values in the table take into account that only inter rows were sprayed.

6.3.2 Joe Linton, Burdekin

In 2011, Joe Linton used the Weedseeker sensors mounted on Redball hoods (5 inter row high rise sprayer). Joe Linton reported on the outcomes of the technology in the “2013 Grower group innovation projects trial results” booklet. His conclusions were similar to ours in terms of efficacy to detect weeds and achieve economic benefit; however he had design issues with his hoods that haven’t been resolved yet. Despite many adjustments, cane leaves were pushed under the shields triggering the sensors and getting sprayed. In 2011, the grower sprayed 1 ha of ratoons (1 m high) with Roundup at 1 L/ha but the damage on cane was too severe so he used Gramoxone at 1.2 L/ha to spray another 5 ha. Like us, he used 02 even nozzles at 2 bars but unlike us they were 80 degrees (ours are 65). He drove at 10 km/h and his water rate was around 90 L/ sprayed ha.

He believed the weed coverage in the sprayed blocks was up to 25 % and consisted of various weeds, summer grass and the odd vine. The device fired on 60% of the area (including the area triggered by cane leaves).
Conclusions: in our trials, knockdown strategies were the best economic and environmental options but they can be risky if the access to the block is limited in the wet season. Knockdown strategies using the Weedseeker technology tended to produce a higher benefit in t/ha provided the shield could fit in the inter row without intercepting cane leaves. At a farm scale where the main weed issues were big isolated clumps of weeds, a grower equipped with the Weedseeker highrise sprayer was entirely satisfied by the resulting savings.
7. Benefits of precision weed spraying technology

7.1. Runoff studies with rainfall simulator

The aim of the rainfall simulation studies was to provide a rapid assessment of the benefits of precision weed spraying (spot spray) in reducing runoff of herbicides. Reduced runoff of herbicides can be delivered in a number of ways:

a) reducing spray coverage by using spot spray – herbicide runoff is expected to be reduced in proportion to the proportion of the area sprayed,

b) enabling weed control using knockdown herbicides instead of with residuals – some knockdown herbicides have chemical properties (e.g. greater sorption) which make them less prone to runoff than residual herbicides and have less toxicity in aquatic environments.

c) enabling more use of banded residual herbicides on the row with precision

Each of these potential benefits needed to be evaluated in the rainfall simulator studies. The target comparisons were:

1. Spot spray 0, 20, 50, 70 100 % coverage – knockdowns, or as a surrogate for banding of residuals.
2. Knockdown vs “old” residuals  Reef – want reduced PSii residuals
3. “Old” vs “emerging” residuals - emerging have less uncertain fate & ecotoxicology

The rainfall simulator was provided by NCEA and was fully serviced and calibrated (Figure 7-1). The runoff study measured how much herbicides are moved in runoff from a standard rain storm applied at 80 mm/hr for 40 minutes, 1-2 days after herbicide application. A preschedule for the runoff study was developed (attached) and outlines the sampling and monitoring requirements.

Figure 7-1 Rainfall simulator undertaking runoff study
Original plans included the deployment of automatic sampling equipment to undertake the runoff study. This approach was not pursued because the automatic sampling equipment required a local presence at field sites for maintenance and collection of samples, whereas changes in project personnel led to personnel all being located in Mackay.

The run off trials were implemented by BSES Ltd, with the rainfall simulator operated by NCEA (led by Jack McHugh). Collaboration with Mark Silburn and Samuel Ponce (DERM) and Stephen Lewis (JCU), who are involved with Reef Rescue Initiatives, was highly effective for maintaining consistency in water quality monitoring protocols.

### 7.2. Trials

A total of five trials were undertaken, three trials with trash blanket and two with bare soil. The bare sites generated sediment. These runoff samples were filtered and tested for dissolved and sediment bound herbicides; these data were used to calculate sediment-water partitioning coefficients.

A run off trial was conducted in Mackay in November 2011 and Bundaberg in December 2011. Three run off trials were carried out between August and September 2012: one in ratoon cane on trash blanket in Bundaberg, one in ratoon on bare soil in the Burdekin and another in plant cane on bare soil in Mackay. The trials were spot sprayed with knock-down treatments that are likely to be associated with WeedSeeker (glyphosate, 2,4-D, fluroxypyr) and also included most of the pre-emergence products used to control the specific weed issues of each district.

Bromide (a mobile salt tracer used as a control), various herbicides which differed somewhat across sites (Table 7-1) was applied. These included knockdowns (glyphosate and 2,4-D amine and in 2012, fluroxypyr), “older” residuals (diuron, hexazinone, atrazine, ametryn, metolachlor) and “emerging” residuals (imazapic, isoxaflutole, metribuzin, pendimethalin). Herbicides were applied as blanket (100% coverage), or 20%, 50% and 70% coverage, or none.

<table>
<thead>
<tr>
<th>Site &amp; year</th>
<th>Cover</th>
<th>Soil</th>
<th>Knockdowns</th>
<th>Residuals 1</th>
<th>Residuals 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mackay 2011 N of Kuttabul</td>
<td>Trash &amp; weeds</td>
<td>Kurosol/Sodosol, fine sandy loam</td>
<td>Glyphosate, 2,4 D</td>
<td>Diuron, hexazinone, metolachlor</td>
<td>Nil</td>
</tr>
<tr>
<td>Bundaberg 2011</td>
<td>Trash &amp; weeds</td>
<td>Black Dermosol</td>
<td>Glyphosate, 2,4 D</td>
<td>Diuron, hexazinone, metolachlor</td>
<td>Nil</td>
</tr>
<tr>
<td>Bundaberg 2012</td>
<td>Trash</td>
<td>Brown Dermosol, clay loam, fine sandy</td>
<td>Glyphosate, 2,4 D, Fluroxypyr</td>
<td>Diuron, Hexazinone, Isonaflutole, Metribuzin</td>
<td>Diuron, Hexazinone, Metribuzin, Imazapic, Atrazine</td>
</tr>
<tr>
<td>Burdekin 2012 7 km SW of Brandon</td>
<td>Bare</td>
<td>TBD</td>
<td>Glyphosate, 2,4 D, Fluroxypyr</td>
<td>atrazine, ametryn, diuron, isoxaflutole, metribuzin</td>
<td>atrazine, ametryn, metolachlor, imazapic, pendimethalin</td>
</tr>
<tr>
<td>Mackay 2012 S of Walkerston</td>
<td>Bare</td>
<td>Soloth/solodic, sandy clay loam</td>
<td>Glyphosate, 2,4 D, Fluroxypyr</td>
<td>Atrazine, Ametryn, Diuron, Isonaflutole, Metribuzin</td>
<td>Atrazine, Ametryn, Metolachlor, Imazapic, Pendimethalin</td>
</tr>
</tbody>
</table>
Two to four plots of each treatment had rainfall applied using a rainfall simulator (3 x 2 m), with measurement of:

- Runoff rate and sediment concentration (almost nil with trash) through time
- Runoff was sampled 7-14 times through time for chemical analysis as a flow weighted composite
- Soil and trash samples were taken before the rain and analysed for the chemicals

The Bundaberg 2011 trial was sprayed and then rained out, but results were obtained by taking runoff samples from natural rainfall on the sprayed plots.

Run off and trash samples were analysed by the commercial laboratory ACS, and data was analysed and compiled by DNRM. The lab results confirmed that ACS was able to detect glyphosate while also qualifying the testing procedure for the run off study.

### 7.3. Results and discussion

Runoff concentrations of all herbicides were directly proportional to the percent spray coverage and the total load of herbicide on the soil and trash – confirming propositions a and c, described earlier. All concentrations refer to event mean concentrations for the entire runoff event and were normalised for the application rate of each herbicide.

The older residuals mostly tended to runoff about the same, as did emerging residuals, with the exception of pendimethalin which ran off much less from bare soil (not tested on trash). Imazapic consistently ran off more than all other compounds, per unit applied, from bare soil (Mackay 2012, Burdekin 2012) and trash (Bundaberg 2012). However, it also had a low application rate and lower runoff concentrations in absolute terms, and has the highest (worst) detection limit and therefore maybe less accurate.

Knockdowns ran off less than or equal to residuals. Glyphosate and fluroxypyr ran off reasonably consistently less than older residuals. 2,4-D often ran off the same as the residuals, but ran off much less where there was trash at Mackay 2011 but not in Bundaberg 2012. This is probably a function of the sorption properties of the compounds, possible absorption into plants where weeds were present and the infiltration characteristics of the site. This informs proposition b above, though more analysis is needed.

Bare soil sites. Most herbicides were transported dominantly in the water phase rather than sediment. However, pendimethalin was mainly transported in sediment. Concentrations of diuron and glyphosate in sediment were up to one third of those in water.

Imazapic had a higher sediment-water partitioning coefficient than all other residual herbicides, except for pendimethalin. This probably little published data for runoff fate and partitioning coefficients for the emerging residuals.
8. **Outputs**  
(Including knowledge, skills, processes, practices, products and technology developed)

Outputs generated from the project are listed below.

**Knowledge**  
Guidelines for using precision weed spraying technologies in sugar  
Performance, limitations and cost benefits of precision weed spraying technology in sugar  
Environmental benefits of spot spraying from runoff study

**Skills**  
Improved weed management strategies based on precision weed spraying technologies  
Industry expertise to assist adoption of precision agriculture relating to weed management

**Practices**  
Weed management (and herbicide application) that targets weeds as opposed to the whole field

**Processes**  
Application of precision agriculture to weed management

**Products**  
Demonstration equipment for spraying weeds based on the detection of weeds from a soil background

**Technology**  
A spray shield and drawings for targeting the sugarcane inter row
9. Intellectual Property and Confidentiality

The project has developed additional IP relating to the shield design of the Weedseeker demonstration unit. The shield design will be formalized through engineering drawings and will be made freely available (in the public domain) to industry via an industry guide for precision weed spraying technologies and strategies. The shield design will also be freely available for machinery manufacturers (Hodge Engineering; Irvin Farm) or fabricators (steel, aluminum, poly).
10. **Environmental and Social Impacts**

The adoption of the Weedseeker technology relying on spot spraying knockdown herbicides instead of blanket spraying results in a reduction of the amount of herbicide sprayed. This reduction in herbicides have a beneficial environmental impact as shown in the runoff study: runoff concentrations of all herbicides were directly proportional to the percent spray coverage and the total load of herbicide on the soil and trash.

The results from the rainfall simulator runoff study confirm the potential benefit of reduced herbicide runoff from precision weed spraying (where the sprayed area is reduced). In instances where weed coverage is greater than 30% the sprayed area however may be as great as 90%. Precision spot spraying strategies are also likely to result in less residual herbicide usage which has greater runoff potential than knockdown herbicides.

The adoption of weed management programs that include the Weedseeker technology also implies a significant reduction in pre-emergent herbicides potentially more susceptible to runoff and harmful to the GBR. The findings of the runoff study prove that glyphosate and fluroxypyr ran off reasonably consistently less than older residuals.

The adoption of the Weedseeker shield spraying technology offers the flexibility to use glyphosate in crop in many situations, limiting the potential use of other herbicides more harmful to the spraying operator (eg. paraquat).
11. Expected Outcomes

The research has successfully qualified economic and environmental benefits associated with weed spot spraying. The green from brown evaluations established optimum weed control strategies using Weedseeker in sugar cane. The evaluations identified that the Weedseeker performance varies from good to poor depending on soil and stubble conditions, and that herbicide saving is not linearly related to weed coverage. An overall weed coverage of 30% for a scattered weed distribution led to at least 90% of the area being sprayed. In suitable conditions, superior weed control was achieved using Weedseeker which has the direct benefit of yield improvements due to reduced competition of weeds.

The runoff study established that runoff concentrations of herbicides were directly proportional to herbicide to the percent spray coverage. Hence, reduced herbicide application by weed spot spraying has the benefit of reduced risk of herbicide entering the environment and promoting an innovative, clean and green image to the wider community.

Social benefits of better understanding of fields and reduced handling of herbicides are expected to be achieved with further dissemination of project outputs, e.g. when the Weedseeker guidelines are released and the green from green sprayer is commercialised.
12. Future Research Needs

Further research requirement arising from the project are listed below. In particular, refinement and additional trial work need to be carried out from the green from green system in the development steps before commercialisation.

Weedseeker
A weed precision spraying guideline for growers highlighting the pros and cons of the Weedseeker technology for the sugar industry will be available by the end of 2013. This guideline is a thorough evaluation of WeedSeeker for sugar cane and no future work is envisaged as being necessary for further evaluations of the technology in the sugar industry.
13. Recommendations

Dissemination
Workshops that build on the Weedseeker evaluation results and guidelines should be conducted to disseminate project results to growers, spray contractors, farming collaborators and extension personnel in the sugar industry.
14. List of Publications

Publications arising from the project are listed below.

Reviewed journal papers
McCarthy, C.L., Rees, S.J. and Baillie, C.P. (2013) ‘Preliminary evaluation of shape and
colour image sensing for automated weed identification in sugarcane’. International Sugar
Journal vol. 15, pp. 14-18. This paper was presented at 2012 Australian Society of Sugar
Cane Technologists annual conference.
‘Development and evaluation of a prototype precision spot spray system using image
analysis to target Guinea Grass in sugarcane’. Australian Journal of Multi-Disciplinary
Engineering vol. 8(2), pp. 97-106.

Conference presentations
Baillie, C and Jensen, T (2013), ‘NCEA research into Precision Agriculture in the Australian
Fillols, E et al. (2012) ‘Adaptation and evaluation of the precision weed spraying technology
Weedseeker® in cane’, International Society of Sugar Cane Technologists, Townsville,
September 2012.
colour image sensing for automated weed identification in sugarcane’. 34th Annual
Conference of the Australian Society for Sugar Cane Technologists, Cairns, 9-14 May.
McCarthy, C et al. (2012) ‘Precision weed sensing technology’, Precision Ag Symposium,
Mildura, September 2012.
Rees, S et al. (2012) ‘Depth and colour image sensing for discrimination of sugarcane and
wild sorghum: first results’, International Society of Sugar Cane Technologists,
Townsville, September 2012.
sensing for interstate sites using broadband internet services’, In: Digital Rural Futures
Conference, 26-28 June 2013, Armidale, Australia.

Industry articles
The project has received coverage in magazine articles for various industries, as listed below.
• Precision Ag News ‘Automated weed id under the spotlight’ (July 2012)
• Australian Grain ‘High-tech sensors targets weeds for zapping’ (August 2012)
• Farmer’s Weekly South Africa ‘Weeding out the bad guys’ (December 2012)
• The Land ‘New weed tech just years away’ (7 March 2013, p.40)
• The Land ‘Research makes spraying a bit sweeter’ (2 May 2013, p.51).
• BSES media release ‘Managing sugarcane weeds cost effectively with precision-
agriculture practices’ (April 2013)
• BSES Bulletin (May 2013)
• A weed precision spraying guideline for growers highlighting the pros and cons of the technology for the sugarcane industry will be available by the end of 2013.

Industry events
• SRDC expos in April 2010, 2011 and 2013
• Canetrend 2013 (Bundaberg field day) – demonstration of the Weedseeker shield sprayer
unit and poster presentation (16 June 2013)
Media interviews
Interviews about the weed spot spraying research have been given for various local rural radio stations in late 2012 and for a regional TV news story in Mackay in April 2013.

Award applications
- Cheryl McCarthy was nominated by USQ for a Young Tall Poppy Science Award in April 2013. The SRDC weed spot spraying research featured prominently in the award application.
- We submitted an entry for the Shell Australian Innovation Challenge in 2012 about our weeds research. We were shortlisted but did not make finalists.