FINAL REPORT 2014/050

Developing an alternative herbicide management strategy to replace PSII herbicides in the Wet Tropics area

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ABSTRACT

Alternative weed management strategies to better control weeds in the Wet tropics without relying on diuron are presented in this report.

Seven field trials comparing the efficacy of alternative pre-emergent herbicides to diuron applied to trash blanketed ratoons showed that Bobcat® i-MAXX efficacy was similar to Barrage at 4kg ha^{-1}. Balance®, Flame® and Barrage at 900 g ha^{-1} often required a mixing partner to enlarge their efficacy spectrum to control the different weed species present in the block and to extend their efficacy duration.

Two field trials comparing the efficacy of pre-emergent herbicides in plant cane showed that most cost effective control strategies included PSII herbicides. The new non PSII herbicide Valor® was effective when only a short period of control was required. The mix isoxaflutole and imazapic was very cost effective ($28 / ha) but could result in phytotoxicity on cane if used in an inappropriate soil type and a rainfall event moved the herbicides to the cane root zone.

Four field trials comparing alternative strategies to spot spray Barrage to control stools of Guinea grass showed that none of the direct spray techniques and herbicide strategies achieved an acceptable control of Guinea grass stools in the cane row. A pot trial showed that a mix of Balance® at 75 g $100L^{-1}$ and Daconate® at 1.5L $100L^{-1}$ was the most effective herbicidal option to use as a spot spray, however it is not endorsed by the products' labels.

Four runoff field trials comparing the runoff losses of 16 herbicides registered in cane using rainfall simulations showed that runoff losses of pre-emergent herbicides were largely driven by their application rate, with the exception of pendimethalin and flumioxazin which were less prone to runoff.

Four cover crop field trials showed that cowpea alone or cowpea mixed with lablab and millet were the best weed suppressants, as long as the cover crops were sown at twice the standard sowing rate and before any weeds germinated. These cover crops performed in no-till, zonal till and full tillage systems.

This report also identified a suitable methodology and a service provider for routine screening of new varieties for herbicide susceptibility. Since 2016, a two-step screening program including a pot trial pre-screening in year one and a field trial in year two to determine any potential cane yield reduction is being carried out by SRA as part of the variety release program.

EXECUTIVE SUMMARY

Pre-emergent herbicides based on diuron (a PSII herbicide) are convenient and cost effective against weeds; however they are closely monitored by the Australian and Queensland Governments which aimed to reduce pesticide pollutant loads by 60% within the Great Barrier Reef (GBR) by 2018. In 2014, alternative strategies were urgently needed to maintain control of the weed population, especially in the Wet Tropics that contributed 61% of the GBR's total annual PSII pollutant load. This project focused on developing cost effective weed management strategies as alternatives to diuron and PSII herbicides for their wide range of applications.

A series of replicated trials were undertaken to assess the efficacy of: alternative pre-emergent herbicide in plant cane and in green cane trash blanketed ratoons; directed spray and spot spray herbicide strategies to control established Guinea grass; and mixed cover crop species to control weeds in fallow. The impact of the alternative pre-emergent strategies to diuron on runoff quality were assessed using replicated rainfall simulations. Fifteen field demonstrations and grower field days were carried out throughout the lifetime of the project to communicate the project findings.

The results from the trials on alternative pre-emergent herbicides in plant cane showed that all tested herbicide treatments were equally effective against the weeds in the trials for the first 30 days. When longer control was required, imazapic mixed with metribuzin or amicarbazone (Amitron®- registration pending); or metribuzin mixed with ametryn or metolachlor were the best options, especially on Guinea grass seedlings. When convolvulus vines were present, isoxaflutole alone was less effective than the other tested treatments. From an environmental perspective, all treatments that achieved a very good weed control had a lower impact than diuron on the water quality, with the exception of the treatment with ametryn that presented a higher environmental risk compared to diuron.

The results from the trials on alternative pre-emergent herbicides in trash blanketed ratoons showed that imazapic + hexazinone (Bobcat® i-MAXX) was the most efficient broad spectrum herbicide with efficacy similar to diuron + hexazinone (Barrage) at 4 kg ha^{-1} (high rate now banned in the Wet Tropics). The upcoming active ingredient amicarbazone (Amitron®) was particularly effective against broadleaves and vines but its efficacy against grasses was limited. Similarly, imazapic, isoxaflutole or Barrage at 0.9 kg ha^{-1} used alone were not controlling enough weed species and would require a mixing partner to enlarge their efficacy spectrum when required by the weed species present in the block. From an environmental perspective, all treatments had a lower impact than diuron high rate on the water quality. In our trials, Bobcat® i-MAXX was at least six times less toxic in runoff water than Barrage high rate. Amicarbazone, imazapic and isoxaflutole were at least twelve times less toxic than Barrage high rate.

The results from the runoff trials showed that most pre-emergent herbicides runoff losses were largely driven by their application rate, with the exception of pendimethalin and flumioxazin. The herbicide loss coming from trash blanketed plots was similar to the bare soil plots, suggesting no impact of trash blanket on herbicide runoff in ratoons. To reduce the impact of pre-emergent herbicides on runoff water quality, herbicides effective at low application rate should be favoured when possible.

The results from the trials on directed spray and spot spray herbicide strategies to control established Guinea grass showed that none of the tested directed spray strategies resulted in acceptable control in the cane row. The herbicide mix (isoxaflutole + MSMA) sprayed on the grasses in the cane row was the most effective grass treatment; however it only generated strong phytotoxicity symptoms and growth reduction on the grasses without achieving an acceptable grass control. On the other hand, it resulted in strong phytotoxicity on cane and reduced cane yield. Asulam also delayed grass growth without achieving an acceptable grass control, but it was a safer

option on cane and resulted in the highest cane yield. While all of the application methods tested (shield, QDAF dual spray bar, octopus leg) failed to control the grasses in the row, they were effective to control the grasses in the interrow. Spot spraying trials showed that isoxaflutole mixed with MSMA was the most effective herbicidal strategy to control Guinea grass; Bobcat® i-MAXX was only efficient if sprayed at high rate (2 L $100L^{-1}$) and Barrage was only effective if sprayed at twice the recommended rate (2 L $100L^{-1}$) and to the point of runoff. Product labels do not currently endorse any of these effective spot spraying strategies.

The results from the trials on mixed-species cover crops showed that cowpea alone or mixed with lablab and millet were the best weed control options and seemed adequate for no-till, zonal till and full tillage systems, as long as the cover crops were sown before weeds germinated. In wet conditions, the full tillage system was more challenging for mixes with Rongai lablab species, whereas Ebony cowpea was fully adapted to extreme wet conditions. Japanese millet performed well in all farming systems: the early germinating millet outcompeted the weeds in the early stages after sowing, while the legumes emerged and competed with the weeds a few weeks later.

The range of alternative strategies to diuron that are presented in this report have been widely communicated to the industry through grower field days, project update meetings, SRA research forums, conferences, CaneConnection, newsletters and media releases and the information has been relayed to the SRA adoption group and the productivity services to contribute to practice changes.

Limited information on the response of new sugarcane varieties to herbicides was available in 2014, and information being collected was not done using a standard protocol or across all varieties. In this project, a methodology and a service provider were identified for routine screening of new cane varieties for herbicide susceptibility. A two-step screening program including a pot trial pre-screening in year one and a field trial in year two to determine any potential cane yield reduction has been validated and this activity has been carried out by SRA since 2016 as part of the variety release program.

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1 BACKGROUND

Yield loss from weed competition is estimated to cost the Australian sugar industry $70 M annually. Herbicides cost the industry an additional $14 M annually and can also lead to phytotoxic yield reduction (McMahon *et al*. in Manual of Cane growing, 2000). Limited information on the response of new sugarcane varieties to herbicides was available in 2014, although information being collected was not done using a standard protocol or across all varieties. Informing growers about variety susceptibility is essential to optimise their herbicide strategy for cost effective weed control and better cane yield with less concern about short-term phytotoxicity effect on cane appearance.

Grass species are the most challenging to manage because they belong to the same family as sugarcane (*Poaceae*). Most registered herbicide options may also affect the cane crop. Pre-emergent herbicides based on diuron (a photosystem II inhibitor herbicide, also referred as PSII herbicide) are convenient and cost effective against grasses; however they are closely monitored by the Australian and Queensland Governments which aimed to reduce pesticide pollutant loads by 60% within the Great Barrier Reef (GBR) by 2018.

In 2014, alternative strategies were urgently needed to maintain control of the grass population, especially in the Wet Tropics that contributed 61% of the GBR's total annual PSII pollutant load. There, 107,000 hectares (80% of the area) were still managed using class C or D weed management practices (Reef Rescue Water Quality Grants and Partnerships Priorities 2013-14 to 2015-16).

Following the Australian Pesticides and Veterinary Medicines Authority (APVMA) review of diuron, product labels were issued limiting the rate in the Wet Tropics to 450 g a.i. ha^{-1}, causing growers to look for alternatives.

Trials in Central Queensland investigated the efficacy of some registered pre-emergent herbicides as alternatives to diuron (imazapic, isoxaflutole, metribuzin); however the results could not be easily extrapolated to Wet Tropics conditions (Fillols and Callow, 2010, 2011; Fillols 2012). To date, water quality researchers are still confident most of these alternative herbicides have lower toxicity or are used at such a low rate that their impact on the GBR would be lower than diuron (Lewis *et al*., 2013). Back in 2014, very limited runoff data were available for the Wet Tropics and reliable efficacy and runoff data from weed management programs using alternative herbicides were necessary to underpin field demonstrations carried out by the QLD Government's Department of Agriculture and Fisheries (QDAF) and productivity services.

Alternative weed management strategies proven effective in other countries were identified for their potential to further reduce the reliance on diuron or other residual pesticides in Australia, e.g.:

- In Reunion Island, Jack bean inter-cropped in plant cane was particularly efficient to control weeds (Chabalier *et al*. 2013). In fallow, velvet beans, lablab, cowpea and Jack beans were highly competitive with other weeds (Marion, personal communication).
- In Cuba, incorporating 10-20 t ha^{-1} of multi-species legume crop residue was an effective weed control (Arevalo and Bertoncini, 2005).
- In Brazil, a bare fallow in a zero tillage system and a velvet bean fallow crop in a conventional tillage system suppressed the weed population (Soares *et al*., 2012).

In Australia, the impact of farming systems on soil properties was intensively studied in the Yield Decline Joint Venture (Garside *et al*., 2006), but with no reporting on the impact on weeds.

2 PROJECT OBJECTIVES

2.1 Identify alternatives to PSII herbicides for the Wet Tropics (Part A)

Development of cost effective weed management strategies to better control weeds in the Wet Tropics without relying on Diuron and contributing to achieving the target of 60 % reduction in pesticide pollutant loads under the Reef Plan program

2.2 Identify a methodology and service provider for routine screening of new cane varieties for herbicide susceptibility (Part B)

Defining the susceptibility of new and promising commercial cane varieties to current and potential new herbicides and at the same time implementing a pathway for industry wide testing by developing a standard methodology to conduct annual phytotoxicity experiments on behalf of the whole industry

3 OUTPUTS, OUTCOMES AND IMPLICATIONS

3.1 Outputs

3.1.1 Outputs Part A: Alternatives to PSII herbicides

This project has identified a range of integrated management strategies that efficiently control troublesome grass weeds in North Queensland.

These strategies have been promoted through guidelines packaged in forms of SRA web pages, SRA videos, online fact sheets and inserts in the SRA Weed Manual. Media releases assisted in their advertising. Fifteen grower field days were organised throughout the life of the project at trial and demonstration sites to promote the findings to the industry (details on communication packages and field days are found in section 4. Industry communication and engagement). Project updates were regularly provided to the industry.

Research papers related to the project have already been published at the Australian Society of Sugar Cane Technology (ASSCT) conference, the Australasian Weed Conference (AWC) and the International Weed Science Society (IWSS). More research papers are going to be published in upcoming conferences and in scientific journals such as Environmental Pollution and Marine Pollution Bulletin.

3.1.2 Outputs Part B: Varietal susceptibility to herbicides (phytotoxicity screening)

The project has delivered a phytotoxicity screening program for the industry to carry out trials on a regular basis and has identified a service provider.

The project report was presented to SRA Board for discussion and selection of an appropriate screening program. The SRA Board agreed that SRA carries out the screening as part as its core activity from 2016.

Trial results are recorded in QCANESelect™ and communicated to the industry as fact sheets.

3.2 Outcomes and Implications

3.2.1 Outcomes and Implications Part A

This project identified a range of efficient weed management strategies for the Wet Tropics using alternative pre-emergent herbicides to diuron. Adoption of these strategies leads to:

- Yield improvement due to reduced weed competition
- Significant reduction of the grass seed bank
- Increase in the number of ratoons.

Ultimately fewer herbicides would be required with consequent reductions in:

- Input cost
- Phytotoxicity on cane
- Risk of herbicide entering the environment.

The project also identified strategies in fallow that would reduce the reliance on herbicide while reducing the weed seed bank. Adoption of these practices in fallow leads to:

- Reduction in the reliance on herbicides (and assist in managing potential withdrawal of specific herbicides)
- Improvement in cane yield (less weed competition plus nutritive value of legume crop)
- Promotion of a clean and green industry image to the wider community.

3.2.2 Outcomes and Implications Part B

The proposed programs to screen herbicides for phytotoxicity to susceptible cane varieties results in yield improvement by:

- Preventing damage to the cane crop
- Informing growers about herbicides safe on cane and efficient on weeds for optimised and timely weed management.

4 INDUSTRY COMMUNICATION AND ENGAGEMENT

4.1 Industry engagement during course of project

During the course of project, several grower field days were organised by Emilie Fillols and Phil Ross at the trial sites:

- Post –emergent trial, Mirriwinni, 11 December 2014 (25 growers attended, Figure 1)
- Post- emergent trial, Gordonvale, 12 December 2014 (20 growers attended)
- Pre and post-emergent trials, Mulgrave, 7 October 2015 (36 people attended including Bayer, growers, productivity services Mossman, Mulgrave, QDAF). Three related articles were published in e-newsletters and emailed to local growers:

  "*Wet Tropics Pre-emergent field walk*" (Mulgrave) e-Newsletter 15/10/2015

  "*Wet Tropics Post-emergent herbicide field walk*" (Mulgrave) e-Newsletter 15/10/2015

  "*Looking for new weed management systems*" (Mulgrave) e-Newsletter 15/10/2015

- Pre-emergent trial, Tully, 3 November 2015 (13 growers, 3 productivity service officers and 5 resellers attended). A related article was published in an e-newsletter and emailed to local growers:

  "*Tully growers compare herbicides*" (Tully) e-Newsletter 20/11/2015

- Post-emergent trial, Garradunga, 19 January 2016 (27 growers, 1 productivity service officer, 5 resellers and 2 other industry people attended). A related article was published in an e-newsletter and emailed to local growers:

  "*Looking for post-emergent control options for Guinea grass in ratoons*" (Innisfail) e-Newsletter 28/01/2016

- Pre-emergent trial, Mulgrave, 19 January 2016 (6 resellers attended)
- Cover crop trial, Port Douglas, 4 February 2016 (16 growers, 2 productivity service officers and another industry person attended) - A related article was published in an e-newsletter and emailed to local growers:

  "*Can cover crops replace herbicides in fallow?*" (Mossman) e-Newsletter 7/03/2016

- Cover crop trial, Mulgrave, 6 April 2016 (9 growers and 2 resellers attended) - A related article was published in an e-newsletter and emailed to local growers:

  "*Mulgrave growers inspect weed management trial with a difference*" (Mulgrave) e-Newsletter 3/05/2016

- Pre-emergent trial in plant cane, Port Douglas, 25 October 2016 (17 growers, 5 productivity service officers, 4 resellers and 4 other people attended). A related article was published in an e-newsletter and emailed to local growers:

  "*Mossman growers investigate herbicide options*" e-Newsletter 18/11/2016

- Pre and post-emergent demonstration, Garradunga, 8 November 2016 (21 growers, 2 productivity service officers, 4 resellers and 5 other people attended). An innovation theme was added to the field day with Marcus Bulstrode presenting and demonstrating the latest UAV technology. A related article was published in an e-newsletter and emailed to local growers:

  "*Innisfail and Babinda growers get to see herbicide and UAV demonstrations*" e-Newsletter 18/11/2016

- Pre-emergent trial in plant cane, Mirriwinni, 15 December 2016 (5 growers, 1 reseller and 2 other people attended)
- Post-emergent demonstration, Craiglie, 20 December 2016 (15 growers, 1 productivity service officer and 1 reseller attended)
- Post-emergent demonstration, Atherton, 20 December 2016 (12 growers, 1 productivity service officer and 1 reseller attended)
- Pre and post-emergent demonstration, Gordonvale, 8 February 2017 (13 growers, 3 productivity service officers and 1 reseller attended). The SRA dual tank shield sprayer and the QDAF dual spray bar were on display at this event
- Cover crop demonstration, Gordonvale, 6 April 2017 (8 growers attended).

Project updates were presented:

- at the 15th SRA/MSF Grower Update
  - Tully, 14 May 2015 (half a dozen growers attended)
  - Gordonvale, 15 May 2015 (about 20 growers attended)

- to the productivity services and participating growers
  - Mulgrave, 30 July 2015
  - Tully, 31 July 2015
  - Mossman, 3 August 2015
- at the Meringa Research forum on the 18th April 2016
- at the Mossman AGM on the 21st April 2016
- to the productivity services (project updates and reviews of research priorities for each district)
  - Tully, 25 August 2016 - Jordan Villaruz (TCPSL), Greg Shannon (Tully Sugar), Michael Porta (MSF)
  - Gordonvale, 25 August 2016 - James Dunn, Bianca Spannagle (IBCPS), Matt Hession, Claire Bailey (MSF Mulgrave), Rik Maatman (MSF Tablelands), Drewe Burgess (Canegrowers Tablelands)
  - Mossman, 26 August 2016 - Daryl Parker, Allan Rudd, Rebecca Stone (MossAg)
  - Mackay, 6 Sept 2016 - John Agnew, Clare Gersch, Andy Humphries, Dave McCallum (MAPS), Harj Singh (PCPSL)
  - Proserpine, 7 Sept 2016 - Peter Sutherland, Frank Millar, Christine Petersen (SSP)
  - Burdekin, 7 Sept 2016 - Rob Milla, Marian Davis, Ashly Wheeler, Terry Granshaw (BPS)
  - Ingham, 8 Sept 2016 - Lawrence Di Bella, Richard Hobbs, Adam Royle, Ash Benson (HCPSL), Phil Patane (SRA)
  - Bundaberg, 20 Sept 2016 - Michael Turner (Bundaberg Sugar Services), Matt Leighton (Bundaberg CANEGROWERS), (Bundaberg Sugar)
  - Maryborough, 21 Sept 2016 - Barry Callow (MSF)
  - Plus email communication with Andrew Dougall (MSF), Rick Beattie (Sunshine Sugar)
- at the Northern Grower update meetings (SRA research forum)
  - Tully, 14 March 2017
  - Gordonvale, 15 March 2017
- At the Central Grower update meeting (SRA research forum)
  - Airlie Beach, 5 April 2018

Special events related to the project:

- The runoff simulator was demonstrated to the SRA Board on 18/08/2016 and to the QLD Minister of Agriculture on 22/09/2016.

- Project results were presented and discussed at the Pesticide Working Group meetings on the 15-16th March 2017 and on the 15th March 2018 in Townsville (annual Pesticide Working Group workshop)
- The rainfall simulator was displayed at the Meringa 100 years celebration open day.

Figure 1 Field day at trial site 5

4.2 Industry communication messages

An e-Newsletter article was published on 6 March 2015 to present project updates: “Preliminary variety x herbicide phytotoxicity trial results” Australian Canegrower 20 July 2015 edition p7.

A handout on the case study for alternative post-emergent herbicides to Diuron was presented by Belinda Billing on the 4th August 2015 at the Sugar Innovation Expo in the Burdekin.

“Alternatives to diuron in the Wet Tropics: Wrap-up of the 2014-2015 trials” was published in Cane Connection Autumn 16 edition.

“2016 project conclusions and feedback” is available on the SRA website. https://sugarresearch.com.au/wp-content/uploads/2017/02/2016-trial-summary-Alternatives-to-diuron-Wet-Tropics.pdf.This document was used in the 2016 project update meetings.

In January 2017, an updated version of the weed manual was released online and hard copies are available at each SRA station. https://sugarresearch.com.au/wp-content/uploads/2017/03/Weed_Management_in_Sugarcane_Manual.pdf

In November 2017, an information sheet (IS17011) “Spot-spraying post-emergent strategies for perennial grasses” was published on the SRA website and posted to Wet tropics growers. https://sugarresearch.com.au/wp-content/uploads/2017/02/IS17011-Spot-spraying.pdf

In November 2017, a booklet summarising the outcomes of 2016 demonstrations was posted to Wet tropics growers: “Developing an alternative herbicide management strategy to replace PSII herbicides in the Wet tropics area- SRA research project 2014050- Demonstrations 2016”. https://sugarresearch.com.au/wp-content/uploads/2017/02/Project-2014050-Demonstrations-F-LowRes.pdf

In March 2018, online videos and a Monkey survey were released to distribute keys messages from the project and obtain feedback from the industry:

- Plant cane video - https://youtu.be/XK_tGL1WWVg
- Ratoon cane video - https://youtu.be/19UR4352JZ8
- Survey monkey - https://www.surveymonkey.com/r/WeedManagement

Results from the Monkey survey can be found in Appendix 2 (to be submitted at a later date in agreement with the RFU).

5 METHODOLOGY

5.1 Part A: Alternatives to PSII herbicides

The main project objective to develop alternative strategies to control weeds and hard to kill grasses in the Wet tropics, was split into five sub-objectives:

- Development of cost effective pre-emergent herbicide strategies in ratoons using alternatives to diuron
- Development of cost effective pre-emergent herbicide strategies in plant cane using alternatives to PSII herbicides
- Development of cost effective post-emergent herbicide strategies to control hard-to-kill grasses using alternatives to diuron
- Assessment of the environmental impact of alternative strategies to diuron
- Development of strategies to reduce the use of herbicides in fallow

A series of replicated trials were undertaken to address each sub-objective and demonstrations were carried out in the last year of the project in all districts.

5.1.1 Field trials on cost effective pre-emergent herbicide strategies in ratoons using alternatives to diuron

Seven replicated trials were conducted on trash-blanketed ratoons over the project duration. Treatments compared alternative registered pre-emergent herbicides versus diuron-based herbicides (Barrage) applied soon after harvest. Each trial was designed as a randomised complete block (RCB) with adjacent untreated controls and three replicates (Table 1). Barrage high rate (T1) was used as a reference treatment because sugarcane growers are very familiar with its performance; however it is only registered for use at the low rate in the Wet tropics region since 2013. Treatments T2 to T5 (see Table 1) are currently registered for pre-emergence application in the Wet Tropics. T6 (Amitron®) registration is pending (it should be on the market in 2018) and T7 (Bobcat IMAXX) was registered in 2015. Six treatments (T1 to T6) were common to all trials and T7 was added to trials R5, R6 and R7 (Table 2). Spraying occurred soon after harvest, at spike stage, using a tractor mounted 6-tank sprayer.

Table 1 Details of treatments in the pre-emergent herbicide trials in ratoon

Treatment	Treatment Description	Active	Rate kg or L ha^{-1}	Water rate L ha^{-1}	Indicative cost \$ ha^{-1}
T1	Barrage high rate (as reference)	diuron 468 g.L^{-1} hexazinone 132 g.L^{-1}	4	300	$74
T2	Barrage low rate (as per new label)	diuron 468 g.L^{-1} hexazinone 132 g.L^{-1}	0.9	300	$17
T3	Flame® max label rate	imazapic 240 g.L^{-1}	0.4	300	$10
T4	Balance® max label rate	isoxaflutole 750 g.kg^{-1}	0.2	300	$35
T5	Clincher® max label rate	metolachlor 960 g.L^{-1}	2.7	300	$49
T6	Amitron® max label rate (pending registration)	amicarbazone 700 g.kg^{-1}	1.4	300	TBA
T7	Bobcat® i-MAXX max label rate	imazapic 25 g.L^{-1} hexazinone 125 g.L^{-1}	3.8	400	$86
T1,T3, T4,T7	Shirquat® 250 added to tank mix to prevent cane foliar uptake	paraquat 250 g.L^{-1}	1.2	300	$5

Table 2 Details of the sites for pre-emergent herbicide trials in ratoon

Trial site	Location	Cane variety Ratoon number	Soil type	Spray date	Weeds in untreated plots
R1	Edmonton	Q208Ⓐ 3 R	Edmonton Friable non-cracking clay or clay loam soils - Dermosols, Ferrosols	17/09/2014	Up to 95% weed coverage Mainly vines (calopo, red convolvulus)
R2	Tully	Q208Ⓐ 1 R	Tully soil series Well-drained alluvial Friable non-cracking clay or clay loam soils - Dermosols, Ferrosols	26/09/2014	Up to 75% weed coverage Mainly grasses (awnless barnyard grass) and broadleaves (blue top)
R3	Edmonton	Q208Ⓐ 4 R	Edmonton Mission Red, yellow or grey loam or earth soils - Kandosols	19/11/2014	Up to 100% weed coverage Mainly vines (calopo) and broadleaves (square weed)
R4	Mossman	Q231Ⓐ 1 R	Newell Seasonally wet soils requiring drainage or special management - Hydrosols	27/11/2014	Up to 20% weed coverage Mainly grasses (sour grass, paspalum) and broadleaves (Ludwigia, sensitive weed)
R5	Tully	Q200Ⓐ 3R	Coom-Tully Seasonally wet soils requiring drainage or special management – Hydrosols	21/08/2015	Up to 45% weed coverage Mainly grasses (Guinea grass, summer grass) and broadleaves (blue top, square weed)
R6	Aloomba	Q200Ⓐ 4R	Liverpool Deep sandy soils - Tenosols, Rudosols	28/08/2015	Up to 90% weed coverage Mainly grasses (awnless barnyard grass, summer grass, Guinea grass) and broadleaves (blue top, spiny spider flower)
R7	Daintree	Q219Ⓐ 2 R	Tully Friable non-cracking clay or clay loam soils - Dermosols, Ferrosols	30/10/2015	Up to 20% weed coverage Mainly broadleaves (blue top, square weed) and grasses (sour grass, paspalum)

Assessments started when weeds started to germinate in the control plots and occurred fortnightly until the weed coverage in the treated plots remained stable. Assessments included a visual estimation of the total weed coverage and of each group of species: grasses, broadleaves, vines and sedges. The assessments combined in one figure an estimate of number, cover, height and vigour of the weeds (virtually the weed volume). The results were expressed as one number (i.e. EWRC weed coverage rating). Six photographs were taken in each plot and Photoshop Elements used to calculate the percentage of weed coverage in each photograph. By increasing the contrast between the weeds and the ground, an accurate selection of the weeds in the photograph was possible (Figure 2). The percentage coverage for each photograph was calculated using the formula:

% weed coverage = number of green pixels/total number of pixels

Splitting by type of weeds was done by visual assessment. For each assessment, the percentage weed coverage of each plot was then calculated using the mean percentage coverage for all the photographs taken for that plot.

The efficacy of the herbicide treatment was expressed in percentage weed reduction compared to the untreated control and calculated using the formula

%weed reduction = (% weed coverage in adjacent control - %weed coverage in treated plot) x 100/ % weed coverage in adjacent control

For each group of species the calculation was calculated following the formula below

%grass reduction = (% grass coverage in adjacent control - %grass coverage in treated plot) x 100/ % grass coverage in adjacent control

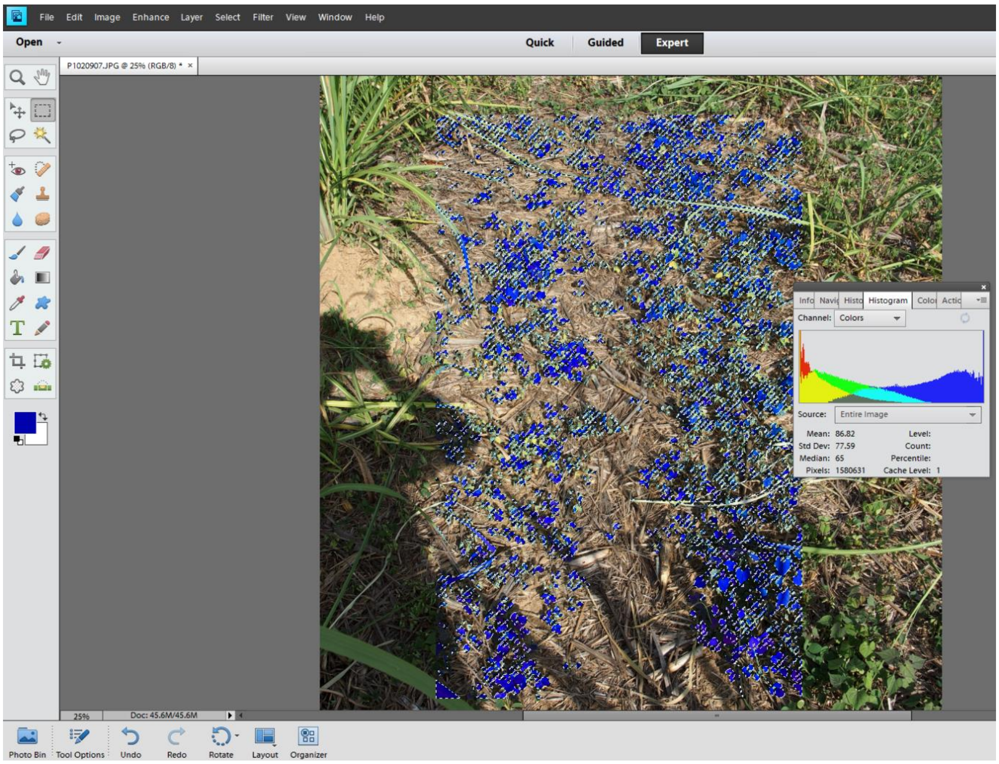


Figure 2 Screen shot of image analysis in Photoshop Elements. The number of selected pixels (bright blue coloured weeds) are reported in the histogram.

Assessment dates for each trial are displayed in Table 3. To facilitate data interpretation the trials results were grouped. Six treatments (T1 to T6) and five assessment dates were common to all trials and results were combined and analysed. Seven treatments (T1 to T7) and five assessment dates were common to trials R5, R6 and R7 and results were combined and analysed separately.

Table 3 Assessment dates for the six pre-emergent herbicide trials in ratoon (DAT: days after herbicide application)

Number of days since Assessment 1	Assessment 1 0	Assessment 2 14	Assessment 3 28	Assessment 4 40	Assessment 5 71
Trial					
R1	112 DAT 17/12/2014	121 DAT 2/1/2015	135 DAT 16/1/2015	146 DAT 27/1/2015	177 DAT 27/2/2015
R2	82 DAT 17/12/2014	96 DAT 31/12/2014	111 DAT 15/1/2015	124 DAT 28/1/2015	153 DAT 26/2/2015
R3	27 DAT 16/12/2014	42 DAT 31/12/2014	55 DAT 13/01/2015	69 DAT 27/1/2015	98 DAT 24/2/2015
R4	39 DAT 5/1/2015	53 DAT 19/1/2015	67 DAT 2/2/2015	83 DAT 17/2/2015	111 DAT 17/3/2015
R5	60 DAT 20/10/2015	74 DAT 3/11/2015	88 DAT 17/11/2015	104 DAT 3/12/2015	137 DAT 5/01/2016
R6	13 DAT 10/09/2015	28 DAT 25/09/2015	46 DAT 13/10/2015	56 DAT 23/10/2015	74 DAT 10/11/2015
R7	68 DAT 6/01/2016	83 DAT 21/01/2016	101 DAT 8/02/2016	112 DAT 19/02/2016	143 DAT 21/03/2016

Rainfall events were also recorded at each site using Onset Hobo rain gauges. The rainfall events and especially the first rain event after spraying are an important information as rain often triggers the weed germination (unless the soil is already moist before spraying, in that case weed germination occurs immediately). Cumulative rain data for each of the seven trials are attached in Appendix 3. Soil analysis was performed for each site by SRA laboratories and reported in Appendix 4.

Variables “total percentage reduction”, “grass percentage reduction”, broadleaf percentage reduction”, “vine percentage reduction” and “sedge percentage reduction” were treated as repeated measurements in the analysis model as they were recorded at repeated time intervals in days. A linear mixed model accounting for the covariance between the repeated measurements by fitting an appropriate covariance structure, in this case sp(pow) (spatial power law) which accounts for correlations declining as a function of time was fitted for these variables. If there was significant evidence from the model that the explanatory variable means differed, a multiple comparison test was used to determine which of the means were different. A Tukey’s multiple comparison test was used to determine which means among a set of means differed from the rest at a family significance level of 5%.

5.1.2 Field trials on cost effective pre-emergent herbicide strategies in plant cane using alternatives to PSII herbicides

Two trials were established in plant cane and herbicides were applied just after planting. Treatments compared alternative registered pre-emergent herbicides versus PSII-based herbicides applied at cane spiking stage (Table 4). Each trial was designed as an RCB with adjacent untreated controls and three replicates (Table 5).

Spraying occurred soon after harvest at spike stage using a tractor mounted 6-tank sprayer. Assessments occurred every two weeks, starting two weeks after spraying. Cut away farming interventions limited the number of assessments. Different treatments were selected at each trial site to take into account soil specificity. Balance® was not applied in PC2 due to the light soil texture and low CEC (2.4 meq.100g^{-1}).

Table 4 Herbicide treatments in pre-emergent herbicide trials in plant cane.

Trial	Treatment	Treatment Description	Active	Rate herbicides kg or L ha^{-1}	Cost $ ha^{-1}
PC1 & PC2	Pend/atraz[1]	Romper® 440EC + Gesaprim® Granules	455 g.L^{-1} pendimethalin + 900 g.kg^{-1} atrazine	3.1 2.2	$81
PC1 & PC2	Meto/atraz[1]	Clincher® Plus + Gesaprim® Granules	960 g.L^{-1} metolachlor + 900 g.kg^{-1} atrazine	2.5 2.2	$57
PC1 & PC2	Amet/metrib[1]	Ametrex® 800 WG + Mentor® WG	800 g.kg^{-1} ametryn + 750 g.kg^{-1} metribuzin	2 1.5	$109
PC1 & PC2	Meto/metrib[1]	Clincher® plus + Mentor® WG	960 g.L^{-1} metolachlor + 750 g.kg^{-1} metribuzin	2.5 1.5	$88
PC1 & PC2	Flumio	Valor®500 WG + Gramoxone®250[2]	500 g.kg^{-1} flumioxazin + 250 g.L^{-1} paraquat	0.35 1.2	$87
PC1	Isox	Balance®750 WG + Gramoxone®250[2]	750 g.kg^{-1} isoxaflutole + 250 g.L^{-1} paraquat	0.2 1.2	$40
PC1	Isox/metrib[1]	Balance®750 WG + Mentor® WG	750 g.kg^{-1} isoxaflutole + 750 g.kg^{-1} metribuzin	0.15 1.5	$80
PC1	Imaz/Bal	Flame® + Balance®750 WG + Gramoxone®250[2]	240 g.L^{-1} imazapic + 750 g.kg^{-1} isoxaflutole + 250 g.L^{-1} paraquat	0.2 0.1 1.2	$28
PC2	Imaz/metrib[1]	Flame® + Mentor® WG + Gramoxone®250[2]	240 g.L^{-1} imazapic + 750 g.kg^{-1} metribuzin+ 250 g.L^{-1} paraquat	0.3 1.5 1.2	$67
PC2	Flumio/atraz[1]	Valor®500 WG + Gesaprim® Granules + Gramoxone®250[2]	500 g.kg^{-1} flumioxazin + 900 g.kg^{-1} atrazine + 250 g.L^{-1} paraquat	0.35 2.2 1.2	$110
PC2	Imaz/amicar[1]	Flame® + Amitron® + Gramoxone®250[2]	240 g.L^{-1} imazapic + 700 g.kg^{-1} amicarbazone + 250 g.L^{-1} paraquat	0.3 0.8 1.2	NA

Table 5 Details of the sites for pre-emergent herbicide trials in plant cane

Trial site	Location	Cane variety	Soil type	Spray date	Weeds in control plots
PC1	Craiglie	Q208$^{(b}$ Plant cane	Mission Red, yellow or grey loam or earth soils – Kandosols.	21/09/2016	Up to 95% weed coverage Mainly grasses (awnless barnyard grass, green summer grass, summer grass) and vines (calopo, red convolvulus)
PC2	Mirriwinni	Q253$^{(b}$ Q208$^{(b}$ Plant cane	Thorpe Red, yellow or grey loam or earth soils – Kandosols.	11/11/2016	Up to 75% weed coverage Mainly grasses (Guinea grass, crowfoot and summer grass)

1 Treatments including a PSII herbicide

2 Paraquat was only added in mixes that either only had pre-emergent properties (paraquat was added as knockdown), or had potential phytotoxic effect on cane through absorption by the shoot (paraquat stopped translocation).

Based on photographs taken in each plot for each assessment date, weed coverages were assessed and transformed into percentage reduction of weed coverage (as describe in methodology section 5.1.1). Phytotoxicity rating on cane was measured using the scale in Table 6.

Table 6 Evaluation of plant tolerance using the European Weed Research Council (EWRC) rating scale

Rating	Visual phytotoxicity ratings
1	No damage/ discoloration/ yellowing
2	Very slight discoloration
3	Slight discoloration/ yellowing. (no practical consequence)
4	Slight damage (acceptable in practice with reservations)
5	Medium damage (no longer economically acceptable)
6	Strong damage (not acceptable)
7	Very strong damage
8	Extremely strong damage
9	Total damage

Three to four herbicide efficacy assessments were carried out in each trial until the grower started to fill in and disturb the soil (Table 7).

Table 7 Assessment dates for the two pre-emergent herbicide trials in plant cane

Trial	Assessment 1	Assessment 2	Assessment 3	Assessment 4
1	0 DAT 21/09/2016	16 DAT 7/10/2016	29 DAT 20/10/2016	
2	0 DAT 11/11/2016	14 DAT 25/11/2016	32 DAT 13/12/2016	42 DAT 23/12/2016

Rain events were recorded using the Onset Hobo rain gauges and soil samples were taken and analysed for each site (Appendix 3 and Appendix 3Appendix 4).

For each trial, the variables “total percentage reduction”, “grass percentage reduction”, “vine percentage reduction” and “phytotoxicity rating” were treated as repeated measurements in the analysis model as they were recorded at repeated time intervals in days. A linear mixed model accounting for the covariance between the repeated measurements, by fitting an appropriate covariance structure, in this case sp(pow) (spatial power law) which accounts for correlations declining as a function of time, was fitted for these variables. If there was significance evidence from the model that the explanatory variable means differed, a multiple comparison test was used to determine which of the means were different. A Tukey’s multiple comparison test was used to determine which means among a set of means differed from the rest at a family significance level of 5%.

5.1.3 Field and pot trials on cost effective post-emergent herbicide strategies to control hard-to-kill grasses using alternatives to diuron

5.1.3.1 Field trials

Four replicated field trials were conducted in trash blanketed ratoons infested with perennial grasses. Trials were designed as an RCB with four replicates. A pre-emergent treatment applied throughout each trial just after harvest helped to control new seedlings.

Treatments compared in each trial were:

- T1 banded spray for asulam (sprayed early), followed by glyphosate interrow using shield (sprayed late)
- T2 diuron low rate + paraquat using octopus leg (sprayed late)

- T3 isoxaflutole low rate + paraquat using octopus leg (sprayed late)[1]
- T4 isoxaflutole low rate + MSMA using octopus leg (sprayed late) (as reference product)[1]
- T5 isoxaflutole low rate + MSMA in the row[1]/ glyphosate interrow using shield (sprayed late)
- T6 isoxaflutole low rate + MSMA in the row[1]/glyphosate interrow using QDAF dual herbicide spray bar “DHSB” (sprayed late)

Additional treatment details can be found in

Table 8. Details of the four trial sites can be found in

[1] Isoxaflutole used as post-emergent, or mixed with MSMA were off label but commonly used and promoted by the productivity services in the dry and wet Tropics.

Table 9.

Table 8 Herbicide treatments in the post-emergent herbicide field trials

Treatment	Treatment description	Active and concentration	Rate kg or L ha^{-1}	Water rate L ha^{-1}
Early post-emergent application				
T1 (band sprayed over the row)	Rattler®400	asulam 400g.L^{-1}	8.5	400
	Wetspray® 1000	surfactant	200 mL/100L	
Late post-emergent applications (cane 1 metre tall, cane before out of hand stage[1])				
T1 (sprayed interrow with shield)	Weedmaster® Argo®	glyphosate 540 g.L^{-1}	5	100
	LI 700*	surfactant	300 mL/100L	
T5 (sprayed interrow with shield)	Weedmaster® Argo®	glyphosate 540 g.L^{-1}	5	100
	LI 700*	surfactant	300 mL/100L	
T5 (sprayed at the base of the row using shield side nozzles)	Balance®750 WG	isoxaflutole 750 g.kg^{-1}	0.1	350
	Monopoly	MSMA 720 g.L^{-1}	3	350
	Activator®	surfactant	125mL/100L	
T2 (sprayed interrow + base of row using Irvin leg)	Diurex® WG	diuron 900 g.kg^{-1}	0.5	350
	Shirquat® 250 (2014 trials)	paraquat 250 g.L^{-1}	1.2	350
	Daconate®(2015 trials)	MSMA 720 g.L^{-1}	3	350
	Activator®	surfactant	125mL/100L	
T3 (sprayed interrow + base of row using Irvin leg)	Balance®750 WG	isoxaflutole 750 g.kg^{-1}	0.1	350
	Shirquat® 250	paraquat 250 g.L^{-1}	1.2	
	Activator®	surfactant	125mL/100L	
T4 (sprayed interrow + base of row using Irvin leg)	Balance®750 WG	isoxaflutole 750 g.kg^{-1}	0.1	350
	Monopoly	MSMA 720 g.L^{-1}	3	350
	Activator®	surfactant	125mL/100L	
T6 (sprayed interrow using DHSB central nozzle)	Weedmaster® Argo®	glyphosate 540 g.L^{-1}	5	100
	LI 700*	surfactant	300 mL/100L	
T6 (sprayed at base of row using DHSB side nozzles)	Balance®750 WG	isoxaflutole 750 g.kg^{-1}	0.1	350
	Monopoly	MSMA 720 g.L^{-1}	3	350
	Activator®	surfactant	125mL/100L	

[1] As the two trials established in 2014 resulted in unacceptable efficacy results across all treatments, it was decided to repeat the late post-emergent treatment applications at out-of-hand stage in the two 2015 trials.

Table 9 Details of the sites for the post-emergent herbicide field trials

Trial site	GGF1	GGF2	GGF3	GGF4
Area	Low rainfall, well drained	High rainfall, well drained	High rainfall, well drained	High rainfall, well drained
Location	Gordonvale	Mirriwinni	Mulgrave-Aloomba	South Johnstone - Garradunga
Cane variety and ratoon number	Q138 21 R	Q208$^{\Phi}$ 2 R	Q208$^{\Phi}$ 2R	Q200$^{\Phi}$ 4R
Soil type	Liverpool Well drained recent alluvium	Thorpe Granite gravel	Liverpool Deep sandy soils - Tenosols, Rudosols,	Eubenangee Friable non-cracking clay or clay loam soils - Dermosols, Ferrosols.
Spraying dates				
Early post emergent-T1 (R)[1]	2/10/2014	27/10/2014	11/8/2015	26/11/2015
Post-emergent cane 1m T1(IR)[2], T2, T3, T4, T5, T6	30-31/10/2014	11-12/11/2014	16-17/9/2015	16-21/12/2015
Post-emergent before OHS[3] T1(IR)[2], T2, T3, T4,T5, T6	NA	NA	5-9/11/2015	28-29/1/2016

The efficacy of post-emergent herbicides was estimated by rating the visual symptoms on cane and Guinea grass for each photograph. The final rating for the plot was then calculated using the mean phytotoxicity ratings for all the photographs taken for that plot. The phytotoxicity rating was measured using the scale in Table 6. In each plot, three ratings were given:

- phytotoxicity of the treatment on cane
- phytotoxicity of the treatment on Guinea grass in the row
- phytotoxicity of the treatment on Guinea grass in the interrow.

Phytotoxicity ratings were measured every two weeks, starting about two weeks after spraying. As Treatment 1 was sprayed earlier, it was assessed at different dates than the other treatments (

[1] (R)-treatment over the row only
[2] (IR)-treatment in the inter row only
[3] OHS- out of hand stage

Table 10).

At harvest sugarcane yield was measured using SRA weigh truck.

The number of grasses in each plot was counted before the first treatment and after harvest. A precision GPS was used to record the position of each grass stool. The percentage reduction in number of grasses was calculated using the following formula:

Percentage grass reduction = (initial number of grasses – final number of grasses) x 100/final number of grasses

Table 10 Assessment dates for the post-emergent field trials

Trial	Initial counting	Assessment 1 15 DAT	Assessment 2 30 DAT	Assessment 3 About 45 DAT	Assessment 4 90 DAT	Final counting
GGF1	7/10/2014	13/11/2014 16/10/2014(T1[1])	26/11/2014 31/10/2014(T1[1])	9/12/2014 13/11/2014(T1[1])	29/12/2014 26/11/2014(T1[1])	NA
GGF2	27/10/2014	25/11/2014 10/11/2014(T1[1])	8/12/2014 26/11/2014(T1[1])	19/12/2014 8/12/2014(T1[1])	10/1/2015 19/12/2014(T1[1])	22/5/2015
GGF3	1/9/2015	14/10/2015 8/9/2015(T1[1])	28/10/2015 14/10/2015(T1[1])	12/11/2015 28/10/2015(T1[1])	10/12/2015 12/11/2015(T1[1])	22/9/2016
GGF4	2/12/2015	4/1/ 2016 11/12/2015(T1[1])	20/1/2016 4/1/2016(T1[1])	11/2/2016 20/1/2016(T1[1])	29/2/2016 11/2/2016(T1[1])	15/12/2016

Rainfall data were recorded using Onset HOBO Rain gauges (Appendix 3).

Data from the four trials were grouped and analysed using linear mixed models using restricted maximum likelihood, ASReml-R (Butler, 2009). The variables "total percentage reduction", "phyto rating" and "cane yield" were investigated. The significance of the fixed terms was tested using asymptotic Wald statistics so the F-values reported in the analysis of variance table are approximate F values, according to Kenward & Roger (1997). The model assumptions were that the residuals were normally distributed and had a constant variance, and that the factor level variances were equal for the treatments, which was tested using the Brown-Forsythe Test. The Shapiro-Wilk test of normality was used to determine if the residuals were normally distributed. If there was significant evidence from the model that the explanatory variable means differed, a Tukey's multiple comparison test was used to determine which means among a set of means differed from the rest at a family significance level of 5%.

5.1.3.2 Pot trials

Two pot trials were established to answer questions generated by the field trials on post-emergent alternative to diuron to control perennial grasses.

Pot trial 1 objective was to understand if glyphosate failure to kill Hamil grass (a tall variety of Guinea grass, very hard to kill and common to the Wet tropics region) in previous field trials may be due to poor translocation related to partial spray coverage and/or water stress.

Pot trial 2 objective was to identify the best combinations of product x concentration x water rate to control Hamil grass.

Four treatments were compared in pot trial 1 which was designed according to a RCB design with four replicates (Table 11).

Table 11 Details of treatments in pot trial 1

Treatment	Water Regime	Spray coverage
T1	dry	Total
T2	dry	Half
T3	wet	Total
T4	wet	Half

[1] As the first application of T1 started earlier, the assessment date on T1 plots differs to the other plots.

Hamil grass stools were dug out from a farm on the bank of the Mulgrave River and re-potted in 30 cm pots filled with potting mix. Pots were fertilised and submitted to two water regimes according to their treatment. They were trimmed and sprayed with Weedmaster® Argo® (glyphosate) on 28/03/2017 as the new growth was about 0.75 m high with some seed heads (Table 12). The product label states "*Control of established perennials is best obtained when plants are at the seedhead stage*" because a higher amount of sap is flowing towards the root system when compared to earlier growth stages.

The pots were lined up and sprayed with a boom placed about 50 cm above the canopy. Two high flow air inducted nozzles (white 08) were used to achieve the desired spot spraying water rate of 117 mL per plant, which was the point of runoff. It was the equivalent of 4700 L ha^{-1} and was achieved while driving at 0.9 km h^{-1} (Figure 3).

To confine the spray to "half coverage" of the grass stools, half of the leaves were wrapped in GLAD ClingWrap while the other half of the plant was sprayed (Figure 4).

After spraying, the pots were placed undercover in their randomised position and the drip irrigation was restored to 1 minute five times a day for the "dry" treatment and to 5 minutes five times a day for the "wet" treatment.

Table 12 Details of spraying in pot trial 1

Treatment	Commercial product	Active ingredient	rate $100L^{-1}$	Water volume per plant
Total and half coverage	Weedmaster® Argo®	glyphosate 540 $g.L^{-1}$	1.35L	117 mL
	LI 700*	surfactant	0.3L	

Figure 3 Spraying in pot trial 1.

Figure 4 "Half spray coverage" treatment wrapped with cling wrap for spraying.

Three herbicidal strategies were compared in pot trial 2. Two spray concentrations and two spray volumes were tested for each strategy (Table 13). Pot trial 2 was designed as an RCB with 13 treatments and four replicates.

Table 13 Details of treatments in pot trial 2.

Treatment	Product	Active ingredient	Wetter and rate	Product concentration in tank in kg or L $100L^{-1}$	Speed / Spray volume
T1	Barrage	Diuron 468 g kg^{-1} Hexazinone 132 g kg^{-1}	BS1000 at 0.5%	1	1.7 km h^{-1} Runoff point (2000L ha^{-1})
T2				1	3.4 km h^{-1} (1000 L ha^{-1})
T3				2	1.7 km h^{-1}
T4				2	3.4 km h^{-1}
T5	Balance®750 WG + Daconate®	Isoxaflutole 750 g kg^{-1} MSMA 800 g L^{-1}	Agral at 0.2%	0.075 + 1.5	1.7 km h^{-1}
T6				0.075 + 1.5	3.4 km h^{-1}
T7				0.15 + 3	1.7 km h^{-1}
T8				0.15 + 3	3.4 km h^{-1}
T9	Bobcat® i-MAXX	Imazapic 25 g L^{-1} Hexazinone 125 g L^{-1}	Activator® at 0.125%	1	1.7 km h^{-1}
T10				1	3.4 km h^{-1}
T11				2	1.7 km h^{-1}
T12				2	3.4 km h^{-1}
control					

In both trials, the pots were assessed at three and seven days after spraying and then weekly. Phytotoxicity measurements and ten individual chlorophyll measurements were taken in each pot. The phytotoxicity scale (Table 6) was used for rating.

The chlorophyll content of leaves was measured using a chlorophyll meter SPAD 502. The chlorophyll value (referred to as SPAD value) was only relevant for the first three dates as SPAD measurements were ineffective on desiccated leaves.

For pot trial 1, a linear mixed model using ASReml-R (Butler, 2009) was used to determine the effect of the treatments on phytotoxicity rating and SPAD value, using a repeated measurement analysis. An *ln* transformation was applied on phytotoxicity rating before fitting a mixed model to the transformed data. The model assumptions were that the residuals were normally distributed, they had a constant variance and were independent. Also, that the factor level variances were equal for the treatments, this was tested using the Brown-Forsythe Test.

For pot trial 2, statistical analysis of data was conducted using the linear mixed model procedure of SAS. Average SPAD and phytotoxicity ratings were treated as repeated measurements in the analysis model as they were recorded at repeated time intervals in days. Phytotoxicity rating was not a continuous variable so a box-cox transformation was applied on it before fitting a mixed model to the transformed data. A linear mixed model which accounted for the covariance between the repeated measurements by fitting an appropriate covariance structure, in this case sp(pow) (spatial power law) which accounts for correlations declining as a function of time, was fitted for the phytotoxicity rating, while first order autoregressive AR(1) was fitted for the average SPAD as there were only two measurement periods.

If there was significance evidence from the model that the explanatory variable means differed, Tukey's multiple comparison test was used to determine which of the means were different at a family significance level of 5%.

5.1.4 Field trials on the environmental impact of alternative herbicides to diuron

To measure the relative environmental impact of alternative herbicides to diuron on surface runoff quality, a rainfall simulator was built, using the same specifications (following Loch *et al*., 2001) as used in previous plot scale water quality research in cropping systems, including the Queensland sugar industry (Masters *et al*., 2013; Melland *et al*., 2016).

A local aluminium fabricator (Greenwood Z&H) built the frame and fittings for the several pump, nozzles and hoses components. David Donald (formerly SRA) assembled the electronic module and developed a computer program that controls the motor responsible for oscillating the nozzles.

The rainfall simulator was completed by end February and calibrated in March 2016 (Figure 5).

Figure 5 SRA Rainfall simulator in trial RO1.

To improve the efficiency of a runoff simulation exercise, it is standard practice to test several herbicides, which means spraying several herbicides on the same patch of soil. However some herbicides are not very compatible when combined in a tank mixture (according to the label) and some mixes can precipitate in the spray tanks.

Runoff trials RO1 and RO3 tested 14 herbicide treatments applied on trash blanketed ratoons, and trial RO2 tested the same herbicides applied on freshly tilled bare soil. Herbicides were grouped in three separate treatments. In each treatment, separate tank mixes were sprayed when necessary to facilitate the mixing and avoid precipitation and blockage of the sprayer. Spray water rates for every tank mix was adjusted to obtain a total of 400 L ha^{-1} for each plot sprayed with pre-emergent herbicides (T1 and T2) and 200 L $ha^{-1}$for each plot sprayed with post-emergent herbicides (T3) (Table 14).

Table 14 Details of treatments in runoff trials

Trial	T	treatment description	Active ingredient	rate product g or mL ha^{-1}
RO1, RO2, RO3	T1	Barrage low rate (as per new label)	diuron 468 g kg^{-1} hexazinone 132 g kg^{-1}	900
RO1, RO2, RO3	T1	Amitron® max label rate (pending registration)	amicarbazone 700 g kg^{-1}	1400
RO1, RO2, RO3	T1	Soccer®700 WG max label rate	metribuzin 700 g kg^{-1}	2200
RO1, RO2, RO3	T1	Balance®750 WG max label rate	isoxaflutole 750 g kg^{-1}	200
RO1, RO2, RO3, RO4	T1	Gesaprim® Granules max label rate	atrazine 900 g kg^{-1}	3300
RO1, RO2, RO3, RO4	T2	Barrage full rate (as reference product),	diuron 468 g kg^{-1} hexazinone 132 g kg^{-1}	4000
RO1, RO2, RO3	T2	Flame® max label rate	imazapic 240 g L^{-1}	400
RO1, RO2, RO3	T2	Clincher® Plus max label rate	metolachlor 960 g L^{-1}	2700

Trial	T	treatment description	Active ingredient	rate product g or mL ha^{-1}
RO1, RO2, RO3	T2	Ametrex®800 WG	ametryn 800 g kg^{-1}	2800
RO1, RO2, RO3	T3	Amine 625	2,4-D 625 g L^{-1}	3500
RO1, RO2, RO3	T3	Decoy 400®	fluroxypyr 400 g L^{-1}	1500
RO1, RO2, RO3	T3	Daconate®	MSMA 800 g L^{-1}	6000
RO1, RO2, RO3	T3	MCPA® 750	MCPA 750 g L^{-1}	1450
RO1, RO2, RO3	T3	Weedmaster® Argo®	glyphosate (potassium and isopropylamine salts) 540 g L^{-1}	5000
RO4	T1	Romper® 440EC	pendimethalin 440 g L^{-1}	3400
RO4	T4	Valor® 500WG	flumioxazin 500 g kg^{-1}	700

The spray area for each plot was 1 m wide by 4 m long. The bottom 3 metres were used to carry out the rainfall simulation whereas the extra top 1 metre was used to collect soil and trash samples just after spraying (Figure 6). As spraying was done using a tractor and sprayer with a 1.5 m boom (to ensure a correct overlap), tarps were used to cover and protect the adjacent plots.

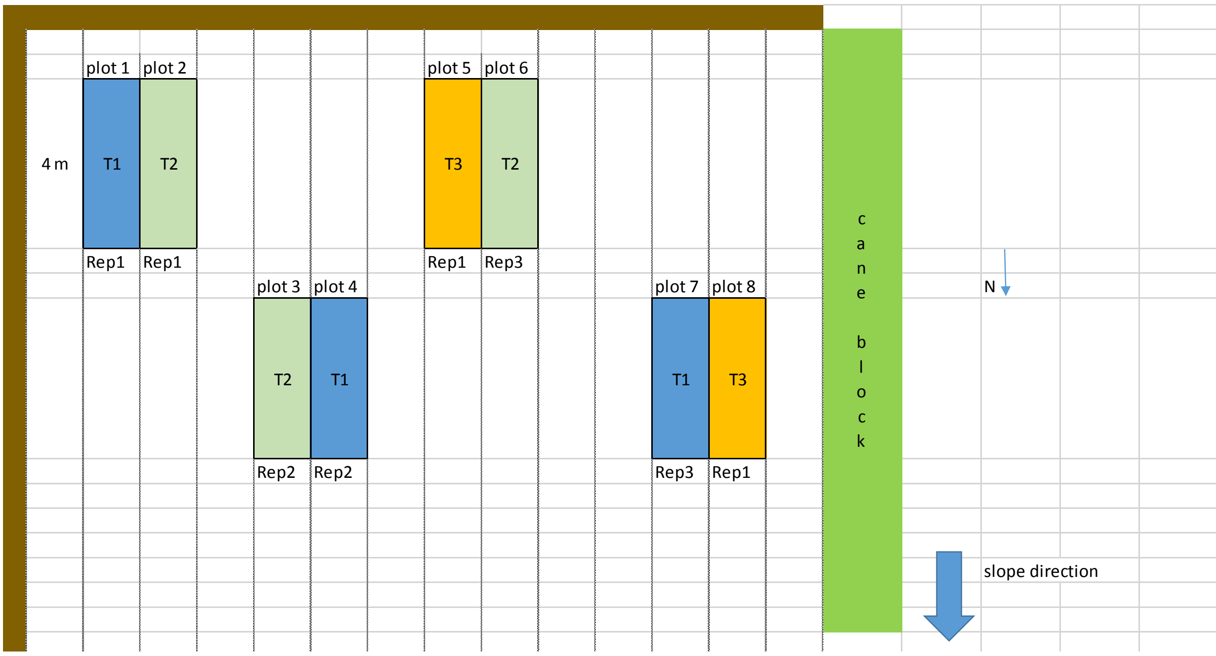


Figure 6 Example of trial design: layout runoff trial RO1

The initial plan was to establish the three runoff trials on the same sites as the pre-emergent trials, with the idea to compare efficacy and environmental data coming from the same site (soil type, cropping system and weather).

Only trial RO1 in Aloomba and trial RO2 in Mossman were implemented at the same sites as the pre-emergent trials R6 and PC1. Delayed harvest at efficacy trial R5 led us to implement trial RO3 at a different location but on a similar soil type.

An additional rainfall simulation (RO4) was carried out in 2017 in order to answer specific questions generated by the 2016 runoff trials and to test a new active ingredient: flumioxazin. Pendimethalin was also added in this trial as a reference. Pendimethalin is known for its low solubility in water and is not prone to runoff. In this trial, the impact of four herbicide treatments was tested when they were sprayed on trash versus bare soil. RO4 trial was set up on a similar soil type as the RO2 trial and therefore could also be related to efficacy trial PC1 (Table 15).

Table 15 Details of sites for runoff trials

Trial	RO1	RO2	RO3	RO4
Location	Aloomba	Mossman	Babinda	Mulgrave
Area	High rainfall, well drained	High rainfall	High rainfall, poorly drained	Moderate rainfall, well drained
Linked to Efficacy trial site	R6	PC1	R5	PC1
Cane variety and ratoon number	Q200⁽ᵇ⁾ 4R	Fallow – soil prepared and rolled for planting cane	Q208⁽ᵇ⁾ 3R	Last ratoon – before plough out
Soil type	Liverpool (and wet variant) Deep sandy soils - Tenosols, Rudosols,	Mission Red, yellow or grey loam or earth soils – Kandosols	Coom Hydrosols Seasonally wet soils requiring drainage or special management	Mission Red, yellow or grey loam or earth soils – Kandosols
Date and time sprayed	5/4/2016 10:15am to 2:05pm	3/5/2016 10:30am to 2:00pm	29/08/2016 11:00am to 1:30pm	20/06/2017 9:30am to 11:30am
Weather conditions at spraying	Cloudy (50%) Temp 32.3 H% 63.4 Delta T 7.1 Wind SSW Average 1.5 km/h Max 2.8 km/h	Sunny Temp 30.1 H% 67.5 Delta T 6.0 Wind SE Average 2.3 km/h Max 8.4 km/h	Sunny Temp 32.9 H% 42.6 Delta T 10.0 Wind S Average 0.4 km/h Max 3.0 km/h	Sunny Temp 25.6 H% 61.8 Delta T 5.1 Wind WSW Average 0.4 km/h Max 4.1 km/h
Equipment used	6 tank research sprayer with boom and 3 air inducted flat fan nozzles			
Date and time runoff simulation	07/04/2016 8:30am to 4:35pm	05/05/2016 9:00am to 3:30pm	31/08/2016 8:30am to 4:30pm	22/06/2017 9:30am to 3:00pm

Simulated rainfall was applied to small field plots (0.75 m wide × 3 m long) two days after the application of herbicides to minimize herbicide degradation and maximize the risk of herbicide loss in runoff. Plot edges were bound by a metal frame driven about 30 to 50 mm into the soil. Runoff was routed through a metal spout for collection (Figure 5). Rain was applied at rates (70−80 mm h^{-1}, Table 2) representing a one in two year average recurrence interval for the region (see Melland *et al.*, 2016). Three rain gauges located in each plot recorded the rainfall amount applied.

Trash and soil samples were taken in each plot just after spraying (outside the rain quadrat) and just after rainfall (inside the rain quadrat). A sampling quadrat (120 mm x 82.5 mm) was used to take six randomised trash and soil samples from each plot at the two sampling times. The soil samples were collected for 0-25 mm depth.

Three composite runoff samples were collected in each plot for four to five seconds (depending on the flow at the site) every five minutes starting when runoff starts. The first composite runoff sample was used to analyse the concentration of herbicides in the water fraction; the second composite runoff sample was used to analyse the concentration of herbicides in the sediment fraction, and the third composite runoff sample was used to measure the amount of sediment lost during the event.

Every five minutes, the runoff flow was measured by timing the duration to fill up a 500 ml jug (Figure 7).

Runoff water, sediment, soil and trash samples were sent to ACS laboratories in Kensington Victoria for herbicide residues analysis on water, sediment, trash and soil. For details on laboratory procedures, refer to Davis and Pradolin (2016).

Figure 7 Rainfall simulation in trial RO2

5.1.5 Field trials on strategies to reduce the use of herbicides in fallow

In 2015, two replicated trials were implemented, one in a well-drained area (CC1), the other in a poorly drained area (CC2).

Treatments compared in CC1 and CC2 were:

- cowpea Ebony 100%
- lablab Rongai 100%
- cowpea Ebony 50% + lablab Rongai 50%
- cowpea Ebony 40% + lablab Rongai 40% + jack bean (*Canavalia ensiformis*) 20%
- cowpea Ebony 40% + lablab Rongai 40% + Shirohie millet 20%

Each treatment was tested at two sowing rates (high rate for green manure / high rate x 2). Each treatment was tested using two herbicide regimes (with herbicide / without herbicide) (Table 16 and Table 17).

CC1 and CC2 trial design was a split plot with three replicates, with the herbicide regime as the main plot and sowing rate x legume species as the subplot. Each plot size was two rows (3.2 m) x 3 m.

In these trials, seeds were broadcast spread using a hand held seeder and incorporated using offset disks (two passes required to cover the seeds).

Table 16 Details of subplot treatments in trials CC1 and CC2

T	Legume species	Ratio	Sowing rate	Theoretical sowing rate[1] kg ha^{-1}
SP1R1	Ebony cowpea	100	Normal	35
SP1R2	Ebony cowpea	100	High	70
SP2R1	Rongai lablab	100	Normal	35
SP2R2	Rongai lablab	100	High	70
SP3R1	Cowpea / lablab	50/50	Normal	17.5 / 17.5
SP3R2	Cowpea / lablab	50/50	High	35 / 35
SP4R1	Cowpea / lablab / Jack bean	40/40/20	Normal	14 / 14 / 8
SP4R2	Cowpea / lablab / Jack bean	40/40/20	High	28 / 28 / 16
SP5R1	Cowpea / lablab / millet	40/40/20	Normal	14 / 14 / 5
SP5R2	Cowpea / lablab / millet	40/40/20	High	28 / 28 / 10

Table 17 Details of main plot treatments in trials CC1 and CC2

T	Treatment detail
H	Weeds managed by herbicide or mechanically by hand (in SP5 plots because no selective herbicide exists for this cover crop mix)
0H	Weeds not controlled

The two trials carried out in 2014-15 indicated the most promising cover crop options. In 2015-16, these options were tested in full scale replicated trials (CC3 and CC4) also comparing different soil preparation practices and the associated sowing techniques. A taller millet variety: "Japanese" millet was sown to achieve better weed competition.

CC3 and CC4 trials were designed as split plot experiments with three replicates with the soil preparation (no tillage, zonal tillage, full tillage) as main plot and the cover crop species (cowpea alone, cowpea + lablab, cowpea + lablab + millet, bare fallow) as subplots (Table 18). Details of all four trial sites are reported in

[1] The sowing rate used in the trials was increased according to the percentage germination of the supplied cover crops (cowpea 86%, lablab 80%, millet 90% according to the seed supplier NQTS. Jack bean germination was 90% as per our own testing)

Table 19.

To sow seeds of different size simultaneously, a specific seeder was required. A Baldan double disk seeder lent by Tolga Honeycombe was able to plant a mix of two seed sizes thanks to the two separate boxes (Figure 8).

When the trash blanket in the no till treatment was too thick to operate the Baldan disk seeder (in trial CC3), it was decided to use a local soybean planter (lent by Mossman Ag) that plants a row of bean on each side of the ex-cane row through the trash. To insure better coverage, we did three offset passes with the soybean planter in an attempt to plant six rows of cover crop on the ex-cane row. The other inconvenience of the common soybean planter was that it could handle only one seed size. Treatment T3 (including millet) could not be planted in the no-till strips in trial CC3.

Figure 8 Planting trial CC3 with the Baldan disk planter from Tolga Honeycombe

Table 18 Details of treatments in the cover crops trials CC3 and CC4

<table>
<tr><th>Main treatment code</th><th>Soil preparation</th><th>Sub treatment code</th><th>Cover crop species</th><th>Type of seeder used in trial CC3</th><th>Type of seeder used in trial CC4</th></tr>
<tr><td rowspan="4">NT</td><td rowspan="4">No tillage</td><td>T1</td><td>Cowpea alone</td><td rowspan="2">Soybean planter. Three passes, 12 rows on two wide beds
Used because of presence of trash blanket</td><td rowspan="6">Baldan seeder. One pass, 17 rows over 3 m width
The shallow row profile and the very light trash blanket allowed for the NT and ZT to be planted across the row profile with the Baldan seeder.</td></tr>
<tr><td>T2</td><td>Cowpea + lablab</td></tr>
<tr><td>T3
only in trial 7</td><td>Cowpea + lablab + millet</td><td>COULD not be planted with the soya bean planter</td></tr>
<tr><td>T4</td><td>None</td><td></td></tr>
<tr><td rowspan="2">ZT</td><td rowspan="2">Zonal tillage using a zonal rotary hoe</td><td>T1</td><td>Cowpea alone</td><td rowspan="2">Baldan seeder. One pass, 9 rows on two beds
The seeder planted only on the raised bed</td></tr>
<tr><td>T2</td><td>Cowpea + lablab</td></tr>
</table>

Main treatment code	Soil preparation	Sub treatment code	Cover crop species	Type of seeder used in trial CC3	Type of seeder used in trial CC4
		T3	Cowpea + lablab + millet	because of the deep row profile.	
		T4	None		
FT	Full tillage using a rotary hoe	T1	Cowpea alone	Baldan seeder. One pass, 17 rows over 3 m width	
		T2	Cowpea + lablab		
		T3	Cowpea + lablab + millet		
		T4	None		

Table 19 Details of the cover crop trial sites

Trial site	CC1	CC2	CC3	CC4
Location	Gordonvale	Meringa	Craiglie	Gordonvale
Trash blanket level at planting	None	None	Medium	Very light
Soil type	Virgil Red earth	Clifton Poorly drained clay	Clifton Red, yellow or grey loam or earth soils – Kandosols	Virgil Red, yellow or grey loam or earth soils – Kandosols
Soil preparation date	None	12/2/2015	16/12/2015	18/2/2016
Sowing date	22/1/2015	3/3/2015	16/12/2015	26/2/2016
Spraying date on selected treatments	20/2/2015	17/4/2015	3/2/2016	29/3/2016
Hand weeding in selected treatments	16/3/2015	20/4/2015	NA	NA
Spray out date	15/4/2015	18/5/2015	NA	NA
Harvesting date	4/5/2015	1/6/2015	24/02/2016	11/5/2016
Weed species present	Mainly summer grass, crowsfoot and nutgrass	Mainly blue top, sedges, rushes, crowsfoot and awnless barnyard grass	Mainly awnless barnyard grass, summer grass, crowsfoot and green summer grass,	Mainly spiny spider flower, passion fruit vine, blue top and green summer grass
Comments			The treatment combination T3-NT does not exist in this trial. Sowing was carried out in weed free conditions.	T3 = T2 in this trial (millet germination failure). Weeds were present in no-till strips at time of sowing .

Based on photographs taken in each plot for each assessment date, weed and cover crop coverages were calculated using the method described in section 5.1.1. Above ground biomass samples (2 m x 3 m) were taken after spray out (CC1 and CC2) or mulching (CC3 and CC4). Fresh and dry weight were measured. Dried samples were ground, sub sampled and analysed for N and C at the Indooroopilly soil laboratory. For trials CC3 and CC4, two weed assessments were carried out in the following plant cane (in unsprayed areas) (

Table 20).

Table 20 Assessment dates for the cover crop trials

Trial	Asses. 1	Asses. 2	Asses. 3	Asses. 4	Asses. 5	Biomass	Asses.PC1	Asses.PC2
CC1	17 DAS 9/2/2015	31 DAS 23/2/2015	50 DAS 11/3/2015	62 DAS 23/3/2015	79 DAS 9/4/2015	4/5/2015		
CC2	15 DAS 18/3/2015	28 DAS 31/3/2015	42 DAS 14/4/2015	56 DAS 28/4/2015	71 DAS 13/5/2015	1/6/2015		
CC3	19 DAS 6/1/2016	34 DAS 21/1/2016	47 DAS 3/2/2016	63 DAS 19/2/2016		24/2/2016	7/10/2016	20/10/2016
CC4	17 DAS 14/3/2016	27 DAS 24/3/2016	45 DAS 11/4/2016	60 DAS 26/4/2016		11/5/2016	26/9/2016	6/10/2016

DAS: Days after sowing the seeds. PC1 and PC2: assessments in following plant cane crop

Rainfall data were recorded using Onset HOBO rain gauges (Appendix 3).

For trials CC1 and CC2, statistical analysis of data was conducted using the linear mixed model procedure of SAS. Cover crop coverage and weed coverage were treated as repeated measurements in the analysis model as they were recorded at repeated time intervals in days. A linear mixed model which accounted for the covariance between the repeated measurements by fitting an appropriate covariance structure, in this case sp(pow) (spatial power law) which accounts for correlations decline as a function of time, was fitted. Biomass and N content data were transformed in cover crop yield per hectare and N available per hectare. These new variables were also analysed by SAS using a linear mixed model.

For CC3 and CC4 trials, linear mixed models using restricted maximum likelihood were used to analyse the data ASReml-R (Butler, 2009). The following variables were analysed: “Percentage cover crop coverage in fallow”, “Percentage weed coverage in fallow”, “Percentage weed coverage in plant cane”, “Nitrogen Available” and “Yield (t ha^{-1})”. The significance of the fixed terms were tested using asymptotic Wald statistics so the F-values reported in the analysis of variance table are approximate F values, according to Kenward & Roger (1997). The model assumptions were that the residuals were normally distributed and had a constant variance. Also, that the factor level variances were equal for the treatments, this was tested using the Brown-Forsythe Test. The Shapiro-Wilk test of normality was used to determine if the residuals were normally distributed.

If there was significance evidence from the model that the explanatory variable means differed, Tukey’s multiple comparison test was used to determine which of the means were different at a family significance level of 5%.

5.1.6 Demonstrations

Five demonstration sites were established from Mossman to Tully in 2016-2017. All sites were selected for their potential high weed pressure according to grower’s knowledge. These demonstrations were used to showcase weed management strategies (herbicide choice and spraying equipment) that were identified in the first two years of the project. All demonstrations except one included a comparison of pre-emergent strategies just after harvest followed by post-emergent strategies if necessary. If Guinea or Hamil grass stools were present, alternative herbicide options to diuron were compared. As the project showed that it was ineffective to use directed spray equipment to control perennial grass stools, the herbicide options compared in these demonstrations were spot sprayed.

The purpose of the demonstrations was to deliver weed management information via field days and factsheets, not to collect and analyse data. Weed management messages related to herbicide efficacies, spraying equipment type and set up, spraying cost, legislation and water quality were delivered to growers and industry participants.

Apart from two spot spraying strategies that were not registered, all other strategies tested in the demonstrations were permitted according to herbicide labels. The objective of each strategy was to achieve an effective control of the weed population, and present to growers several efficient options to diuron to control their weed population.

Methodology and outcomes from the demonstrations can be found in the booklet “Developing an alternative herbicide management strategy to replace PSII herbicides in the Wet tropics area- SRA research project 2014050- Demonstrations 2016” https://sugarresearch.com.au/wp-content/uploads/2017/02/Project-2014050-Demonstrations-F-LowRes.pdf

5.1.7 Botanical name of weed species recorded in the trials (Table 21)

Table 21 Common name and Latin name of the Weed species encountered in the trials

Common name	Latin name
Awnless barnyard grass	*Echinochloa colona*
Crowsfoot	*Eleusine indica*
Guinea grass, Hamil grass	*Panicum maximum var maximum*
Green summer grass	*Brachiaria subquadripara*
Paspalum	*Paspalum dilatatum, P. virgatum*
Rushes	*Juncus spp.*
Sour grass	*Paspalum conjugatum*
Summer grass	*Digitaria ciliaris*
Blue top	*Ageratum conyzoides*
Ludwigia	*Ludwigia octovalvis*
Sensitive weed	*Mimosa pudica*
Spiny spider flower	*Cleome aculeata*
Square weed	*Spermacoce latifolia*
Calopo	*Calopogonium mucunoides*
Red convolvulus	*Ipomoea hederifolia*
Pink convolvulus	*Ipomoea triloba*
Stinking passion fruit	*Passiflora foetida*
Nutgrass	*Cyperus rotundus*

5.2 Part B: Varietal susceptibility to herbicides (phytotoxicity screening)

The sub-project objective was to identify a standard methodology for a cost effective variety screening for herbicide tolerance. The following steps were undertaken:

- consultation with the whole industry to select the varieties and herbicides that will be tested
- development of a cost effective methodology based on literature review
- validation of the methodology
- total costing of the screening
- reporting and identification of a service provider.

5.2.1 Consultation with the industry

Late May 2014, an email was sent to all productivity services requiring their input to select cane varieties and herbicide treatments for the phytotoxicity pot trials. They ranked treatments by preference for their region (preferred variety will receive a mark of 100, second choice will receive a mark of 90, third choice will be marked 80 and so on). Their rating was then multiplied by a coefficient proportional to the area grown under cane in each region. All districts but three participated into the treatment selection.

As the maximum number of pots for the experiment was limited to 360 by the infrastructure, a maximum of 90 combinations of herbicide x variety could be compared (four replicates needed for a robust statistical analysis). Eight herbicide treatments (including control) were tested on 11 varieties. Two varieties were used as reference: one known to be not very susceptible to herbicides – Q208[Φ], and one known to be quite sensitive – KQ228[Φ].

5.2.2 Methodology based on literature review

From 1985 to 1992, most phytotoxicity trials in sugarcane in Australia were carried out yearly by BSES. Trials were established in the field (each plot was 2 rows x 4 m long) at different locations with no replication or two replicates, and only visual assessments were carried out.

In 2001, SRDC project BSS186 final report "Development of a method to aid decision making on herbicide use for Australian canegrowers" concluded that spraying at the 3-4 leaf stage of cane varieties grown in pots and measuring elongation and biomass 10 weeks after spraying was a robust technique; however no correlation with yield from field trials was established.

In 2007 and 2008, BSES carried out pot trials with six replicates and assessed mainly shoot elongation and carried out visual assessments.

To assess crop susceptibility to herbicide, the European Plant Protection Organisation has established a standardised protocol for various crops. In Australia, herbicide tolerance testing is conducted annually to provide information on cultivar susceptibilities to commonly used herbicides for a range of broadacre crop species.

From these protocols, the following indicators were shortlisted for their suitability for herbicide tolerance trials in sugarcane:

- Height and biomass: these indicators are reliable according to O'Grady's project. They were also used by BSES in 2007-2008
- Visual symptoms: this indicator is widely used. Scales used to measure crop tolerance to herbicide vary from 0 to 10 in the 1990s to 1 to 9 in the latest trials. They do not take into account deformations and don't differentiate the type of damage (see Table 6)
- NDVI or SPAD: these indicators have not been tested in herbicide tolerance trials in sugarcane but would have the advantage of providing a continuous variable for analysis
- Number of tillers: this indicator was not proven reliable according to O'Grady's SRDC project
- Yield: field trials in sugarcane are the only way to assess a yield impact of the treatments; however they take a long time (15 months) and are high risk (external factors likely to affect yield more than the tested herbicide treatment).

To assess visual damage and measure early impact on growth, pot trials represent less risk than field trials: they are more homogeneous and less susceptible to external factors.

We proposed a two stage evaluation program for herbicide tolerance testing (as in grain crops): the first stage screens most recently released varieties and some max propagation varieties against a range of commercially available herbicides. It is implemented in pots and checked for significant visual damage or growth reduction.

The second stage only tests the combination of variety by herbicide that displayed significant symptoms in the pot trial by comparison with tolerant varieties and untreated control. It is implemented as a field trial and the final yield is measured.

5.2.3 Trials methodology

5.2.3.1 Pot trial

The pot trial was established in 2014 in Mackay and tested:

- 11 varieties: Q240$^{\phi}$, Q252$^{\phi}$, Q232$^{\phi}$, Q242$^{\phi}$, Q253$^{\phi}$, Q238$^{\phi}$, Q249$^{\phi}$, Q250$^{\phi}$, SP801816, Q208$^{\phi}$ and KQ228$^{\phi}$
- 7 herbicides: 2,4-D, metribuzin, ametryn + trifloxysulfuron, asulam, MSMA, 2,4-D + ioxynil and metolachlor compared to an untreated control.

Herbicide treatments were sprayed at their maximum label rate, using the minimum water volume according to the label and using any adjuvant as recommended by the label (Table 22).

Table 22 Details of herbicide treatments in the herbicide tolerance pot trial

active	ametryn/ trifloxysulfuron	MSMA	metolachlor	metribuzin	asulam	2,4-D / ioxynil	2,4-D
Commercial product	Krismat® WG	Monopoly	Clincher® Plus	Soccer®700 WG	Rattler®400	Actril®DS	Amicide® Advance 700
concentration g kg^{-1} or mL L^{-1}	731.5 / 18.5	720	960	700	400	577 / 100	700
max rate kg or L ha^{-1}	2.00	6.60	2.70	2.20	8.50	2.00	3.10
min volume water L ha^{-1}	150	300	60	250	100	100	50
recommended adjuvant	Agral	non-ionic (activator)	non-ionic (activator)	none	Wetspray® 1000	none	Activator®
recommended adjuvant rate mL $100L^{-1}$	250	125	125		200		120

Cane sticks were harvested from the MAPS farm, stripped, and 60 to 80 mm long one eye setts were cut and stored in onion bags overnight at room temperature. The next day, setts were dipped in Shirtan, planted in 80 mm Jiffy pots, watered and placed in the germination chamber. The first trays to germinate were removed from the germination chamber and placed in a glasshouse to slow down their development. The last trays to germinate were left longer in the germination chamber to catch up.

When plants reached the one to three leaf stage, the trays were transferred to outside benches to harden-up. The following week, three seedlings of the same variety were potted in 30 cm pots filled with potting mix. An automatic irrigation system (one 10 L h^{-1} drip per pot) was set up. One stalk per pot was tagged and measured to the height of the terminal visible dewlap (HTVD) before spraying.

At spraying, cane was at the 4-5 leaf stage and actively growing. Pots of the same herbicide treatment were lined up on a spraying area and sprayed on 12/08/2014 using a tractor-mounted 6-tank sprayer.

The trial was set up as randomised complete block design with four replicates.

HTVD of a marked stalk, Normalized Difference Vegetation Index (NDVI) value (using a Trimble Greenseeker), and visual ratings of colour, deformation and necrosis were measured weekly. Two months after spraying, all aerial parts were harvested from each pot and dried out in a drying oven at 75^{o}Cto measure the dry biomass.

All variables were analysed by SAS. Mixed linear models were used to analyse HTVD, NDVI and biomass variables (

Table 23). The visual rating data did not fit any of the models tested when combining all factors (rep, variety, product, date) so data subsets were analysed separately for each date using a Poisson regression and a log transformation.

Table 23 Statistical models used to analyse the herbicide tolerance pot trial data.

Dependent Variable	Greenseeker_value	Log HTVD	Dry biomass
Covariance Structures	Variance Components, Heterogeneous Toeplitz	Variance Components, Unstructured	Variance Components
Subject Effect	Rep x product x variety	Rep x product x variety	Rep x product x variety
Estimation Method	REML	REML	REML
Residual Variance Method	None	None	Profile
Fixed Effects SE Method	Kenward-Roger	Kenward-Roger	Kenward-Roger
Degrees of Freedom Method	Kenward-Roger	Kenward-Roger	Kenward-Roger

5.2.3.2 Field trial

The conclusions from the phytotoxicity pot trial carried out in 2014 pointed to several combinations of herbicide x variety potentially susceptible to yield reduction. The following treatments were compared in a field trial on Meringa SRA station.

- 4 varieties: Q232^(^, Q238^(^ and Q250^(^ plus Q242^(^ used as a reference variety because it received minimum impact in the pot trial.
- 4 herbicides: Krismat®, Clincher®, Monopoly and Soccer®, and an untreated control

On 7/08/2015, the herbicide treatments were sprayed at their maximum label rate, using the minimum water volume according to the label and using any adjuvant as recommended by label (Table 22).

Cane material used in this trial was collected from plant breeding blocks on Meringa SRA station.

We aimed to apply the herbicides when the cane was at its most susceptible stage (4 to 6 leaf stage); however the slow germination of Q232^(^ delayed the ideal timing of spraying the other varieties. As it impacts on results, cane stage at spraying was used as a covariate in the analysis. This consideration illustrates why a pot trial is a more reliable protocol: it makes it possible to control cane growth and therefore spray all varieties on the same day at a similar stage.

Visual rating and HTVD were measured every second week. HTVD was measured on 13 marked stalks in each plot. Final cane yield was measured at harvest using a weigh truck.

All variables were analysed by SAS. Mixed linear models were used to analyse visual rating and yield variables (

Table 24). The Log HTVD data followed a Gamma distribution and the Wald test was performed.

Table 24 Statistical models used to analysis the herbicide tolerance field trial data

Dependent Variable	Visual rating	Yield
Covariance Structures	Variance Components, Spatial Anisotropic Power	Variance Components, Spatial Anisotropic Power
Subject Effect	Plot number	Intercept4
Estimation Method	REML	REML
Residual Variance Method	Profile	Profile
Fixed Effects SE Method	Kenward-Roger	Kenward-Roger

Dependent Variable	Visual rating	Yield
Degrees of Freedom Method	Kenward-Roger	Kenward-Roger

5.2.4 Reporting and identification of a service provider.

A final report including trials methodology, costing and results was combined for the SRA Board to consider future provision of herbicide tolerance screening. The Board decision was communicated to the whole industry.

6 RESULTS AND DISCUSSION

6.1 Part A: Alternatives to PSII herbicides

Results and discussion for each sub-objective defined in the methodology section are presented separately.

6.1.1 Field trials on cost effective pre-emergent herbicide strategies in ratoons using alternatives to diuron

6.1.1.1 Results

Results of the seven trials were grouped when possible to facilitate their interpretation. Six treatments (T1 to T6) and five assessment dates were common to all trials and results were combined and analysed. Seven treatments (T1 to T7) and five assessment dates were common to trials R5, R6 and R7 and results were combined and analysed separately. Graphs are used to display the results of the grouped analyses for the variables "total percentage weed reduction", "grass percentage reduction", broadleaf percentage reduction", "vine percentage reduction" and "sedge percentage reduction".

6.1.1.1.1 Total percentage weed reduction

The combined analysis for all trials (comparing T1 to T6) showed significant differences for the interaction Treatment x date (P<0.001). Results are presented in Figure 9 and mean comparisons for each date are included in the graph. Results indicated no significant difference between Amitron® (T6) and Barrage full rate (T1), showing promise in this future herbicide to replace diuron based herbicide. Results also indicated that the performance of Flame® (T3), Balance® (T4) or Barrage low rate (T2) was lower and short lasting compared to Barrage (T1). Clincher® (T5) was proven ineffective on trash blanket.

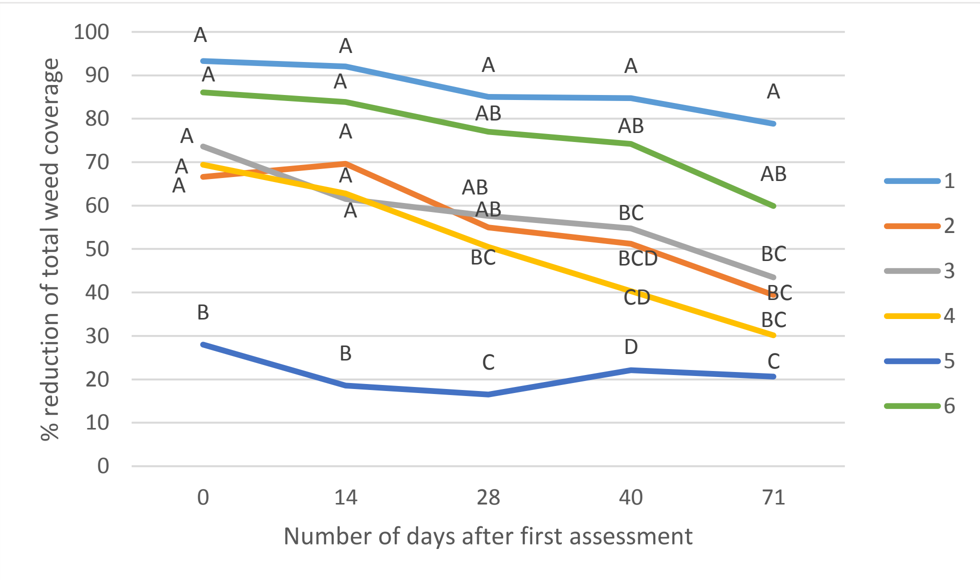


Figure 9 Mean of percentage reduction of total weed coverage compared to the adjacent untreated controls for the seven trials[1].

[1] The x-axis is in number of days after the first assessment started at each trial site. For each date, same letter mean no significant difference between treatments. Treatment code: 1-Barrage full rate; 2-Barrage low rate, 3-Flame®, 4-Balance®, 5-Clincher®, 6-Amitron®.

The combined analysis for trials R5, R6 and R7 (comparing the seven herbicide treatments) showed no significant difference for the interaction Treatment x date (P 0.57), whereas significant differences existed between treatments (P<0.001). Therefore, average percentage reductions across all assessment dates are presented in Figure 10.

Results indicated that Bobcat® i-MAXX (T7) was more effective than Diuron low rate (T2) and Clincher® (T5) across the three sites. Results also showed that Bobcat® i-MAXX (T7) was as effective as Barrage full rate (T1). As in the combined analysis for all trials, Amitron® (T6) again showed promise with no significant differences among the best performing herbicides. Despite no significant differences with Barrage full rate (T1), Flame® (T3), Balance® (T4) and Barrage low rate (T2) did not match Barrage performance.

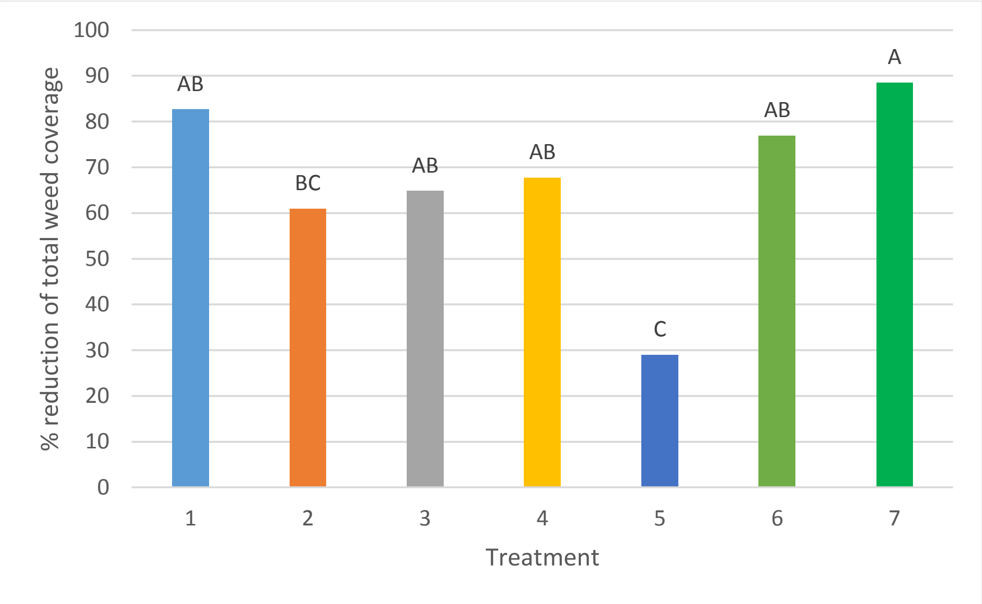


Figure 10 Mean of percentage reduction of total weed coverage compared to the adjacent untreated controls for three trials[1]

6.1.1.1.2 Percentage grass reduction

The combined analysis for all trials showed no significant differences for the interaction Treatment x date (P 0.56) and significant differences between treatments (P 0.046); however, mean comparisons between treatments did not reveal any differences. The differences must be due to a random chance. In other words, this falls in the 5 % error that we say treatments are different when actually they are not. The results showed that Barrage full rate (T1) and Flame® (T3) tended to have the best long term efficacy on grasses across the trials. Balance® (T4), usually effective on grasses, was short lasting in these trials, with efficacy dropping below 60% one month after incorporation. Amitron® (T6) also showed weaknesses to control grasses (Figure 11). Clincher® (T5) and Barrage low rate (T2) performance against grasses was low (50% reduction).

[1] Same letter means no significant difference between treatments. Treatment code: 1-Barrage full rate; 2-Barrage low rate, 3-Flame®, 4-Balance®, 5-Clincher®, 6-Amitron®, 7- Bobcat® i-MAXX

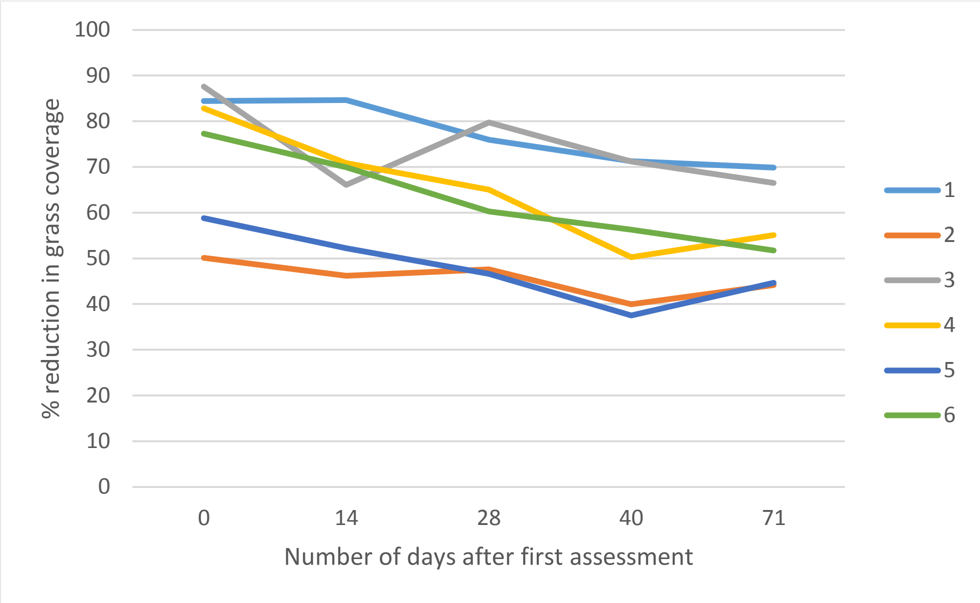


Figure 11 Mean of percentage reduction of grass coverage compared to the adjacent untreated controls for the seven trials[1]

The combined analysis for trials R5, R6 and R7 that compared the seven herbicide treatments showed no significant difference for the interaction Treatment x date (P 0.92) and no significant differences between treatments (P 0.41). However Bobcat® i-MAXX (T7) tended to be more effective than the other treatments across the assessment period with efficacy above 80% for 71 days after incorporation (Figure 12).

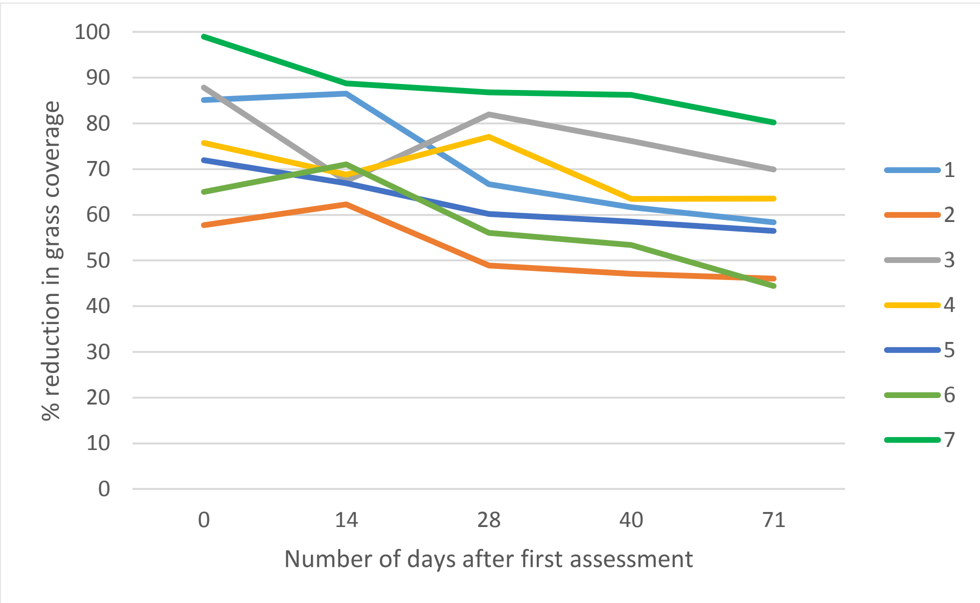


Figure 12 Mean of percentage reduction of grass coverage compared to the adjacent untreated controls for three trials[1]

6.1.1.1.3 Percentage broadleaf reduction

The combined analysis for all trials (comparing T1 to T6) showed no significant difference for the interaction Treatment x date (P 0.11), whereas significant differences existed between treatments

[1] The x-axis is in number of days after the first assessment started at each trial site. Treatment code: 1-Barrage full rate; 2-Barrage low rate, 3-Flame®, 4-Balance®, 5-Clincher®, 6-Amitron®.

(P<0.001). Therefore, the average percentage reductions across all assessment dates are presented in Figure 13.

The results showed that Amitron® (T6) was as effective to control the broadleaves as Barrage full rate (T1) across six trial sites (not enough broadleaves at one site to assess). Balance® (T4) was significantly less effective on broadleaves than Barrage high rate (T1) or Amitron® (T6) (Figure 13). Site specific results showed that Balance® (T4) was ineffective to control square weed (See Project report update in Appendix 5).

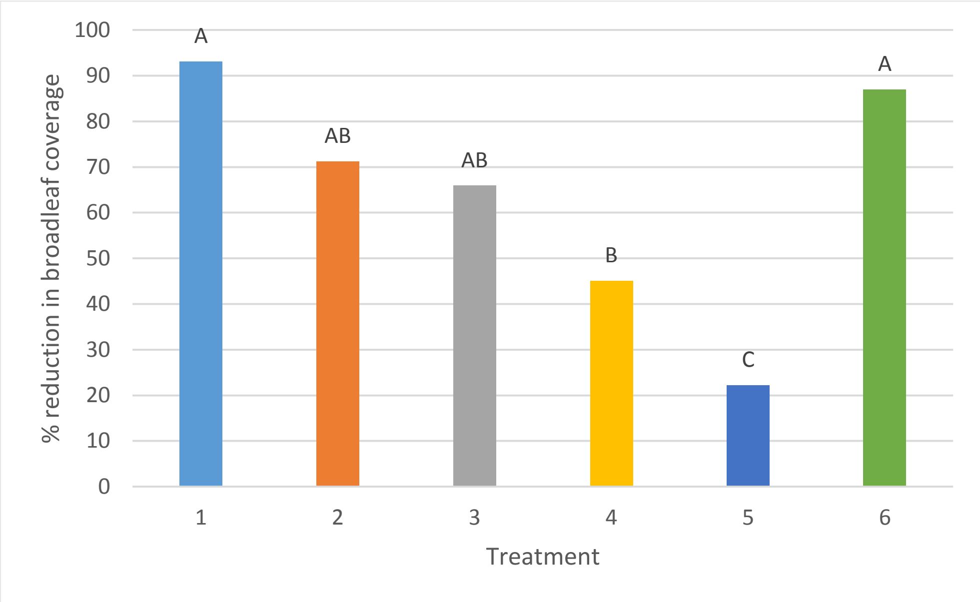


Figure 13 Mean of percentage reduction of broadleaf coverage compared to the adjacent untreated controls for six trials[1]

The combined analysis for trials R5, R6 and R7 (comparing the seven herbicide treatments) showed no significant difference for the interaction Treatment x date (P 0.06), whereas significant differences existed between treatments (P<0.001). Therefore, average percentage reductions across all assessment dates are presented in Figure 14.

The results showed that Amitron® (T6) and Bobcat® i-MAXX (T7) were as effective as Barrage full rate (T1) to control the broadleaves across the three trial sites. Balance® (T4), Flame® (T3) and Barrage low rate (T2) were only 60 - 70 % effective.

[1] Same letter means no significant difference between treatments. Treatment code: 1-Barrage full rate; 2-Barrage low rate, 3-Flame®, 4-Balance®, 5-Clincher®, 6-Amitron®

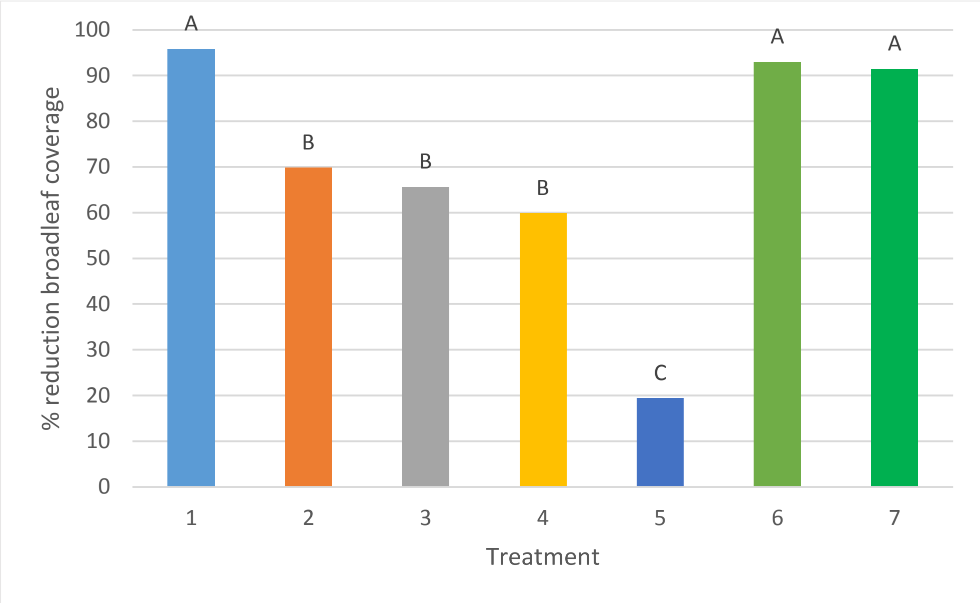


Figure 14 Mean of percentage reduction of broadleaf coverage compared to the adjacent untreated controls for three trials[1]

6.1.1.1.4 Percentage vine reduction

The combined analysis for all trials showed a significant difference for the interaction Treatment x date (P <0.001). Results are presented in Figure 15 and mean comparisons for each date are included in the graph.

Despite clear differences in the graph, only Clincher® (T5) was significantly less effective than Amitron® (T6) for one assessment date. Amitron® (T6) tended to be as effective as Barrage full rate (T1) to control the vines, at least for the first month after incorporation. Site specific results showed that Flame® (T3) was performing particularly well in sites with red and pink convolvulus; whereas Balance® (T4) was more effective against Calopo. Refer to project report update in Appendix 5.

These results highlight the benefit of using two actives to widen the spectrum of efficacy: Bobcat® i-MAXX and Barrage are a premix of imazapic or diuron as a grass control and hexazinone as a broadleaf control.

[1] Same letter means no significant difference between treatments. Treatment code: 1-Barrage full rate; 2-Barrage low rate, 3-Flame®, 4-Balance®, 5-Clincher®, 6-Amitron®, 7- Bobcat® i-MAXX.

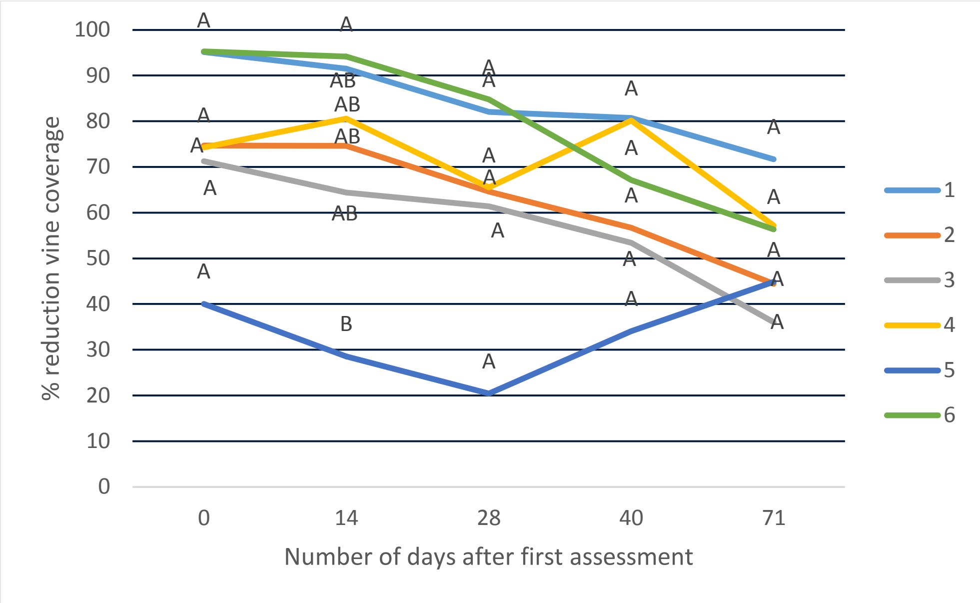


Figure 15 Mean of percentage reduction of vine coverage compared to the adjacent untreated controls for the seven trials[1]

The combined analysis for trials R5, R6 and R7 (comparing the seven herbicide treatments) showed no significant difference for the interaction Treatment x date (P 0.45) and no significant difference for Treatment (P 0.5). Bobcat® i-MAXX (T7) performance seemed equivalent to Amitron® (T6) and Barrage (T1) at most assessment dates. Results need to be taken with caution as the vine population was quite low in these three trials (Figure 16).

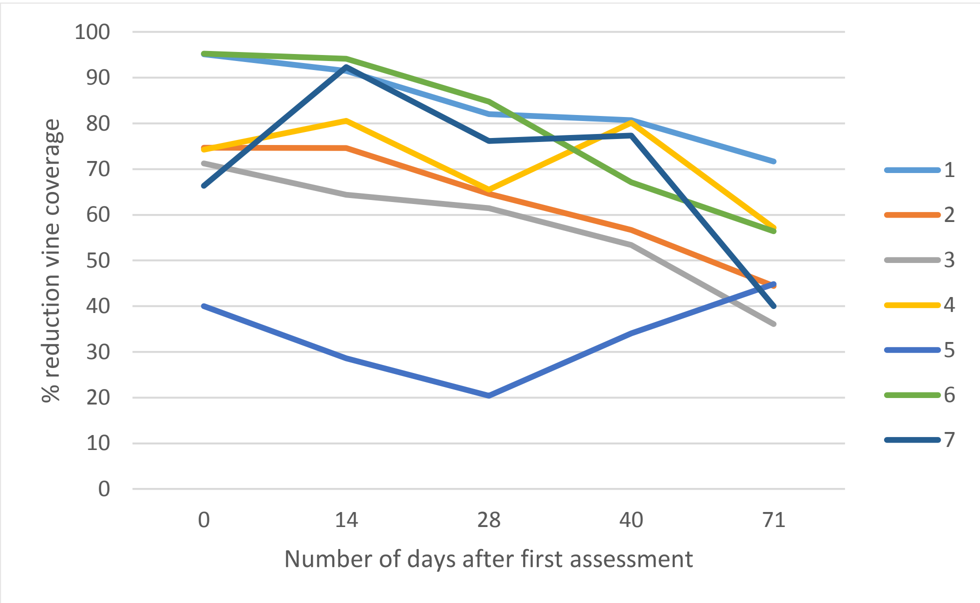


Figure 16 Mean of percentage reduction of vine coverage compared to the adjacent untreated controls for three trials[1]

[1] The x-axis is in number of days after the first assessment started at each trial site. For each date, same letter means no significant difference between treatments. Treatment code: 1-Barrage full rate; 2-Barrage low rate, 3-Flame®, 4-Balance®, 5-Clincher®, 6-Amitron®.

6.1.1.1.5 Percentage sedge reduction

Only three of the seven trials had enough data on sedges to be rated. The combined analysis of these trials (R2, R4, R6) showed no significant differences for the interaction Treatment x Date (P 0.99) and for the effect Treatment (P 0.54). Flame® (T3), Bobcat® i-MAXX (T7) Barrage full rate (T1) and Amitron® (T6) tended to be the most effective options to control the sedges (Figure 17).

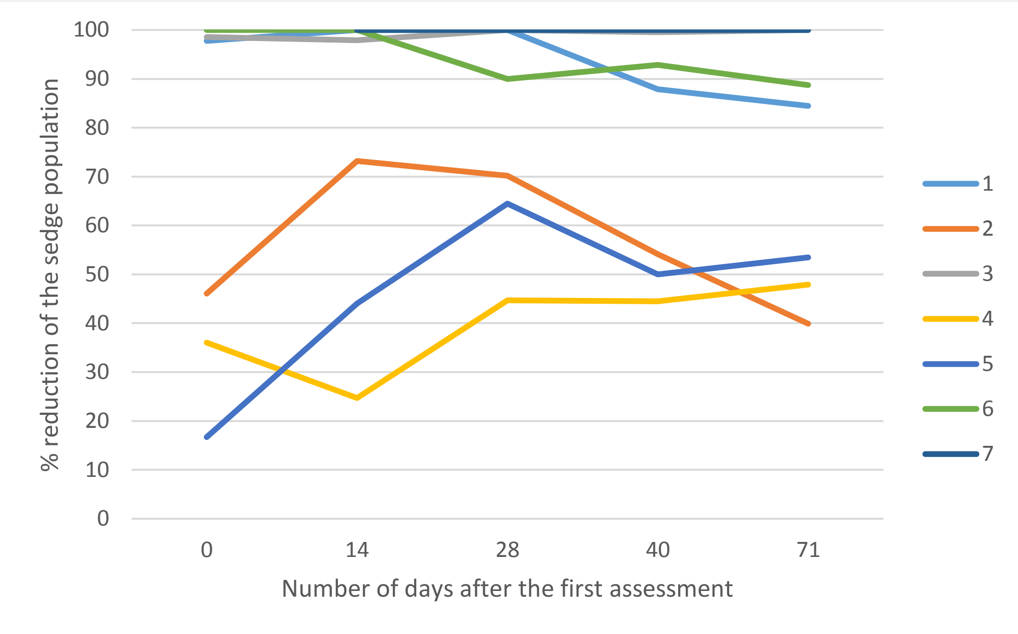


Figure 17 Mean of percentage reduction of sedge coverage compared to the adjacent untreated controls for two trials[1]

6.1.1.2 Discussion

Barrage high rate (T1) was a very effective herbicide across all trial sites, regardless of the soil type and the weed composition. It had a particularly long period of efficacy regardless of the soil type and the rainfall amount when compared with other herbicides like Flame® and Balance®. In dry conditions (2014-15), Barrage high rate was particularly stable during the very long drought period that preceded its incorporation, and was very efficient at controlling weeds after activation. Barrage high rate is not registered in the Wet Tropics anymore, but was used as a reference treatment in the trials.

Bobcat® i-MAXX efficacy was similar to Barrage full rate at the three trial sites where it was tested in 2015-16. Like Barrage high rate, it had a particularly long period of efficacy regardless of the soil type and the rainfall amount when compared with other herbicides like Flame® and Balance®. The addition of hexazinone to imazapic is an effective complement to control a wider weed spectrum and extend its period of activity.

Against broadleaves and vines, Amitron® was as effective as Bobcat® i-MAXX or Barrage high rate, however its efficacy against grasses was quite low and short lasting. Amitron® registration is pending.

[1] The x-axis is in number of days after the first assessment started at each trial site. For each date, same letter mean no significant difference between treatments. Treatment code: 1-Barrage full rate; 2-Barrage low rate, 3-Flame®, 4-Balance®, 5-Clincher®, 6-Amitron®, 7- Bobcat® i-MAXX.

Flame® performance varied in relation to the weed species present in the trials. It was particularly effective against grasses and sedges but its efficacy against broadleaves was only short lived and it did not control the legume vines (like calopo). Its efficacy was reduced in the soil with high Fe content (328 mg kg^{-1} in trial R7 and 202 mg kg^{-1} in trial R6), whereas it was not affected by high Al content in acidic soils (68 mg kg^{-1} in trial R5). Individual trial results are reported in the project report updates for each district in Appendix 5, Appendix 6, and Appendix 7.

Balance® performance varied in relation to the weed species present in the trials. It was more effective against the grasses than the broadleaves. It was particularly effective against legume vines (calopo), but controlled poorly the broadleaf square weed. Its main downfall was a short period of efficacy. Its efficacy was not limited by the soil type as suggested by the label and no phytotoxicity on ratoon cane was observed. Balance® label states:

> *DO NOT apply at any rate to soils of cation exchange capacity (C.E.C.) less than 3 meq.100g^{-1} or with clay content less than 10%, or with organic carbon content of less than 0.8%.*
>
> *DO NOT apply at rates of 125 g ha^{-1} or higher to soils with organic carbon content of less than 1.0%, unless the cation exchange capacity (C.E.C.) is above 9.5 meq.100g^{-1}.*
>
> *DO NOT apply at rates of 125 g ha^{-1} or higher to soils of cation exchange capacity (C.E.C) less than 4.5 meq.100g^{-1}.*

In trials R1 and R3, CEC was 2.5 and 2.66 meq.100 g^{-1} respectively and Balance® should not have been applied according to the label. No toxicity on cane was observed, likely because R1 and R3 were third and fourth ratoons with a well established root system. In trials R4, R5, R6 and R7, CEC values were between 3.12 and 4.2 meq.100 g^{-1}, and again no phytotoxicity on cane was observed despite Balance® being applied at full rate (Refer to soil analysis report in Appendix 4). Phytotoxicity on <u>ratoon</u> cane pre-emerged with Balance® seems unlikely regardless of the soil type.

Barrage low rate was more effective at controlling broadleaves than grasses; however, its period of efficacy was quite short. In trials where its incorporation was overly delayed, Barrage low rate did not perform.

Clincher® efficacy was mediocre on broadleaves; however it had some relative efficacy against grasses in two trials. The best results were obtained when incorporation by rainfall occurred soon after spraying (as Clincher® is not UV stable) as in trials R5 and R6 with rainfall occurring within two weeks after harvest. It remains a bad option to consider after harvest in rainfed systems.

To summarise, Bobcat® i-MAXX (T7) was the most efficient broad spectrum herbicide with efficacies similar to Barrage full rate (T1). Amitron® (T6) was particularly effective against broadleaves and vines but its efficacy against grasses was limited. Flame® (T3), Balance® (T4) or Barrage low rate (T2) used alone were not controlling enough weed species. Amitron®, Flame®, Balance® and Barrage low rate would require a mixing partner to enlarge their efficacy spectrum when required by the weed species present in the block.

6.1.2 Field trials on cost effective pre-emergent herbicide strategies in plant cane using alternatives to PSII herbicides

Due to different treatments compared in trials PC1 and PC2, results from each trial are presented separately. Both are interpreted in a common discussion.

6.1.2.1 Results trial PC1

The first 10 mm rain event occurring 10 days after spraying successfully incorporated and activated all pre-emergent herbicides. For this trial, the total percentage reduction, the percentage grass reduction and the percentage vine reduction can be presented in one table due to the simplicity of the analyses outputs (no significant difference for the interaction Treatment x Date for each variable).

6.1.2.1.1 Percentage weed reduction

All herbicides were very efficient in controlling the total weed population (>80% reduction) and the grass population (>90% reduction) at this site for one month after spraying without significant differences for the interaction Treatment x Date and no significant differences between treatments. All treatments except Isoxaflutole alone (Isox) were more than 95% effective to control the vines. Isoxaflutole alone was significantly less effective with 88% vine reduction. Average percentage reductions for the two assessment dates are presented in Table 25.

Table 25 Average percentage reduction in pre-emergent trial PC1

	Total percentage weed reduction		Percentage grass reduction		Percentage vine reduction		
Treatment	Mean estimate	Standard Error	Mean estimate	Standard Error	Mean estimate	Standard Error	Letter Group
Pend/atraz	86.3	7.1	91.4	2.9	99.8	2.4	A
Meto/atraz	92.6	7.1	93.7	2.6	99.1	2.3	A
Amet/metrib	83.3	7.0	97.3	2.6	96.7	2.3	A
Isox	89.0	6.9	100	2.6	88.0	2.3	B
Isox/metrib	92.8	7.0	99.7	2.6	99.8	2.3	A
Imaz/Bal	89.9	6.9	98.5	2.6	96.0	2.3	A
Meto/metrib	95.4	6.9	94.3	2.6	99.8	2.3	A
Flumio	91.4	7.1	98.5	2.6	99.1	2.3	A
P Treatment	0.93		0.15		0.0332		
P Treatment x Date	0.66		0.57		0.89		

6.1.2.1.2 Phytotoxicity on cane

Unlike trials with pre-emergent herbicides done in ratoon cane during the course of this project, some strong phytotoxicity symptoms were observed after product application in this trial. For this data set the analysis revealed a significant interaction Treatment x Date. Results are presented for each date in Table 26. Isoxaflutole and isoxaflutole+ metribuzin were more phytotoxic than any other treatments at both assessment dates. Sixteen days after spraying, isoxaflutole was more phytotoxic than isoxaflutole + metribuzin. As the soil analysis revealed a CEC of 4.2 meq.100 g^{-1}, Balance® should have been only applied at a reduced rate of 125 g instead of 200 g ha^{-1}. As expected, the highest phytotoxicity symptoms were recorded when Balance® was applied at full rate (200 g ha^{-1}). When applied at 150 g ha^{-1} in combination with metribuzin, the toxicity symptoms were slightly milder two weeks after spraying, but were then similar one month after application. When applied at 100 g ha^{-1} in combination with imazapic, no phytotoxicity was recorded, in accordance with labels recommendations of rate below 125 g ha^{-1} for CEC below 4.5 meq. 100 g^{-1}.

Table 26 Average phytotoxicity rating on cane in pre-emergent trial PC1

	16 DAT			29 DAT		
Treatment	**Mean estimate**	**Standard Error**	**Letter Group**	**Mean estimate**	**Standard Error**	**Letter Group**
Isox	2.62	0.21	A	3.42	0.23	A
Isox/metrib	1.99	0.26	B	3.12	0.25	A
Meto/atraz	0.99	0.21	C	1.17	0.28	B
Imaz/Bal	0.99	0.21	C	1.11	0.24	B
Meto/metrib	0.98	0.21	C	1.11	0.24	B
Amet/metrib	0.96	0.21	C	1.07	0.22	B
Pend/atraz	0.95	0.21	C	1.13	0.29	B
Flumio	0.95	0.21	C	1.04	0.21	B
P Treatment x Date	0.0002					

6.1.2.2 Results trial PC2

A 5 mm rain event two days after spraying followed by 40 mm eight days later successfully incorporated and activated the pre-emergent herbicides. The weed population in this trial was mainly composed of grasses. The percentage total weed reduction and the percentage grass reduction data are presented in two separate sections due to the complexity of the analysis output (significant interaction between treatment and date in both data sets). There was not enough data on broadleaves or vines in the trial to analyse.

6.1.2.2.1 Percentage total weed reduction

The analysis revealed a significant interaction Treatment x Date. Results are presented for each date in Table 27.

All herbicides were very efficient in controlling the weed population (more than 75% efficacy) at this site for one month after spraying (at 14 DAT and 32 DAT) without significant differences between them.

At 42 DAT, flumioxazin+ atrazine was significantly less effective than the strategies including imazapic or metribuzin. Despite being a label recommendation, the addition of atrazine to Valor® was detrimental to the efficacy of flumioxazin. The best long term weed control was achieved with imazapic + amicarbazone and metribuzin mixed with ametryn, imazapic or metolachlor.

Table 27 Percentage total weed reduction in pre-emergent trial PC2

	14 DAT				32 DAT				42 DAT			
Treatment	Estimate	Standard Error	Mean back transformed	Letter Group	Estimate	Standard Error	Mean back transformed	Letter Group	Estimate	Standard Error	Mean back transformed	Letter Group
Imaz/amicar	4832	533	98.3	A	4802	429	98.0	A	4559	464	95.5	A
Imaz/metrib	3927	535	88.6	A	4739	443	97.4	A	4550	477	95.4	A
Amet/metrib	4821	520	98.2	A	4411	446	93.9	A	4002	512	89.5	A
Meto/metrib	4784	531	97.8	A	3563	430	84.4	A	3726	466	86.3	A
Meto/atraz	4694	515	96.9	A	3538	445	84.1	A	2879	491	75.9	AB
Pend/atraz	4239	528	92.1	A	3287	431	81.1	A	2672	493	73.1	AB
Flumio	4253	529	92.2	A	3971	429	89.1	A	2453	454	70.0	AB
Flumio/atraz	4817	528	98.2	A	2837	451	75.3	A	605	507	34.8	B
P Treatment x Date	<0.0001											

6.1.2.2.2 Percentage grass reduction

The analysis revealed a significant interaction Treatment x Date. Results are presented for each date in Table 28.

All treatments were effective (>98% efficacy) to control the grasses at 14 days after spraying without significant differences between them.

At 32 DAT, flumioxazin + atrazine was less effective to control the grasses than both treatments including imazapic.

At 42 DAT, imazapic + metribuzin was more efficient against grasses than metolachlor + atrazine, flumioxazin and flumioxazin + atrazine. Imazapic + amicarbazone was also more efficient than the treatments including flumioxazin. Flumioxazin + atrazine was the least effective treatment against the grasses with only 37% reduction whereas all the other treatments were above 75% reduction.

Table 28 Percentage grass reduction in pre-emergent trial PC2

Treatment	14 DAT				32 DAT				42 DAT			
	Estimate	Standard Error	Mean back transformed	Letter Group	Estimate	Standard Error	Mean back transformed	Letter Group	Estimate	Standard Error	Mean back transformed	Letter Group
Imaz/metrib	4891	370	98.9	A	4995	318	100.0	A	4974	333	99.7	A
Imaz/amicar	4893	368	98.9	A	4937	309	99.4	A	4902	328	99.0	AB
Amet/metrib	4896	362	99.0	A	4687	320	96.8	AB	4382	357	93.6	ABC
Meto/metrib	4813	368	98.1	A	3769	310	86.8	AB	4126	330	90.9	ABC
Pend/atraz	4843	367	98.4	A	3658	311	85.5	AB	3307	343	81.3	ABC
Meto/atraz	4814	358	98.1	A	3813	319	87.3	AB	3234	347	80.4	BC
Flumio	4894	367	98.9	A	4585	309	95.8	AB	2922	321	76.4	C
Flumio/atraz	4896	365	99.0	A	3039	323	78.0	B	703	352	37.5	D
P Treatment x Date	<0.0001											

6.1.2.2.3 Phytotoxicity on cane

Slight phytotoxicity symptoms were visible only at the first assessment date (14 DAT). The data analysis revealed no significant difference between treatments. We can note that treatments including either ametryn or imazapic displayed slight phytotoxicity, but these symptoms were only temporary (Table 29).

Table 29 Phytotoxicity rating on cane in pre-emergent trial PC2

Treatment	14 DAT	
	Mean Estimate	Standard Error
Amet/metrib	2.00	0.35
Imaz/metrib	2.00	0.35
Imaz/amicar	2.00	0.35
Pend/atraz	1.33	0.35
Meto/atraz	1.33	0.35
Meto/metrib	1.33	0.35
Flumio	1.00	0.35
Flumio/atraz	1.00	0.35
P Treatment x Date	0.215	

6.1.2.3 Discussion

In trial PC1, all herbicide treatments adequately controlled the weed population for 30 days. The duration of control required before fill-in was very short and it is likely that some herbicides tested would have provided a longer protection, however it is difficult for growers to predict the exact period of efficacy needed (related to weather conditions).

Apart from flumioxazin + atrazine, all other treatments in trial PC2 also achieved efficacies above 80% for the first month after spraying. 42 days after spraying, only four herbicides treatments were more than 80% effective to control the weeds present at trial PC2 (mainly Guinea grass seedlings). They are presented below by increasing cost per hectare.

- imazapic + metribuzin ($67 / ha)
- metolachlor + metribuzin ($88 / ha)
- ametryn + metribuzin ($109 / ha)
- imazapic + amicarbazone (cost not available for amicarbazone)

In trial PC2, metolachlor + atrazine, pendimethalin + atrazine and flumioxazin reduced the weed coverage by only 70% at 42 DAT. The addition of atrazine to flumioxazin was detrimental to the treatment efficacy which dropped below 30% at 42 DAT.

In trial PC1, all herbicide treatments were very effective against the grasses and the vines with the exception of isoxaflutole alone, which was less effective against the vines. Isoxaflutole weakness against convolvulus vines is well known. If convolvulus vines are expected, it should not be the preferred control option.

In trial PC2, mixtures including imazapic (with metribuzin or amicarbazone) were the best options to control Guinea grass seedlings (cost $67 for the mix with metribuzin). Metribuzin mixed with ametryn or metolachlor were also very effective, but more expensive ($109 and $88 per ha). The traditional grower treatments (metolachlor + atrazine at $57 per ha; pendimethalin + atrazine at $81 per ha) were slightly less effective to control Guinea grass seedlings in trial PC2. The new active ingredient flumioxazin was very effective for the first 32 days but its efficacy declined to 70% by 42 DAT.

In terms of phytotoxicity on cane, treatments with Balance® above 125 g ha^{-1} created severe phytotoxicity and some visible delay in cane growth in trial PC1. As the soil analysis revealed, Balance® should have been only applied at a reduced rate of 125 g instead of 200 g ha^{-1}. The highest phytotoxicity symptoms were recorded when Balance® was applied at full rate (200 g ha^{-1}). When applied at 150 g ha^{-1} in combination with metribuzin the toxicity symptoms were slightly milder. When applied at 100 g ha^{-1} in combination with imazapic, no phytotoxicity symptoms occurred. These results highlight the importance of using a soil analysis before applying isoxaflutole, especially in plant cane. No phytotoxicity issues were recorded during the course of this project when using isoxaflutole just after harvest on trash blanketed ratoons, regardless of the soil type.

When used at lower rate, isoxaflutole applied in combination with another herbicide like imazapic is still an effective option (free of PSII herbicides) that needs consideration.

In trial PC2, no isoxaflutole was applied as the CEC was low: 2.4 meq. 100 g^{-1}. No notable phytotoxicity on cane was observed with the tested treatments.

This study shows that most cost effective control strategies in plant cane included PSII herbicides. The new non PSII herbicide Valor® applied at 350 g $ha^{-1}$was effective when only a short period of control was required. Increasing the application rate would have likely provided a longer control. The mix isoxaflutole and imazapic was very cost effective ($28 / ha) but can result in phytotoxicity on cane if used in an inappropriate soil type. A big rainfall event moving the herbicides to the cane root zone could also be a potential issue for the cane.

6.1.3 Field and pot trials on cost effective post-emergent herbicide strategies to control hard-to-kill grasses using alternatives to diuron

6.1.3.1 Field trials results

To facilitate data interpretation, data from the four trials were grouped. Phytotoxicity on grass in the row/inter row, phytotoxicity on cane, percentage grass reduction, and cane yield are presented separately.

6.1.3.1.1 Phytotoxicity on grass in the row

The combined analysis of the data “phytotoxicity rating on grass in the row” across the four sites shows a significant difference for the interaction site x treatment x date (P 0.012). Results of analysis at each trial site are presented in Figure 18, which displays the confidence interval for each treatment. Figure 19 summarises the data from the four trials.

Across all sites and all dates, treatments 4 and 5 were the most damaging on the perennial grasses in the row, especially at 30 and 45 DAT whereas treatments 1 and 2 had the lowest visible impact on the grasses. Treatments 4 and 5 involved the use of isoxaflutole + MSMA in the row (using Irvin leg or shield side nozzles) which were very damaging on the perennial grasses. Treatment 1 consisted of an early spray of asulam over the row, followed by glyphosate interrow using a shield. Treatment 2 consisted on a late application of diuron low rate + paraquat using an octopus leg.

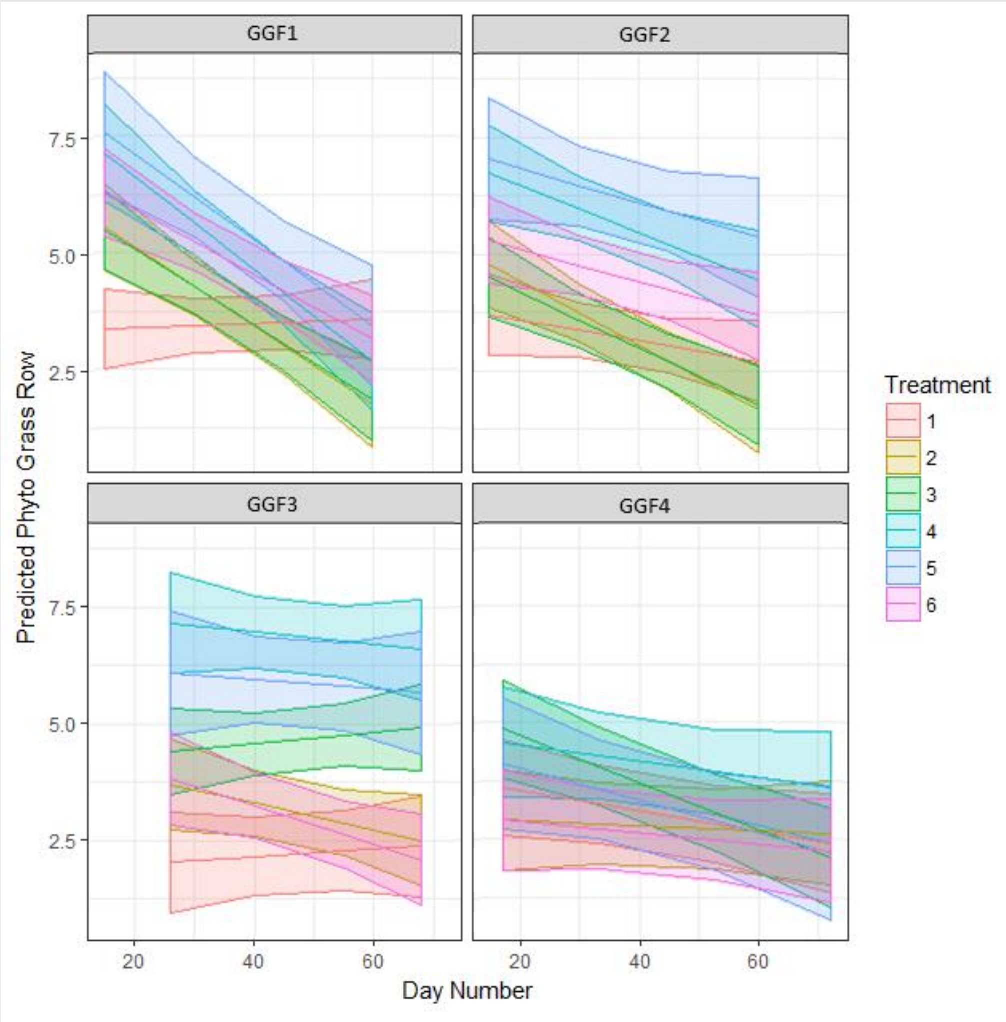


Figure 18 Mean phytotoxicity on grass in the row and confidence interval at each trial site[1]

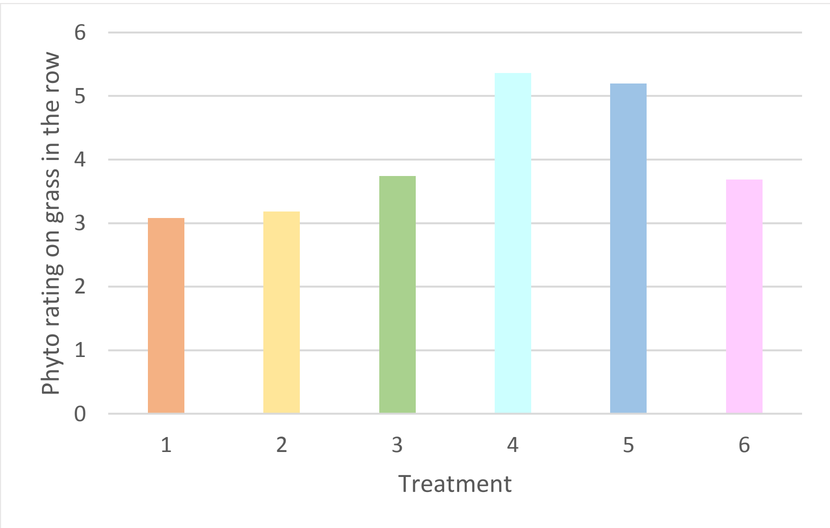


Figure 19 Phytotoxicity rating on grass in the row (mean of four trials across all dates)[1]

[1] T1: asulam banded spray (early), then glyphosate interrow using shield (late); T2: diuron low rate + paraquat using octopus leg (late); T3: isoxaflutole low rate + paraquat using octopus leg (late);T4: isoxaflutole low rate + MSMA using octopus leg (late); T5: isoxaflutole low rate + MSMA in the row/ glyphosate interrow using shield (late); T6: isoxaflutole low rate + MSMA in the row/glyphosate interrow using QDAF dual herbicide spray bar (late).

6.1.3.1.2 Phytotoxicity on grass in the interrow

The combined analysis of the data "phytotoxicity rating on grass in the interrow" across the four sites shows a significant difference for the interaction site x treatment x date (P <0.001). Results of analysis at each trial site are presented in Figure 21, which displays the interval of confidence for each treatment. Figure 22 summarises the data from the four trials.

Across all sites and all dates, treatments 1, 5 and 6 were the most damaging on the perennial grasses in the interrow, whereas treatments 2 and 3 had the lowest visible impact on the grasses in the interrow. Treatments 1 and 5 involved the application of glyphosate with a shield, which is the most effective way to control grasses in the interrow. Treatment 6 was also effective as it also involved the use of glyphosate without a shield. Treatments 2, 3 and 4 were all applied with an Irvin leg. Among those, the best control was obtained for treatment 4 using Balance® plus Daconate®.

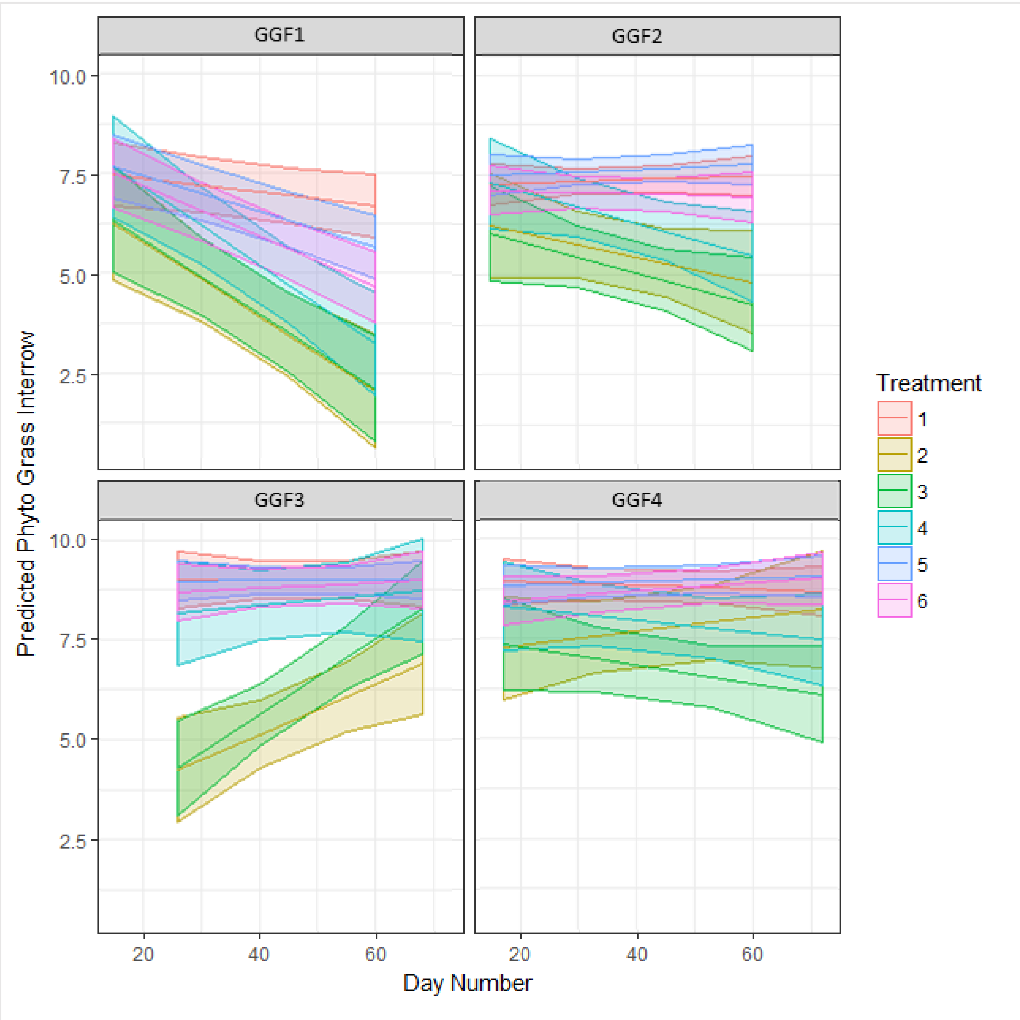


Figure 20 Mean phytotoxicity on grass in the interrow and confidence interval at each trial site[1]

[1] T1: asulam banded spray (early), then glyphosate interrow using shield (late); T2: diuron low rate + paraquat using octopus leg (late); T3: isoxaflutole low rate + paraquat using octopus leg (late);T4: isoxaflutole low rate + MSMA using octopus leg (late); T5: isoxaflutole low rate + MSMA in the row/ glyphosate interrow using shield (late); T6: isoxaflutole low rate + MSMA in the row/glyphosate interrow using QDAF dual herbicide spray bar (late).

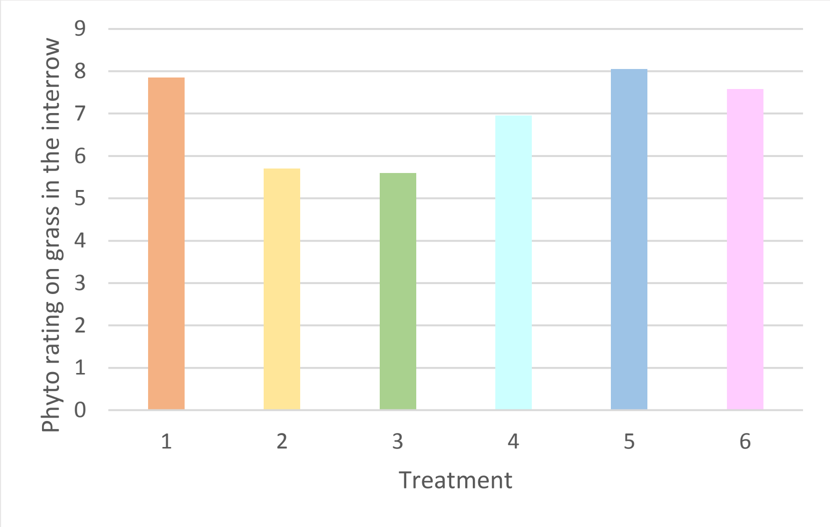


Figure 21 Phytotoxicity rating on grass in the interrow (mean of four trials across all dates)[1]

6.1.3.1.3 Phytotoxicity on cane

The combined analysis of the data "phytotoxicity rating on cane" across the four sites shows a significant difference for the interaction site x treatment x date (P <0.001). Results of analysis at each trial site are presented in Figure 23, which displays the interval of confidence for each treatment. Figure 24 summarises the data from the four trials.

Across all sites and all dates, treatments 3, 4 and 5 tended to be the most damaging on cane, whereas treatments 1 and 6 had the lowest impact on cane appearance. Treatments 3, 4 and 5 involved the use of isoxaflutole + paraquat or MSMA in the row (using Irvin leg or shield side nozzles) which were very damaging to the cane. Even if T4 and T5 were the most effective on grasses, these treatments were also detrimental to the cane. It is interesting to note that T3 was more detrimental to cane than perennial grasses, which makes this product combination inadequate.

In trials GGF1 and GGF2, symptoms from treatment 1 increased overtime. The early application of asulam did not result in any phytotoxicity symptoms on cane, however the following application of glyphosate with the shield must have created spray drift on the cane row in trials GGF1 and GGF2. It is to note the second application on T1 was sprayed 30 and 15 days later than the first application in GGF1 and GGF2 respectively, and therefore the curve for T1 should be shifted 30 and 15 days to the left if the second herbicide application is to be compared to the other treatments. This significant difference at 60 DAT is therefore mainly due to this timing artefact. This spray drift phenomenon did not occur in 2015 trials (GGF3 and GGF4) as the shield was lowered further to avoid drift.

[1] T1: asulam banded spray (early), then glyphosate interrow using shield (late); T2: diuron low rate + paraquat using octopus leg (late); T3: isoxaflutole low rate + paraquat using octopus leg (late);T4: isoxaflutole low rate + MSMA using octopus leg (late); T5: isoxaflutole low rate + MSMA in the row/ glyphosate interrow using shield (late); T6: isoxaflutole low rate + MSMA in the row/glyphosate interrow using QDAF dual herbicide spray bar (late).

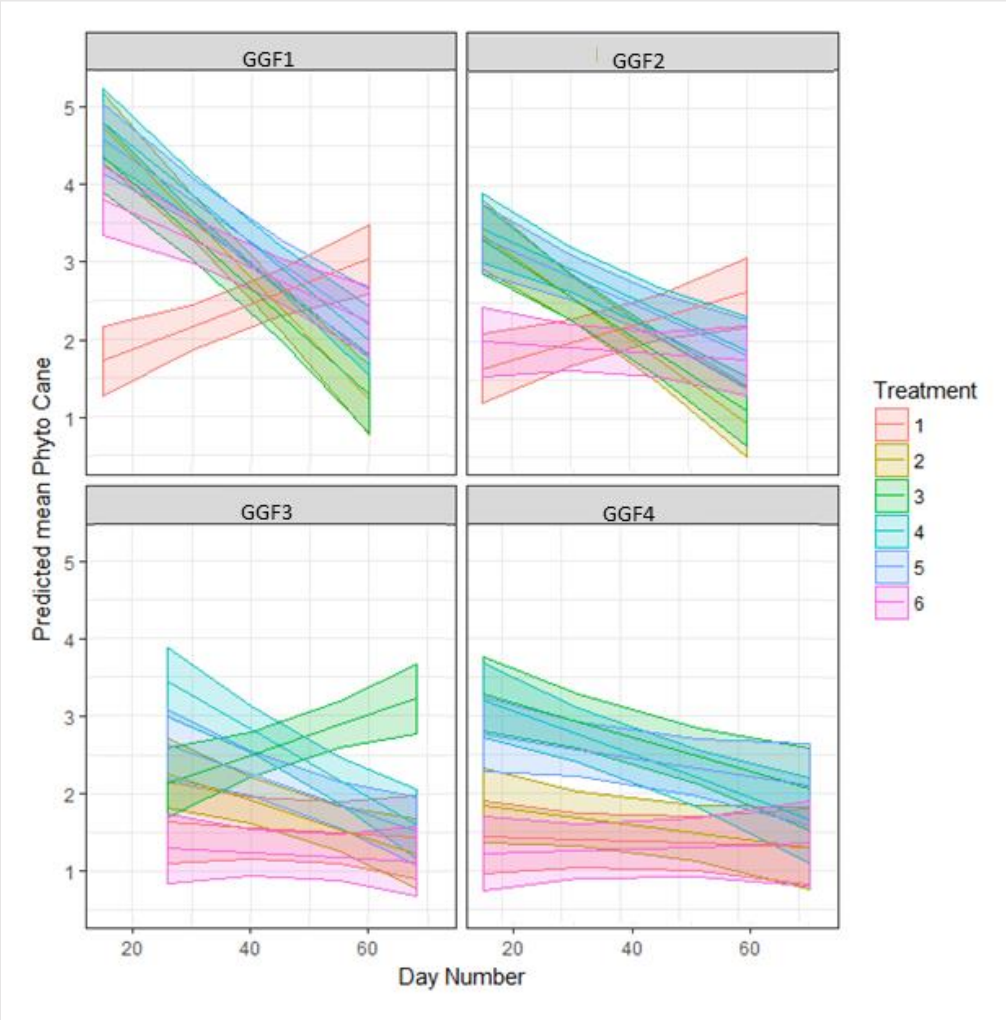


Figure 22 Mean phytotoxicity on cane and confidence interval at each trial site[1]

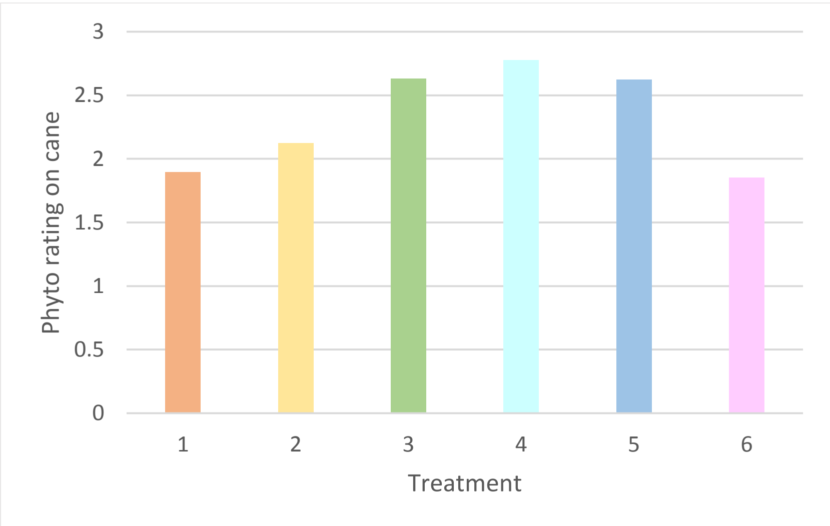


Figure 23 Phytotoxicity rating on cane (mean of four trials across all dates)[1]

[1] T1: asulam banded spray (early), then glyphosate interrow using shield (late); T2: diuron low rate + paraquat using octopus leg (late); T3: isoxaflutole low rate + paraquat using octopus leg (late);T4: isoxaflutole low rate + MSMA using octopus leg (late); T5: isoxaflutole low rate + MSMA in the row/ glyphosate interrow using shield (late); T6: isoxaflutole low rate + MSMA in the row/glyphosate interrow using QDAF dual herbicide spray bar (late).

6.1.3.1.4 Percentage of grass reduction

Perennial grasses in each plot were counted before the treatment was applied and again one year later (after the following harvest) to estimate the long term efficacy of the treatments (the percentage reduction takes into account the survival rate and potential propagation of new Guinea grass seedlings).

The combined analysis of the percentage reduction in number of grasses across three sites (GGF2, GGF3, GGF4) shows a significant difference for the interaction Site x Treatment (P 0.036). Results are presented in Figure 24 and mean comparisons are added in the graph. No data was available for trial GGF1 (access impossible after harvest).

Results show no significant difference between treatments at each trial site. The main differences are between sites, with 30 to 66% grass reduction at trial GGF2, 0 to 67% control at trial GGF3 and 4 to 14% control at trial GGF4. These differences between trials are likely caused by different environmental conditions at each site (level of Guinea grass infestation at the start of the experiment, weather conditions).

Treatment 4 tended to be the most effective for long term grass control at all sites. At best, it achieved up to 67% reduction in the number of grasses in trials GGF2 and GGF3. Treatment 1, 5 and 6 achieved about 60% long term control but only in trial GGF2.

None of these levels of control are acceptable.

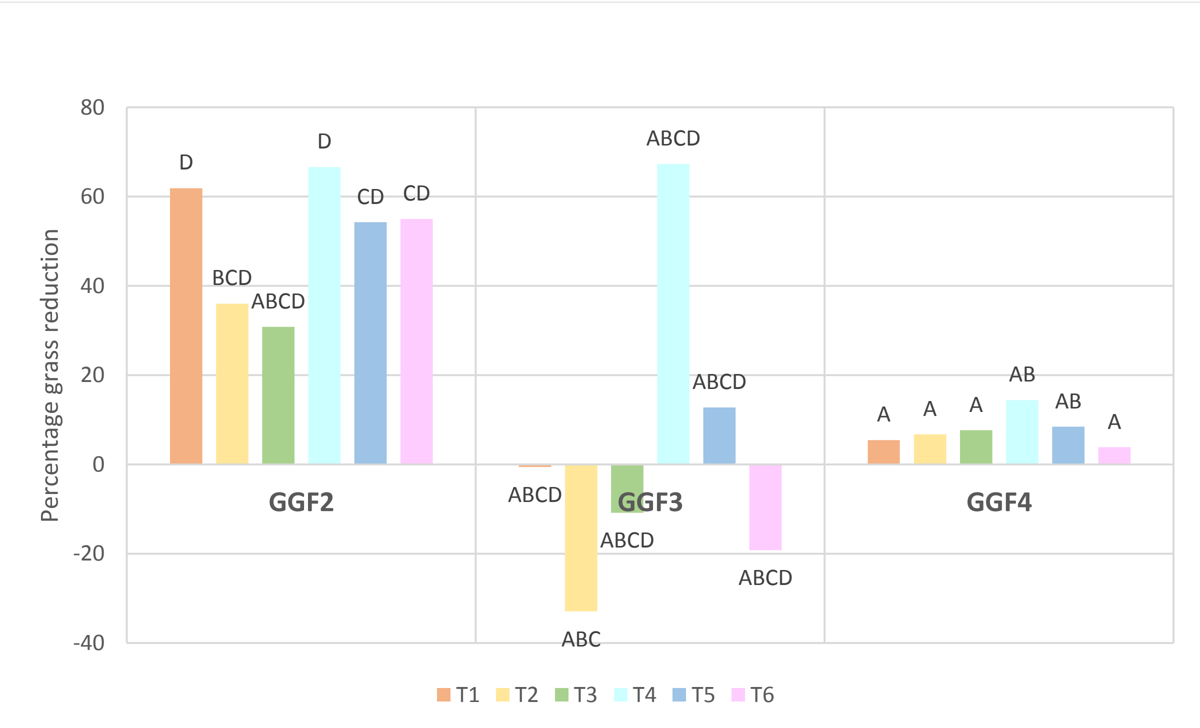


Figure 24 Mean of percentage reduction of grasses in each trial[1,2]

[1] Same letters mean no significant difference between treatments

[2] T1: asulam banded spray (early), then glyphosate interrow using shield (late); T2: diuron low rate + paraquat using octopus leg (late); T3: isoxaflutole low rate + paraquat using octopus leg (late);T4: isoxaflutole low rate + MSMA using octopus leg (late); T5: isoxaflutole low rate + MSMA in the row/ glyphosate interrow using shield (late); T6: isoxaflutole low rate + MSMA in the row/glyphosate interrow using QDAF dual herbicide spray bar (late).

6.1.3.1.5 Cane yield

The combined analysis of the cane yield data shows no significant differences for the interaction Site x Treatment and a significant difference between treatments (P 0.003) and between sites (P 0.011). Yield data were only available for trials GGF3 and GGF4.

Treatment 1 produced more yield than treatments 3, 4, 5 and 6 (Figure 25).

This result can be related to the low phytotoxicity on cane of treatment 1. Asulam also has the particularity to slow down the growth of the perennial grasses (without strong phytotoxicity symptoms). This reduction in grass growth in the early growth stage of cane would have reduced competition with cane. All other treatments resulted in unacceptable yield losses (about 30-40% yield loss compared to treatment 1) mainly due to phytotoxicity on cane.

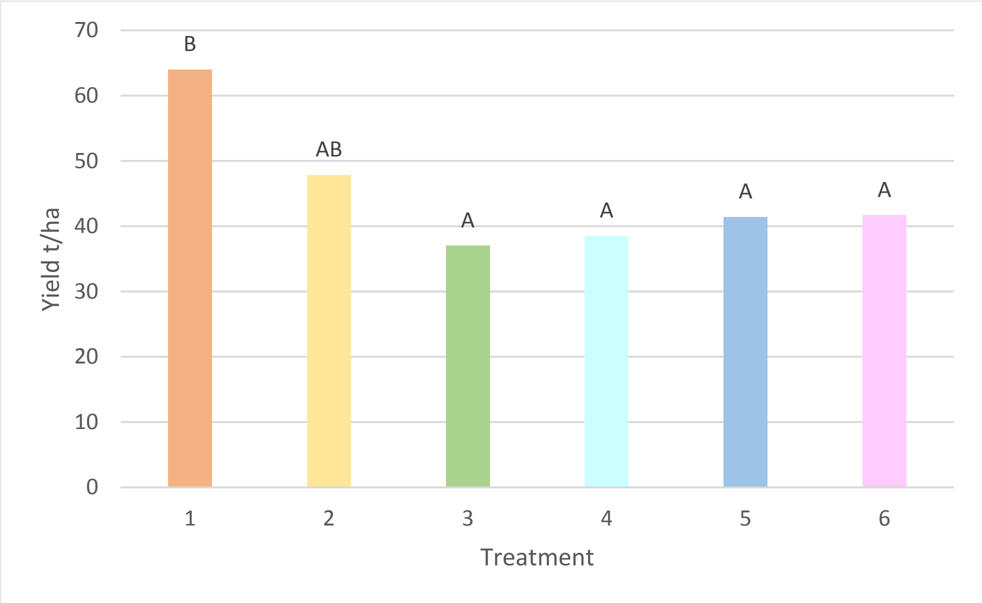


Figure 25 Cane yield data (mean of GGF3 and GGF4)[1, 2]

6.1.3.2 Field trial discussion

None of the tested treatments resulted in acceptable control of Hamil grass in the row.

The QDAF dual spray bar was effective to control grasses in the interrow, but not in the row. The conservative set up and low height of the boom to avoid cane phytotoxicity damage from glyphosate also restricted the spray coverage of isoxaflutole + MSMA on grasses in the interrow.

The use of the glyphosate under shield was also very effective to control grasses in the interrow and seemed safe on cane. The herbicide mix (isoxaflutole + MSMA) sprayed on the grasses in the row resulted in strong phytotoxicity symptoms on the grasses thanks to the non-conservative set up of the side nozzles that sprayed quite high in the canopy. On the other hand, it also resulted in strong phytotoxicity on cane and reduced the yield.

The octopus leg was also set up in a non-conservative manner, aiming high into the row canopy (50 cm high). The most effective herbicides to control the grasses in the row and in the interrow in the long term was isoxaflutole + MSMA using the octopus leg. Grasses in the interrow were successfully

[1] Same letters mean no significant difference between treatments

[2] T1: asulam banded spray (early), then glyphosate interrow using shield (late); T2: diuron low rate + paraquat using octopus leg (late); T3: isoxaflutole low rate + paraquat using octopus leg (late);T4: isoxaflutole low rate + MSMA using octopus leg (late); T5: isoxaflutole low rate + MSMA in the row/ glyphosate interrow using shield (late); T6: isoxaflutole low rate + MSMA in the row/glyphosate interrow using QDAF dual herbicide spray bar (late).

controlled, however grasses in the row only displayed mild phytotoxic symptoms and their growth was only slowed down despite a repeated treatment application. The impact on cane was also quite alarming with phytotoxicity symptoms lasting more than eight weeks and lower cane yield.

Isoxaflutole + paraquat applied with the octopus leg was slightly less effective on the grasses (row and interrow) than the previous herbicides, however its phytotoxicity on cane was comparable to isoxaflutole + MSMA and it also resulted in low cane yield.

Diuron + MSMA applied with the octopus leg was a softer option on cane; however it was also less effective to control the grasses in the row and in the interrow. It was the second best yielding treatment.

Asulam was very safe on cane. Delayed grass growth combined with crop safety resulted in the higher yield, however it did not achieve acceptable grass control.

These trials did not identify a direct spray herbicide strategy that effectively controlled Guinea grass located in the cane row and did not impact on cane yield.

6.1.3.3 Pot trials results and discussion

As field trial results indicated that directed spray was inadequate to control perennial grasses, pot trials were carried out to better understand the causes and find alternative strategies. Pot trial 1 focused on the causes of glyphosate failure to kill Hamil grass in the row in previous field trials, by investigating the translocation process. Pot trial 2 focused on identifying the best combination of Product x Concentration x Water rate to control Hamil grass.

6.1.3.3.1 Pot trial 1 results

Phytotoxicity rating were measured at three and seven days after spraying and then weekly. SPAD measurements were only measured for the first five assessments due to the increasing amount of desiccated leaves in some treatments.

Phytotoxicity rating

The statistical analysis showed no significant interaction Water regime x Spray coverage x Date (P 0.184), however there was a significant effect of the interaction Water regime x Spray coverage (P 0.02). Results from the mean comparisons are included in Figure 26.

Entirely sprayed grasses ("total spray coverage") displayed stronger symptoms and appeared dead as soon as three weeks after spraying with no difference related to their hydration level at time of spraying (Figure 27). Grasses that were only half sprayed ("half coverage") and "fully hydrated" displayed less toxicity symptoms than the entirely sprayed grasses: in one pot, the Hamil grass survived the Treatment Half spray coverage x Fully hydrated.

This result illustrates the need to ensure full coverage when spot spraying Hamil grass stools with glyphosate, especially when the plants are not water stressed.

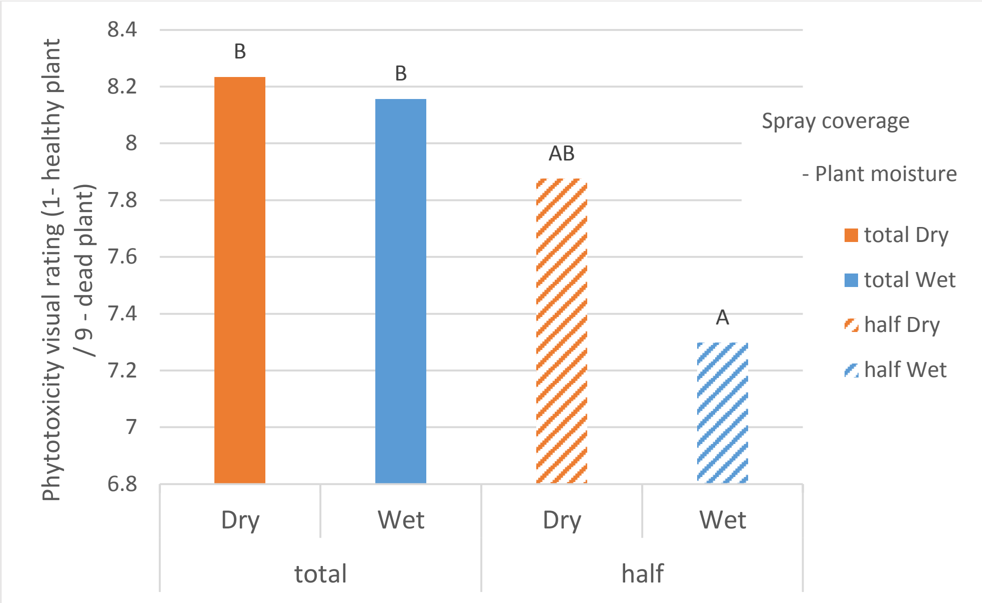


Figure 26 Mean of Phytotoxicity visual rating on Hamil grass in pot trial 1 (grouped for all assessment dates)[1]

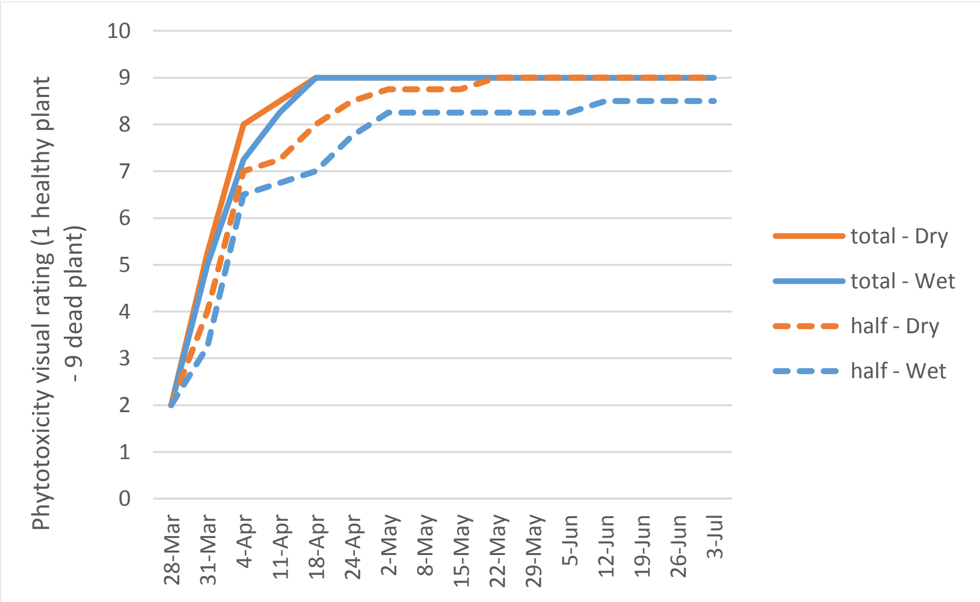


Figure 27 Mean of Phytotoxicity visual rating on Hamil grass for each assessment date in pot trial 1

SPAD measurements

The statistical analysis showed no significant interaction Water regime x Spray coverage x Date (P 0.514) and no significant interaction Water regime x Spray coverage (P 0.183), however there was a significant effect for the variable Spray coverage (P<0.001) and a significant effect for the interaction Water regime x Date (P 0.009). Results from the mean comparisons are included in Figure 28 and Figure 29.

The SPAD values were significantly lower for the treatment "total spray coverage", confirming phytotoxicity rating results (Figure 28).

[1] Same letters mean no significant difference between treatments

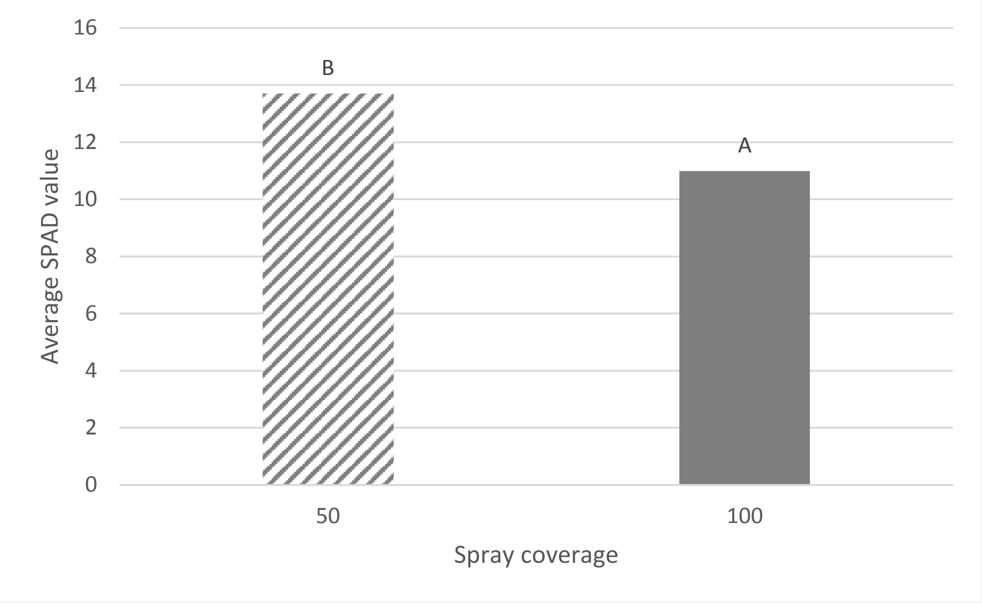


Figure 28 Mean SPAD values (grouped for date and water regime) in pot trial 1[1]

The SPAD values were significantly lower for the fully hydrated grasses at the last assessment date. These results confirmed the phytotoxicity rating that showed that fully hydrated grasses were most affected by the glyphosate treatment (Figure 29).

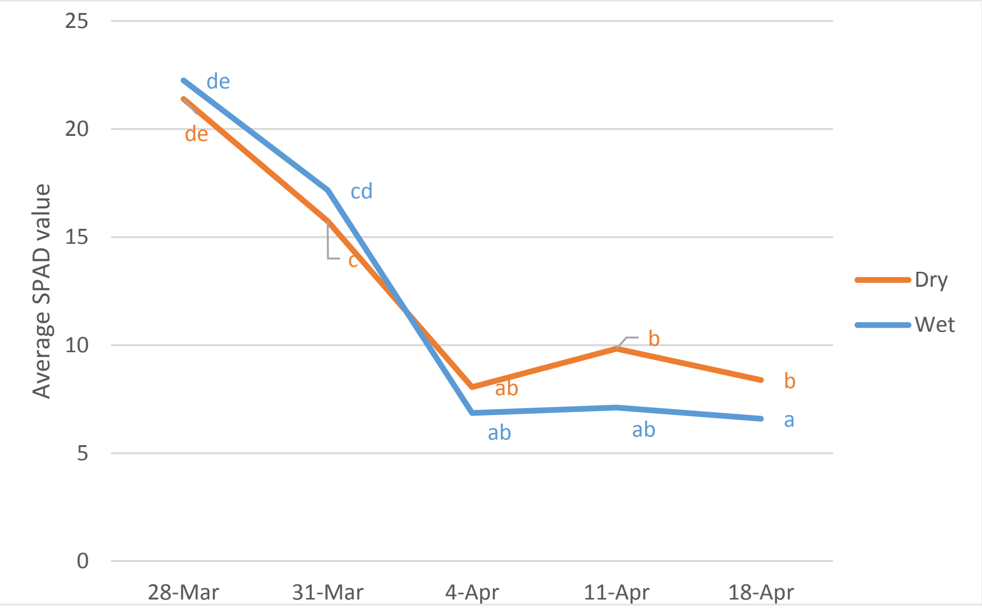


Figure 29 Mean SPAD values (grouped for spray coverage) in pot trial 1[1]

6.1.3.3.2 Pot trial 1 discussion

As expected, the spray coverage was the most crucial factor for successful control of Hamil grass. Partial (half) coverage resulted in a delayed (and ultimately incomplete control). Glyphosate is an active that translocates through the plant, however this translocation is a slow phenomenon and may not always be 100% reliable to achieve full control.

Unexpectedly, the water stress actually contributed to a better treatment efficacy especially for the half spray coverage. The herbicide treatments were faster to kill the water stressed plants when

[1] Same letters mean no significant difference between treatments

compared to the fully hydrated plants. Most glyphosate labels state: "*Apply to actively growing plants. DO NOT apply to drought stressed plants*", because the stress reduces sap flow and therefore translocation of the herbicide.

In our experiment, the volume of irrigation was lowered for one week before being totally stopped to obtain plants displaying water stress symptoms. During this 10-day period of low irrigation regime for the water stressed treatment, it is likely that the induction to flowering was triggered. This difference in the physiological stage may have favoured the translocation of the herbicide into the root system and achieved a better kill. Interestingly, Weedmaster® Argo® label does not mention any effect of drought stress when spraying perennial weeds, but the importance of targeting the seed head stage.

6.1.3.3.3 Pot trial 2 results

Phytotoxicity ratings were measured at three and seven days after spraying and then weekly. SPAD measurements were only measured for the first two assessments due to the amount of desiccated leaves in some treatments.

Phytotoxicity rating

The statistical analysis showed a significant interaction Treatment x Date (P <0.0001). Figure 30 displays the means for each treatment at each assessment date. This graph helps understand the efficacy dynamic for each treatment, with some treatments resulting in strong symptoms soon after spraying but followed by plant recovery. Results from the mean comparisons at the last assessment date are presented in Table 30. The last assessment, taken four month after spraying, is the best indication of final performance of the treatment to control the grasses.

Results showed that Balance® + Daconate® was the most effective treatment at all tested application rates and speed (Figure 30). Application speed could be doubled without affecting the treatment efficacy.

Bobcat® i-MAXX was only effective when used at 2L $100L^{-1}$. At this concentrated rate, both speeds were efficient even if the slowest speed worked faster.

Barrage was only effective when used at twice the recommended rate (2L $100L^{-1}$) and only for the lowest speed which achieved the point of runoff.

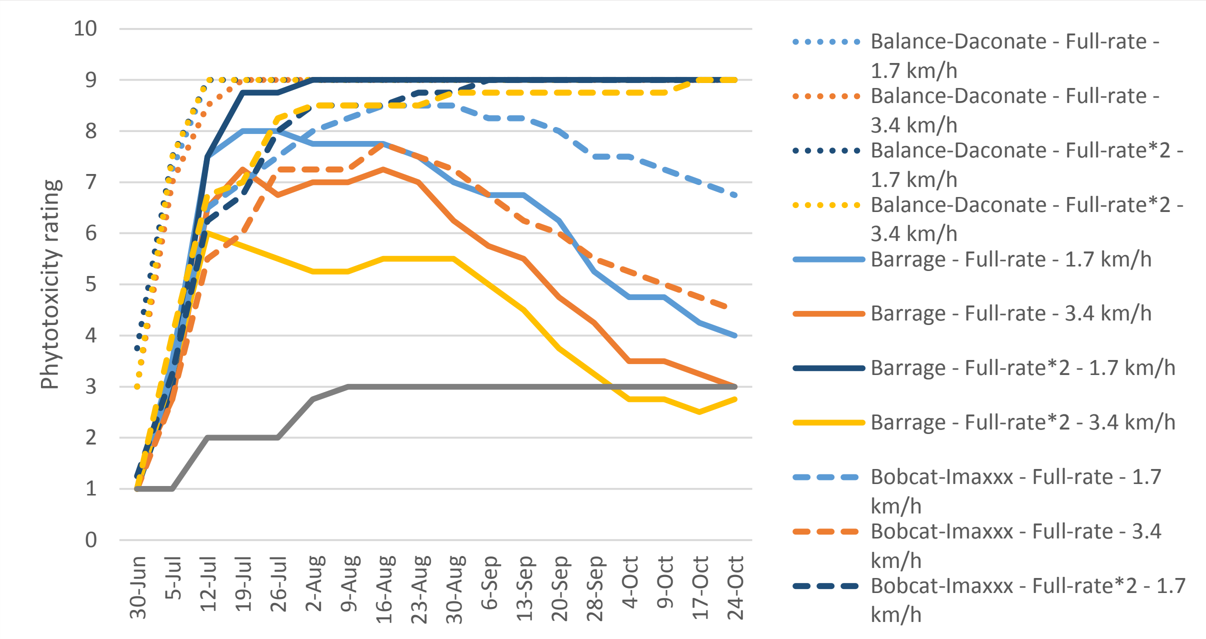


Figure 30 Phytotoxicity ratings for the 18 assessments done in pot trial 2.

Table 30 Mean comparisons of the Effect=Treatment x Date for the last assessment date for Phytotoxicity rating in pot trial 2.

T	Treatment description	DAT	Estimate	Standard Error	backtr	Letter Group
8	Balance® + Daconate® – Full rate x 2– 3.4 km.h^{-1}	116	9.00	0.553	8.772	A
11	Bobcat® i-MAXX – Full rate x 2 – 1.7 km.h^{-1}	116	9.00	0.553	8.772	A
5	Balance® + Daconate® – Full rate – 1.7 km.h^{-1}	116	9.00	0.553	8.772	A
6	Balance® + Daconate® – Full rate – 3.4 km.h^{-1}	116	9.00	0.553	8.772	A
7	Balance® + Daconate® – Full rate x 2 – 1.7 km.h^{-1}	116	9.00	0.553	8.772	A
3	Barrage – Full rate x 2 – 1.7 km.h^{-1}	116	9.00	0.553	8.772	A
12	Bobcat® i-MAXX – Full rate x 2 – 3.4 km.h^{-1}	116	9.00	0.553	8.772	A
9	Bobcat® i-MAXX – Full rate – 1.7 km.h^{-1}	116	6.75	0.553	6.941	AB
10	Bobcat® i-MAXX – Full rate – 3.4 km.h^{-1}	116	4.50	0.553	5.059	BC
1	Barrage – Full rate – 1.7 km.h^{-1}	116	4.00	0.553	4.632	BC
13	control	116	3.00	0.553	3.766	C
2	Barrage – Full rate – 3.4 km.h^{-1}	116	3.00	0.553	3.766	C
4	Barrage – Full rate x 2 – 3.4 km.h^{-1}	116	2.75	0.553	3.546	C

SPAD measurement

The statistical analysis showed a significant interaction Treatment x Date (P <0.0001), however because some treatments were missing on the second measurement date (grass leaves on Balance® + Daconate® treatments were too desiccated for a valid reading), only the mean comparisons for the Effect Treatment for the first assessment date are presented in Table 31. SPAD measured at the first date confirmed that the strongest symptoms were obtained with the Balance® + Daconate® treatments (except T5 that was not significantly different to the control). Bobcat® i-MAXX treatment T9 was also significantly different to the control at this first assessment.

The SPAD measurement was not an adequate measurement in this trial due to the rapid desiccation of leaves in some treatments.

Table 31 Mean SPAD values for the first assessment date in pot trial 2

T	Treatment description	Date	Estimate	Standard Error	Letter Group
13	control	30/06/2017	38.60	1.237	A
1	Barrage – Full rate – 1.7 $km.h^{-1}$	30/06/2017	36.43	1.237	AB
4	Barrage – Full rate x 2 – 3.4 $km.h^{-1}$	30/06/2017	33.85	1.237	ABCD
10	Bobcat® i-MAXX – Full rate – 3.4 $km.h^{-1}$	30/06/2017	33.60	1.237	ABCD
2	Barrage – Full rate – 3.4 $km.h^{-1}$	30/06/2017	32.04	1.237	ABCD
5	Balance® + Daconate® – Full rate – 1.7 $km.h^{-1}$	30/06/2017	32.04	1.237	ABCD
11	Bobcat® i-MAXX – Full rate x 2 – 1.7 $km.h^{-1}$	30/06/2017	31.95	1.237	ABCD
3	Barrage – Full rate x 2 – 1.7 $km.h^{-1}$	30/06/2017	31.90	1.237	ABCD
12	Bobcat® i-MAXX – Full rate x 2 – 3.4 $km.h^{-1}$	30/06/2017	31.83	1.237	ABCDE
6	Balance® + Daconate® – Full rate – 3.4 $km.h^{-1}$	30/06/2017	30.49	1.237	BCDEF
8	Balance® + Daconate® – Full rate x 2– 3.4 $km.h^{-1}$	30/06/2017	30.27	1.237	BCDEF
9	Bobcat® i-MAXX – Full rate – 1.7 $km.h^{-1}$	30/06/2017	29.38	1.237	CDEFG
7	Balance® + Daconate® – Full rate x 2 – 1.7 $km.h^{-1}$	30/06/2017	27.73	1.237	DEFG

6.1.3.3.4 Pot trial 2 discussion

Pot trial 2 revealed a range of alternatives to diuron to control Hamil grass using spot spraying.

Balance® + Daconate® is not registered for spot spraying perennial grasses, however it is a common industry practice as both herbicides are registered for broadcast application in cane. These results could potentially be used to extend their current registration in order to include spot spraying application. Balance® + Daconate® was the most effective treatment in this trial and the recommended rate from the industry 0.075 kg $100L^{-1}$ Balance® + 1.5L $100L^{-1}$ Daconate® was more than adequate to achieve effective control. A faster spray speed that did not achieve the point of runoff on the grass leaves still resulted in full efficacy. The spray rate could potentially be lowered further but more trials would be required.

Bobcat® i-MAXX was only 100% effective when used at 2L $100L^{-1}$. At this concentrated rate, both speeds were efficient even if the slowest speed worked faster. Bobcat® i-MAXX SG (150 g kg^{-1} imazapic, 750 g kg^{-1} hexazinone) is a new granular formulation to be registered later in 2018. The label will include a spot spraying rate at 350 g 100 L^{-1}. Our tested rate of 2L $100L^{-1}$ is equivalent to the spot spraying rate at 350g 100 L^{-1} of the soon to be released granular formulation.

Barrage was only effective when used at twice the recommended rate (2L $100L^{-1}$) and only for the lowest speed which achieved the point of runoff. These results confirm growers' observations that regrowth of perennial grass can occur when using Barrage. Growers noticed it is necessary to drench the perennial grass stools with Barrage to achieve good control. Another option identified in this pot trial is to double the concentration of the spray mix.

Until the release of Bobcat® i-MAXX SG, no efficient strategies to control Hamil grass are yet registered for spot spraying in cane.

6.1.4 Field trials on the environmental impact of alternative herbicides to diuron

6.1.4.1 Surface runoff

Surface runoff volumes were highly variable for each of the plots across the rainfall simulations for all four sites (Figure 31). At trial RO1, the runoff varied from 21 to 51 mm with a mean of 40 mm. Runoff from trial RO2 was generally lower and varied from 10 to 40 mm with a mean of 24 mm. The runoff at trial RO3 ranged between 16 and 56 mm with a mean of 36 mm. The runoff at trial RO4 ranged between 4 and 39 mm with a mean of 26 mm without clear runoff differences between trash and bare soil. The differences in runoff highlight considerable variability across a paddock which could reflect issues such as preferential wheel traffic-compaction, fine scale soil pore variability, antecedent soil moisture, differences in soil type or the presence/absence of trash (and interactions between these factors), both within and between sites. In any case, across all simulations, the rainfall applied to the paddock (about 80 mm hr^{-1}) and the surface runoff from the plots highlight that a high proportion of surface runoff (in the order of 30-50%) can occur during intense rainfall events. The high amount of surface runoff combined with the recent application of herbicides (two days prior to simulation) represents a worst case scenario where highest surface losses of herbicides would be expected.

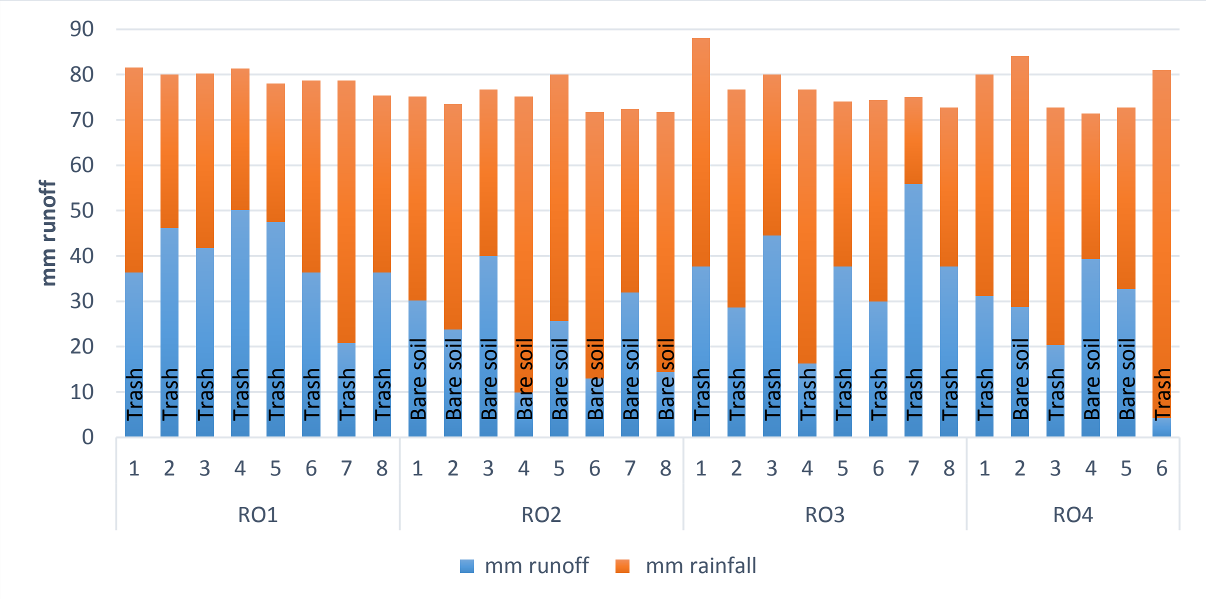


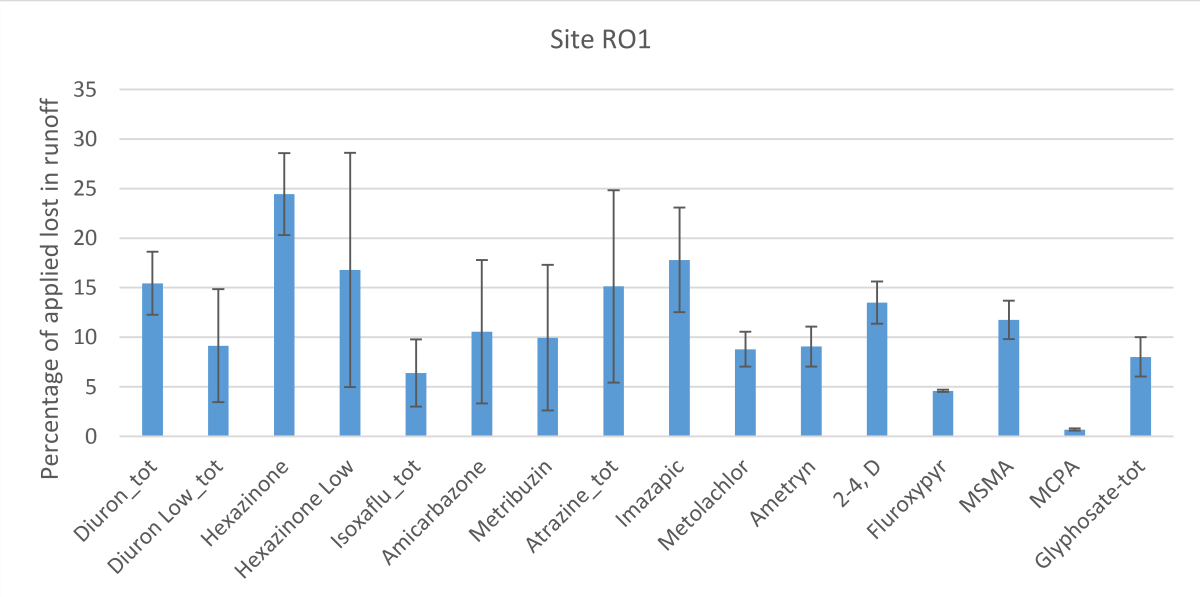
Figure 31 Variability of rainfall and runoff (in mm) in each plot across the four runoff trials.

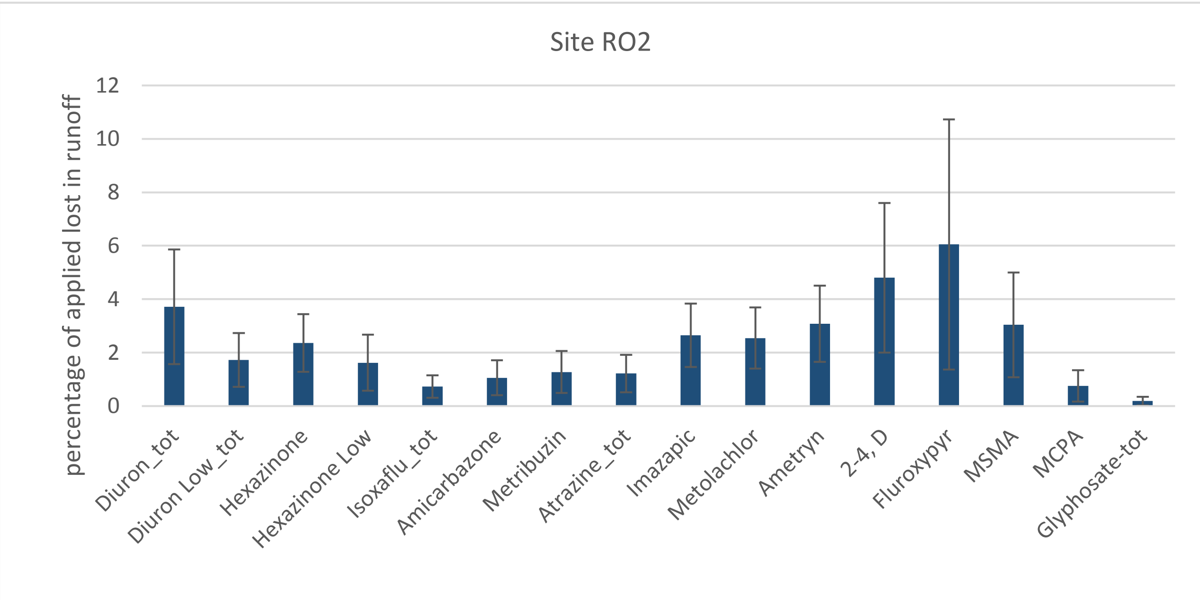
In order to best explain the rainfall simulation results, we conducted two separate analyses of the herbicide runoff data (we present all results as the mean of each specific treatment with standard deviation of the replicated treatments). The first analysis examines the percent losses of the herbicides applied to the paddock (the load of the herbicide in surface runoff divided by the total amount of active ingredient applied) (Figure 32). While this analysis shows how much of the active ingredient product applied may be lost from the paddock, it does not provide a good direct comparison of comparative load losses across the different herbicides due to their variable label application rates. Hence in the second analysis we examine the grams of active ingredient lost per hectare (the load of the herbicide in surface runoff divided by the plot area) (Figure 34). This second analysis allows for direct comparisons to be made between the different herbicides in terms of surface water loads lost to the environment, as the results take into account the amount of active ingredient applied to the paddock.

The herbicide surface runoff losses as a percentage of active ingredient applied show high variability between herbicides and between the four sites (Figure 32). Overall the herbicide losses at site RO2 were much lower (<6% for all herbicides) than the other two sites (most herbicides >10% lost). The herbicide losses were similar between trash and bare soil at site RO4, suggesting the absence of trash alone is not a consistent explanation for lower losses in bare soil at trial RO2.

The data also revealed potential relative differences between the losses from fluroxypyr application on the trash (sites RO1 and RO3) compared to bare soil. Fluroxypyr loss was only 3% at site RO3 and 5% at site RO1 and was one of the lowest of all herbicides, while at site RO2 the loss (6%) was the highest of all other herbicides in the trial (Figure 32). These results likely reflect the different properties of the herbicides (binding potential to trash or soil) and site differences in relation to factors such as organic matter and other soil chemistry properties. Fluroxypyr has not been thoroughly investigated at field scale in the Queensland sugar context and probably warrants further research.

The results demonstrate that under certain conditions (i.e. heavy rainfall shortly after application), very high surface runoff losses of herbicides (>15% of active ingredient applied) are possible.





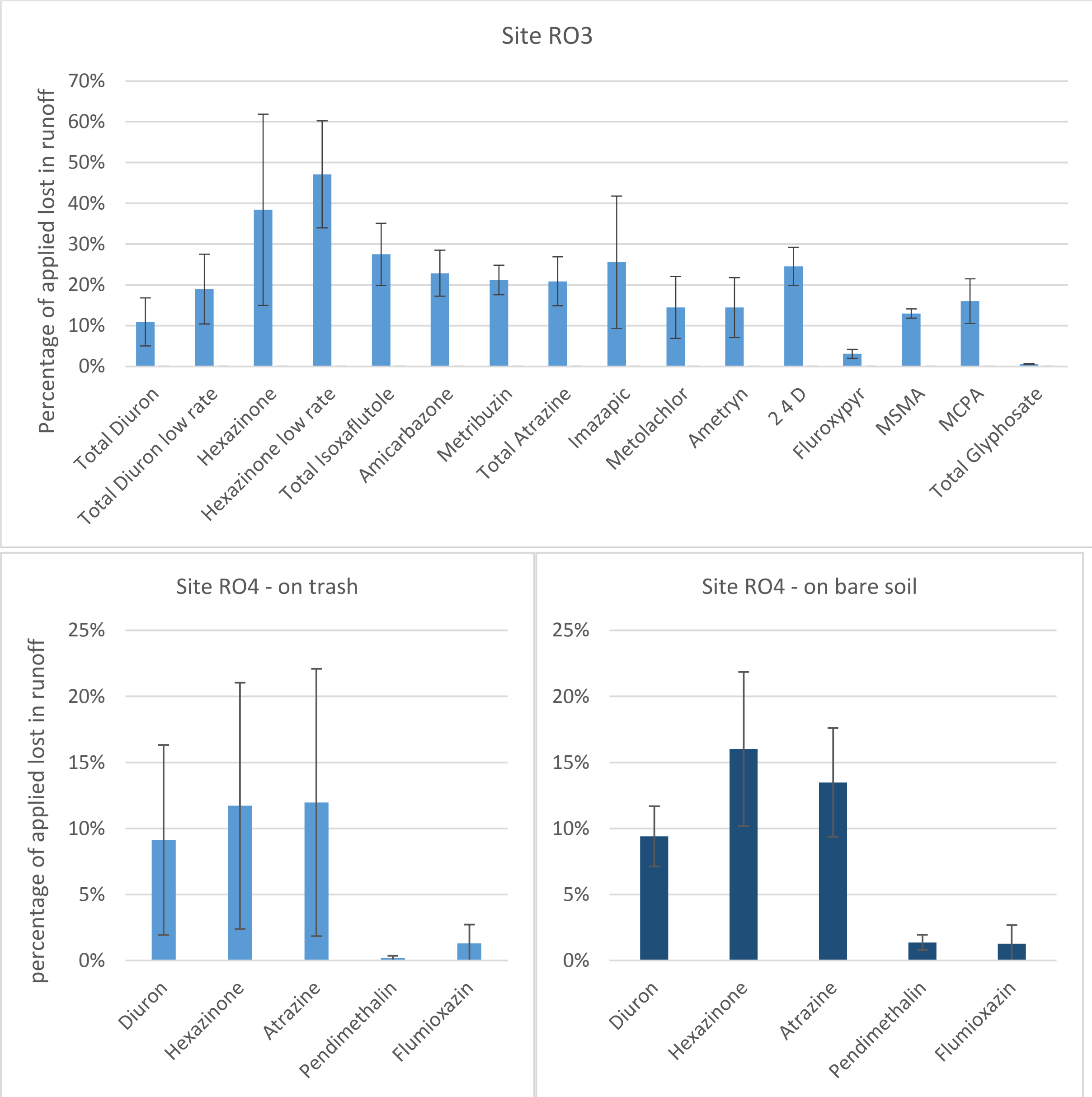


Figure 32 Herbicide runoff losses as percentage of applied active ingredient at each runoff trial site

When comparing the herbicide losses across the four trial sites in percentage of applied, hexazinone and imazapic tended to have higher runoff losses in percentage of active (15 – 20 % loss), whereas the losses from pendimethalin and flumioxazin were always significantly lower (loss <1.3%) (Figure 33) These results are expected as hexazinone and imazapic are highly soluble in water (solubility of 33000 and 2230 mg L^{-1} respectively) and are relatively mobile in soil (Koc of 137 and 54 mg L^{-1} respectively) versus pendimethalin and flumioxazin which have low solubility in water (0.33 and 0.786 mg L^{-1} respectively) and are less mobile in soil (Koc of 17491 and 889 mg L^{-1} respectively) (Table 32). However, most of the pre-emergent herbicides had similar losses to diuron (±20%). Their behaviour can be explained by their physico-chemical properties with the exception of amicarbazone and metribuzin which should have been found in runoff in higher amounts according to their physico-chemical properties. For the knockdown herbicides, 2,4-D generated the most losses with 15% losses in runoff, whereas fluroxypyr and glyphosate were the least prone to runoff. Glyphosate has a high Koc and therefore low mobility, and fluroxypyr solubility in water is lower than the other knockdowns (Table 32).

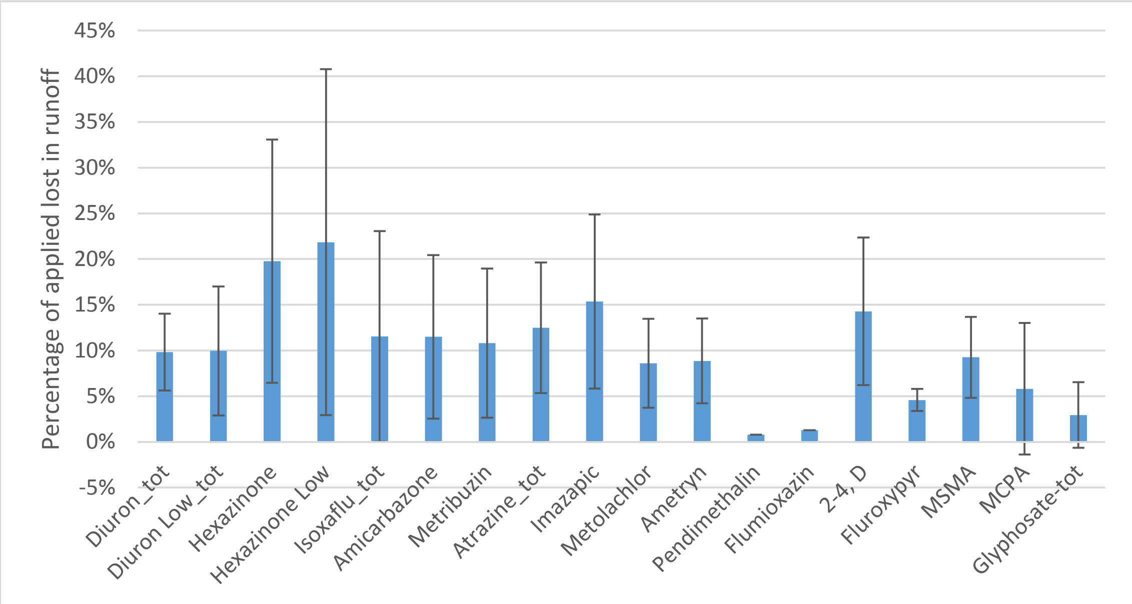


Figure 33 Average of herbicide runoff losses across all trial sites in percentage of applied

Table 32 Physico-chemical properties of herbicides[1]

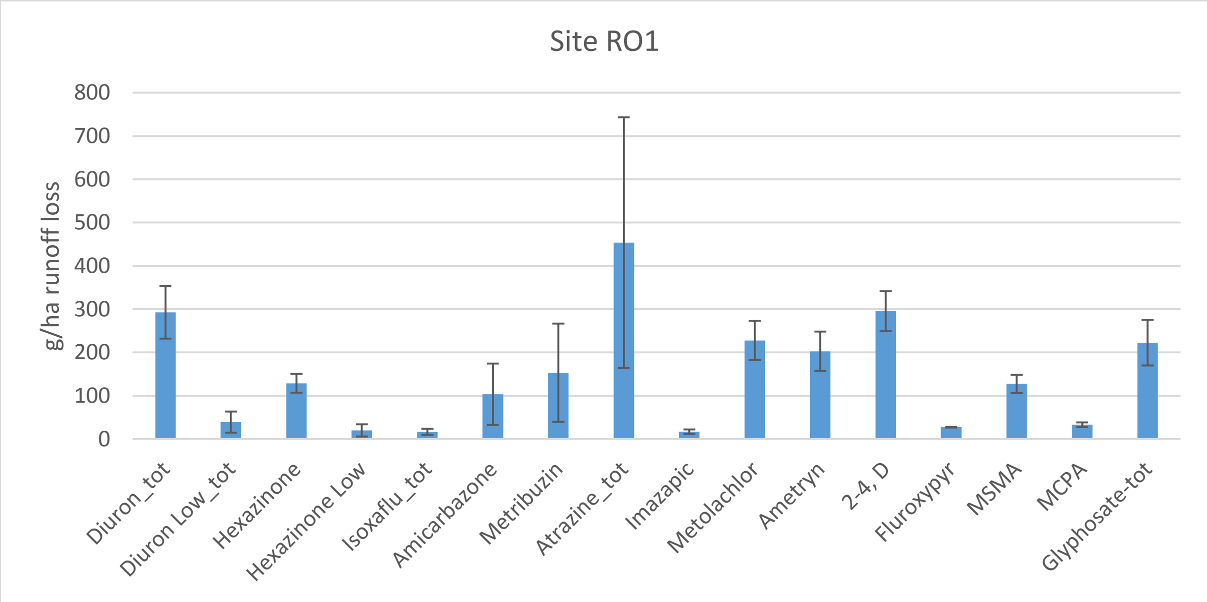
Active ingredient	Solubility in water in mg L^{-1}	Soil organic carbon partitioning factor (linear Koc, mg L^{-1})	Volatility (vapour pressure at 25°C)
atrazine	35 (low)	100 (moderately mobile)	0.039 (non volatile)
ametryn	200 (moderate)	316 (moderately mobile)	0.365 (low)
amicarbazone	4600 (high)	30 (mobile)	0.0013 (non volatile)
diuron	35.6 (low)	813 (slightly mobile)	0.00115 (non volatile)
flumioxazin	0.786 (low)	889 (slightly mobile)	0.32 (low)
fluroxypyr	6500 (high)	68[2] (mobile)	3.8×10^{-6} (non volatile)
glyphosate (isopropylamine salt)	11600 (high)	6920 (non mobile)	NA
hexazinone	33000 (high)	54 (mobile)	0.03 (non volatile)
imazapic	2230 (high)	137 (moderately mobile)	0.01 (non volatile)
isoxaflutole	6.2 (low)	145 (moderately mobile)	3.22×10^{-5} (non volatile)
metolachlor	530 (high)	120 (moderately mobile)	1.7 (low)
metribuzin	1165 (high)	38[2](mobile)	0.121 (low)
MCPA	29390 (high)	74[2] (mobile)	0.4 (low)
MSMA	580000 (high)	1680[3] (low mobility)	NA
pendimethalin	0.33 (low)	17491 (non mobile)	3.34 (low)
2,4-D	24300 (high)	39.3 (mobile)	0.009 (non volatile)

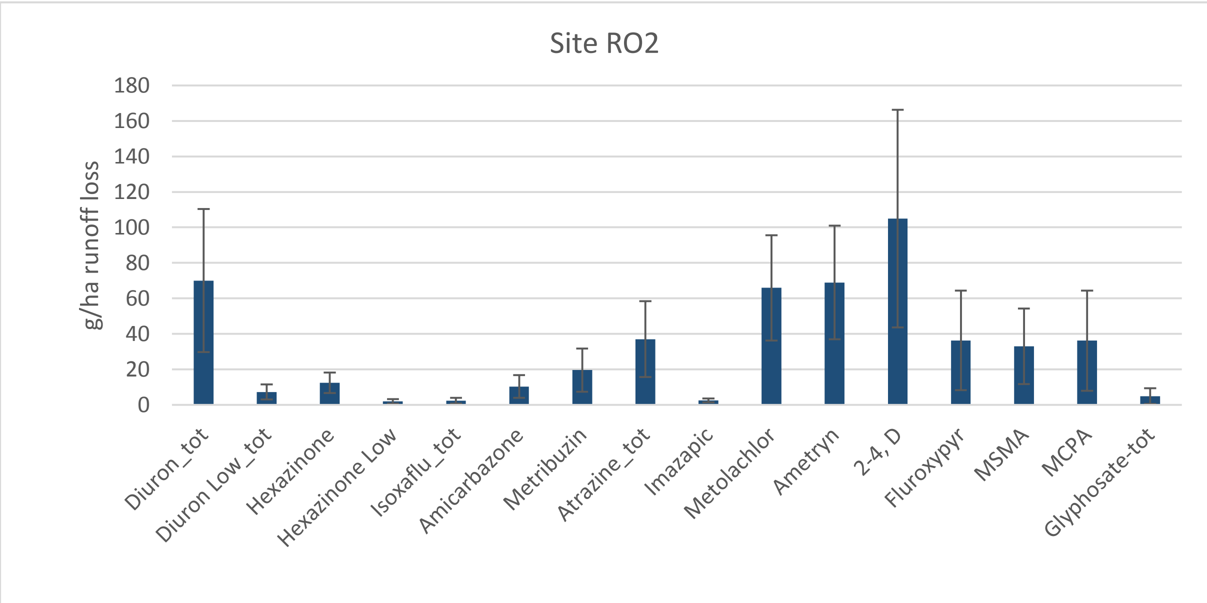
The grams per hectare surface runoff herbicide losses generally displayed consistent relative trends across the sites with diuron, metribuzin, atrazine, metolachlor, ametryn and 2,4-D having relatively higher loss rates, while diuron (lower rate), hexazinone (lower rate), isoxaflutole, imazapic and fluroxypyr generally had lower amounts lost (Figure 34). The main driver for the difference in grams per hectare surface runoff herbicides losses between herbicides at each site clearly was the

[1] Data from the Pesticide Properties Database (IUPAC website), 27/02/2018.
[2] Freundlich Koc, rather than linear
[3] http://www.pesticideinfo.org/Detail_Chemical.jsp?Rec_Id=PC32882

application rate. Considerable variability in amounts of active ingredient lost occurred across the sites: much lower amounts ran off at site RO2 compared to the other sites. This result is only partially explained by the lower amounts of surface runoff at site RO2 (24 mm of surface runoff in trial RO2 versus 40 and 36mm in trials RO1 and RO3 respectively).

We note that the relatively high standard deviations for some of the herbicides (error bars) largely reflect the variability in runoff from plot to plot (Figure 31), rather than any marked differences in relative loss behaviour of herbicides between sites (i.e., relative load loss patterns were generally consistent between sites).





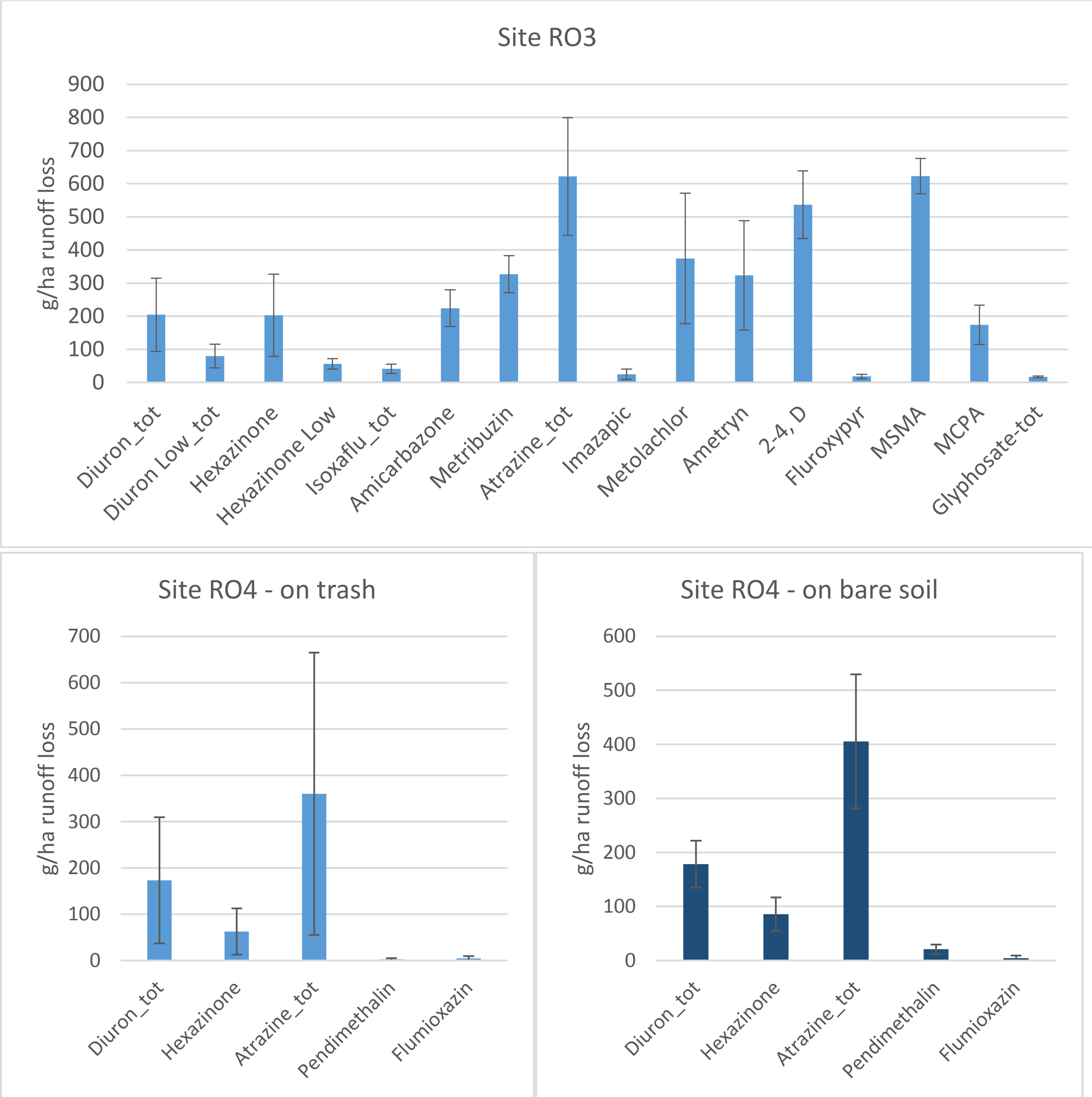


Figure 34 Herbicide runoff losses in g per hectare of active ingredient at each runoff trial site

Breakdown products (i.e., degradates) of several herbicides were frequently detected, although they usually made relatively minor contributions to the total applied herbicide loads leaving paddocks. Atrazine is well known to degrade into several metabolites of variable toxicity and persistence. Two of atrazine's breakdown products, desthylatrazine (DEA) and desisopropylatrazine (DIA), are phytotoxic, with DEA considered almost as toxic as the parent compound (Graymore *et al*., 2001). Both of these products were detected in the majority of samples analysed over the course of this study and their concentrations were added to the parent compound in this study (referred to as Atrazine_tot). Similarly, a number of the biodegradation metabolites of diuron (including 3-(3,4-dichlorophenyl)$^{-1}$-methylurea (DCPMU) detected in this study) have been found to be both several times more toxic to an array of standard toxicological biota as well as more persistent than the parent compound (Tixier *et al*., 2000) and its concentration was added to the parent compound (referred to as Diuron_tot). The relatively low amounts of these compounds in plot runoff is not especially surprising given the short time periods between product application and rainfall application in this study.

The major exception where a significant component of an herbicide breakdown product left plots was isoxaflutole. Isoxaflutole presents a somewhat special case, as it is specifically designed to rapidly undergo hydrolysis to form the herbicidally active diketonitrile (DKN) degradation product through the opening of the isoxazole ring (Pallett *et al*., 2001; Beltran *et al*., 2003). While isoxaflutole has a very short half-life in soil, it rapidly degrades to DKN, which has a longer half-life of 8-61 days (Pallet *et al*., 2001). In this sense, isoxaflutole acts a precursor (or proto-herbicide) rather than a parent compound. The aqueous solubility of DKN is 50 times greater than that of isoxaflutole (326 mg L−1 vs. 6.2 mg L−1) (Beltran *et al*., 2002), and also possesses a lower Koc than its parent compound (Mitra *et al*., 1999). The toxicity of breakdown products (often not well-known) does complicate risk assessments of management practices and product selection. Isoxaflutole metabolite concentrations were added to the parent compound in this study (referred to as Isoxaflu_tot).

Breakdown products of flumioxazin were not analysed in this study, however they have been reported in literature reviews and should be considered in future runoff work.

6.1.4.2 Herbicide losses in the sediment fraction

Average amounts of sediment lost per hectare were 55, 1644, 58, 9 and 290 $kg.ha^{-1}$ in trials RO1 (trash), RO2 (bare soil), RO3 (trash), RO4 (trash) and RO4 (bare soil) respectively. As expected, more sediment was lost from bare soil plots than trash plots. Six times more sediment ran off from the RO2 site which was a freshly tilled plant cane paddock compared to the RO4 site which was an old ratoon paddock without trash (trash was raked).

There was sufficient suspended sediment in the runoff water at trials RO2 and RO4 (bare soil) to analyse herbicide residues on the sediment fraction (Figure 35). The analysis could not be performed for the trial sites on trash blanket due insufficient sediments. Results show that less than 1% of the herbicide applied can be found on the sediment fraction of the runoff for all pre-emergent herbicides. Amongst pre-emergent herbicides, pendimethalin was the one that bound the most to the sediment fraction. Up to 4% of MSMA applied and 2% of glyphosate applied was found on the sediment fraction, showing a specific sediment binding behaviour for these actives. These results are aligned with their high Koc values.

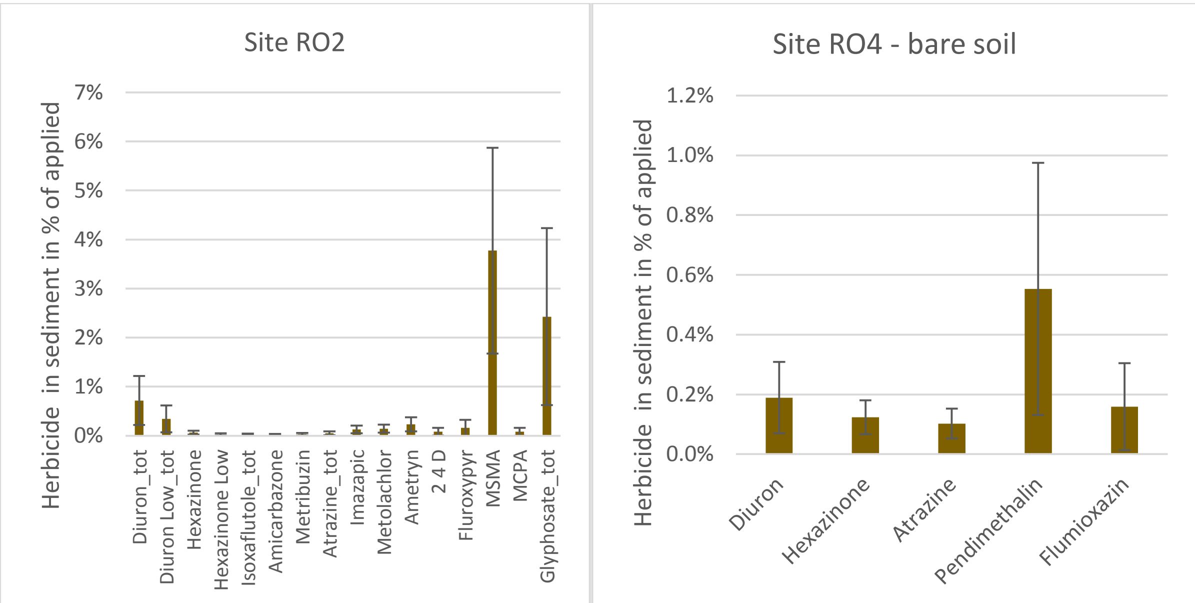


Figure 35 Herbicide residues in sediments in percentage of applied at trials RO2 and RO4 (bare soil)

6.1.4.3 Herbicide residues in the soil

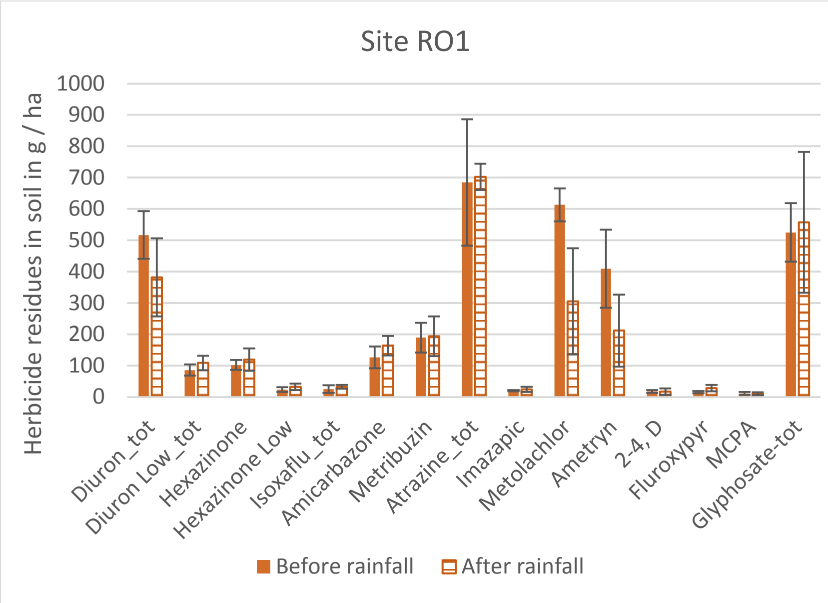
Herbicide residues in soil before rainfall (just after spraying) were three to ten times higher at the trash-free sites RO2 and RO4 (the bare soil treatment) compared to the other sites (Figure 36). These results are fully expected as the herbicides were sprayed directly onto the soil at these sites, whereas they were sprayed on the trash that covered the ground at RO1, RO3 and RO4 (trash). The differences in the amount found in the soil in these three sites after spraying on trash are likely due to the variable thickness of the trash between trial sites. Around 2000 g ha^{-1} of diuron was found in the soil at both bare sites, which validates the sampling methodology, however twice as much hexazinone and atrazine was found in the soil just after spraying at trial site RO4 compared to trial site RO2. These differences are difficult to explain, but could simply reflect random variability in herbicide application rates in sub-sampled areas of the plot, or even rapid volatilisation of herbicides during and after application.

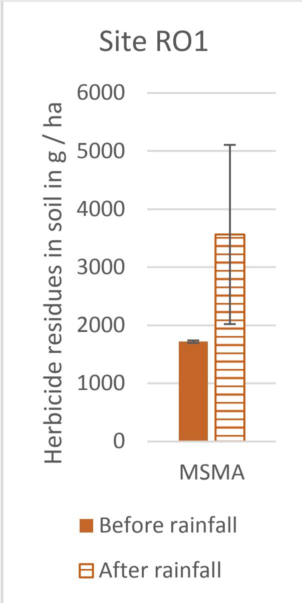
As a general rule, the amount of herbicide residues found in the soil after spraying are well correlated to their application rates and are consistent across sites. For instance, atrazine, metolachlor, ametryn and diuron sprayed at rates ranging from 1872 to 2970 g ha^{-1} generated higher herbicide residues in soil, when compared to isoxaflutole or imazapic sprayed at rates below 150 g ha^{-1}. MSMA sprayed at 4800 g ha^{-1} was also found at concentrations close to its application rate in the soil. MSMA has low mobility and high soil binding potential (Koc of 1680 mg L^{-1}). It is an arsenic derivative and environmentally stable.

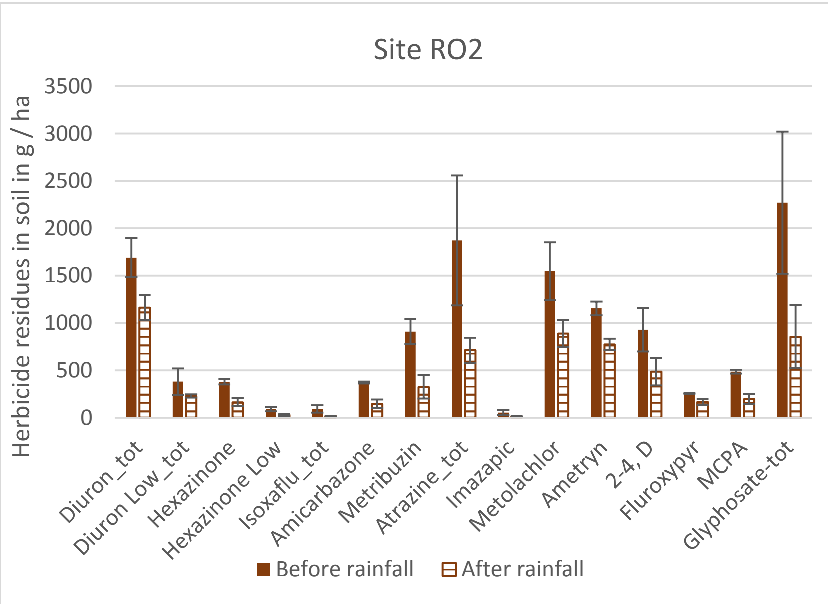
Application of rainfall affected the temporal dynamic of the herbicide concentration in soil of trash blanketed plots differently to the bare soil plots. Herbicide residues in bare soil plots reduced from 30 to 70% after rainfall, whereas they increased by up to two fold in the soil under trash blanketed plots following rainfall. This result was expected as the residues are washed from the soil by the rainfall event in the bare soil scenario, whereas they are washed from the trash onto the soil (and runoff water) in the trash blanketed scenario. Soil results from the trash blanketed trials are difficult to interpret because of the additional retention of herbicides in the trash, however results are fairly consistent between the three trial sites (RO1, RO3 and RO4 trash). For example, the concentration of atrazine after rainfall was the highest of the pre-emergent herbicides and ranged from 400 to 700 g ha^{-1}. Diuron concentration ranged from 100 to 400 g ha^{-1}, metolachlor 220 to 300 g ha^{-1}, hexazinone 60 to 100 g ha^{-1}, isoxaflutole 13 to 30 g ha^{-1} and imazapic 4 to 24 g ha^{-1}.

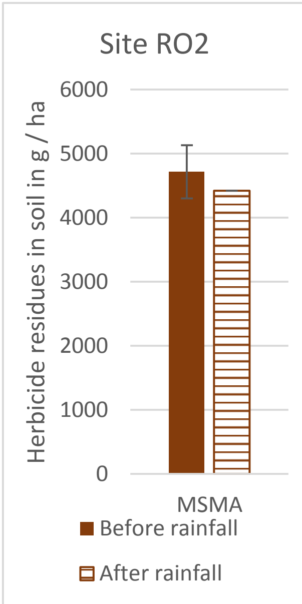
Calculated losses from the soil before and after rainfall in bare soil trials show that 30 to 70% of herbicide applied departed the top 25 mm of soil (except MSMA). The percentages of active found in the top 25mm of soil after rainfall compared to the amount in soil after spraying are well aligned with their Koc values, especially for actives that have a high Koc value (Table 33).

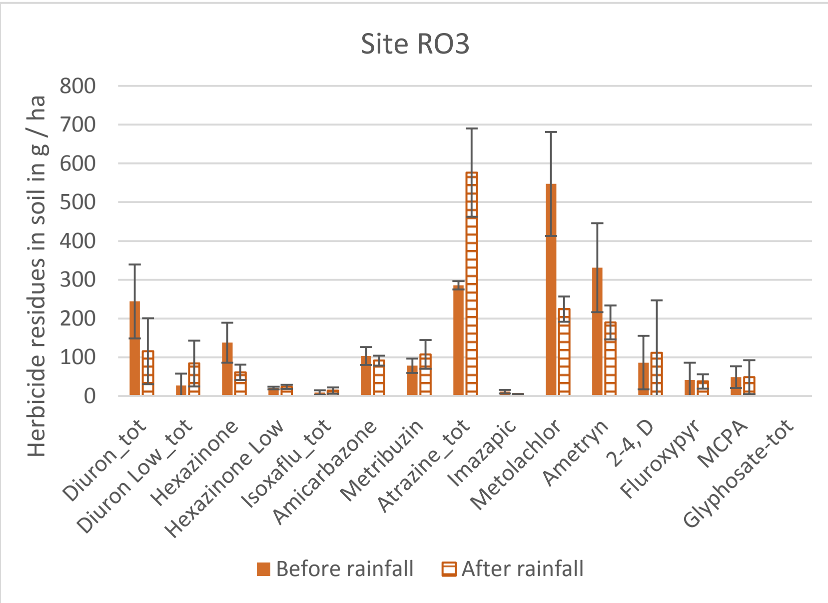
As runoff loads only accounted for 0.7 to 16% of the herbicide applied in these bare soil trials (refer to previous section) and 9 to 62% of the herbicide applied remained in the soil after rainfall (data not shown), most of the herbicide applied remained unaccounted for after rainfall. As the soil samples were only taken to 25 mm depth, it is likely that significant amounts of the herbicides leached deeper into the soil profile following the 80 mm rain event and therefore were not captured in this study. This highlights the need to investigate other loss pathways for herbicides (volatilisation, deep drainage) in cane farming systems. It should be noted the specific soil sampling in this study was conducted to assess dynamics of herbicide active ingredient retained in the top 25 mm of soil (where they are efficacious), rather than to calculate detailed mass balances of all herbicide loss pathways following application.

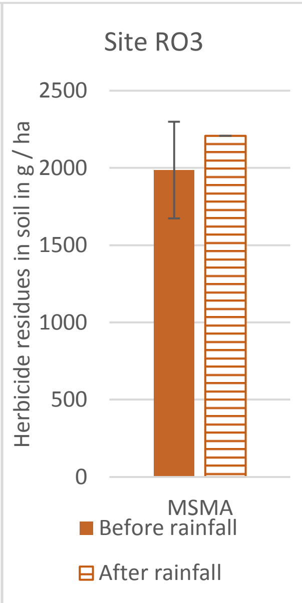

Site RO1
Herbicide residues in soil in g / ha
1000
900
800
700
600
500
400
300
200
100
0
Diuron_tot
Diuron Low_tot
Hexazinone
Hexazinone Low
Isoxaflu_tot
Amicarbazone
Metribuzin
Atrazine_tot
Imazapic
Metolachlor
Ametryn
2-4, D
Fluroxypyr
MCPA
Glyphosate-tot
Before rainfall
After rainfall


Site RO1
Herbicide residues in soil in g / ha
6000
5000
4000
3000
2000
1000
0
MSMA
Before rainfall
After rainfall


Site RO2
Herbicide residues in soil in g / ha
3500
3000
2500
2000
1500
1000
500
0
Diuron_tot
Diuron Low_tot
Hexazinone
Hexazinone Low
Isoxaflu_tot
Amicarbazone
Metribuzin
Atrazine_tot
Imazapic
Metolachlor
Ametryn
2-4, D
Fluroxypyr
MCPA
Glyphosate-tot
Before rainfall
After rainfall


Site RO2
Herbicide residues in soil in g / ha
6000
5000
4000
3000
2000
1000
0
MSMA
Before rainfall
After rainfall


Site RO3
Herbicide residues in soil in g / ha
800
700
600
500
400
300
200
100
0
Diuron_tot
Diuron Low_tot
Hexazinone
Hexazinone Low
Isoxaflu_tot
Amicarbazone
Metribuzin
Atrazine_tot
Imazapic
Metolachlor
Ametryn
2-4, D
Fluroxypyr
MCPA
Glyphosate-tot
Before rainfall
After rainfall


Site RO3
Herbicide residues in soil in g / ha
2500
2000
1500
1000
500
0
MSMA
Before rainfall
After rainfall

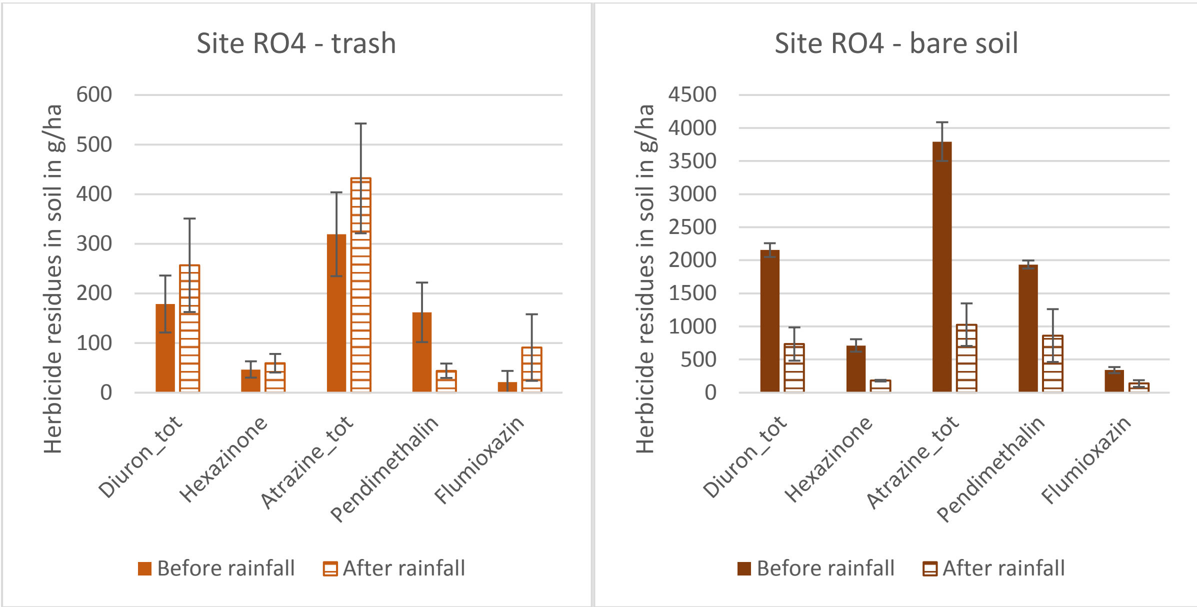


Figure 36 Herbicide residues in soil in g ha^{-1} at each runoff trial site

Table 33 Herbicide retained in top 25mm of soil after rain compared to before rain

Active ingredient	Trial RO2	Trial RO4 (bare soil)	Koc
	Percentage active in soil after rain compared to after spraying		
Pendimethalin		50%	17491
MSMA	94%		1680
Flumioxazin		40%	889
Diuron	68%	34%	813
Ametryn	67%		316
Metolachlor	55%		120
Atrazine	38%	27%	100
Hexazinone	43%	26%	54
Amicarbazone	39%		30
Metribuzin	36%		38
Imazapic	25%		137
Isoxaflutole	15%		145

6.1.4.4 Herbicide residues in the trash

Herbicide residues on trash at site RO1 and RO4 generally decreased after rainfall, with the exception of pendimethalin and flumioxazin (Figure 37). These results were expected as most tested herbicides are relatively soluble in water (35 mg L^{-1} for atrazine to 33000 mg L^{-1} for hexazinone): the rainfall displaced a portion of herbicide residues into the runoff water or into the soil. Pendimethalin and flumioxazin display a different behaviour as they seem to largely remain in the trash fraction due to their low solubility (0.33 mg L^{-1} for pendimethalin, 0.78 mg L^{-1} for flumioxazin) and relatively high propensity for soil-organic matter partitioning (17491 mg L^{-1} for pendimethalin, 889 mg L^{-1} for flumioxazin) (

Figure 33 Average of herbicide runoff losses across all trial sites in percentage of applied

Table 32).

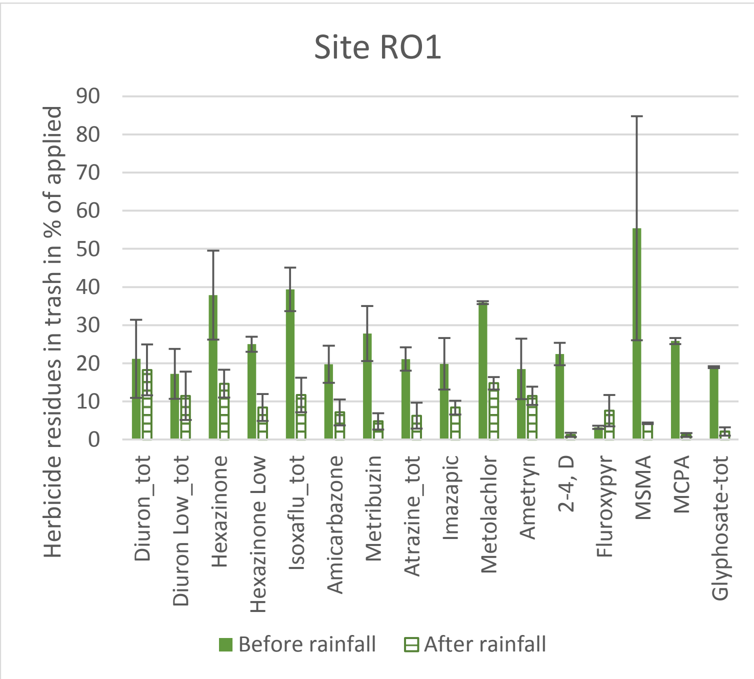
At RO1, the percentage of knockdown herbicide residues on trash reduced a lot after rainfall, reflecting their high mobility and solubility, with the exception of fluroxypyr, which remained in the trash after rainfall. Fluroxypyr losses in runoff were very low in trash blanketed trials versus the bare soil trial in plant cane and it could be explained by this binding to the trash. Its solubility (6500 mg L^{-1}), lower than the other knockdown herbicides, could partially explain our results. More research on this active ingredient is required to better understand its loss pathways.

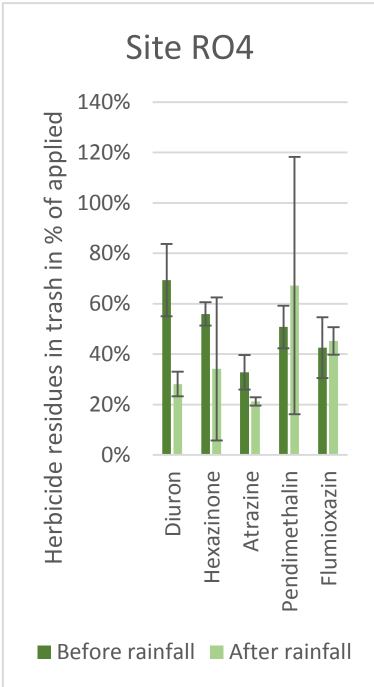
It is interesting to note that the amount of herbicide found in the trash after spraying is much lower than the application rate (20% to 70% of the actives applied was found in the trash after spraying). Dang *et al.* (2016), also observed a large difference between the amount applied and the amount on cane trash and presumed it was a result of volatilisation or photodecomposition.

Results in trial RO3 were mostly consistent with the other trials, however extreme variability between replicates was recorded (large error bars). Residues of most herbicides were lower after rainfall than before, with the exception of metolachlor, ametryn and fluroxypyr. These results are probably an artefact due to the sampling method.

The sampling method for the trash samples proved to be difficult for a couple of reasons:

- at some sites, the trash thickness was extremely variable both within a plot and between plots. This patchy variability likely affected the collection of representative herbicide concentration between trash samples and the subsequent upscaling to a hectare scale.
- the interface trash/ soil was difficult to separate, especially after rainfall, therefore contaminating the trash sample with muddy soil.





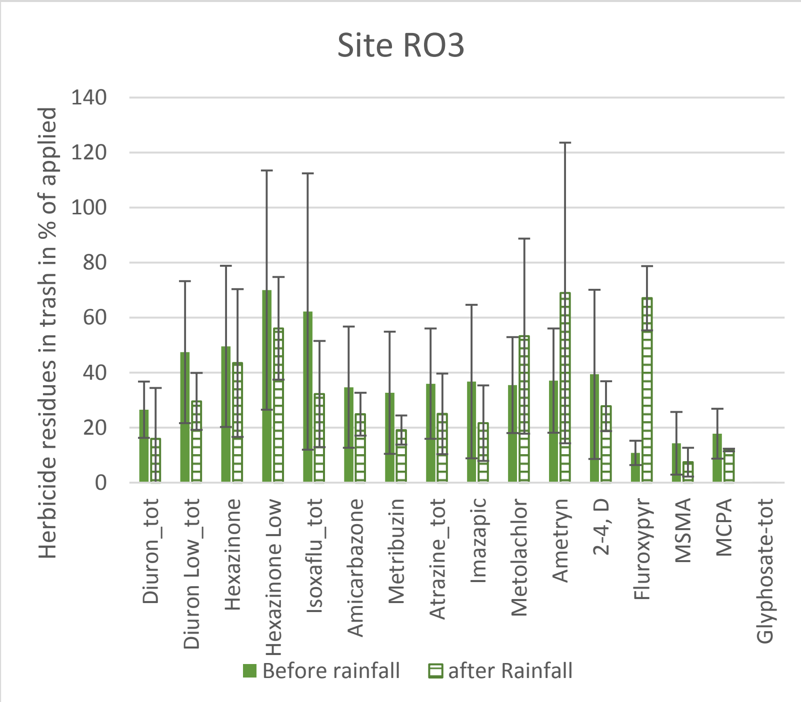


Figure 37 Herbicide residues in trash in percentage of applied at runoff trial sites RO1, RO4 and RO3

6.1.4.5 Discussion

Loads of herbicide in runoff water are related to their application rate

With the exception of pendimethalin and flumioxazin, which have a low solubility and therefore were less prone to runoff, the other pre-emergent herbicides behaved quite similarly, and their runoff losses were largely driven by their application rate. Herbicides with lower application rates (i.e., isoxaflutole, imazapic, low rate diuron) consistently contributed less to the total herbicide loads documented in runoff water. In Figure 38, the average loads of residual herbicides (except pendimethalin and flumioxazin) from all ratoon trials were plotted against their application rate and a linear regression fitted to the data with R^2 of 0.91. For these herbicides, 13% of the amount applied ended up in the runoff water across all ratoon trials. This result illustrates the importance of application rate for these herbicides. These results provide field validation of similar outcomes documented in modelled loss dynamics and environmental risk assessments targeting Queensland sugarcane herbicides and climatic regimes (Davis *et al.*, 2014). In the freshly tilled plant cane trial RO2, herbicide loads in runoff were still quite proportional to their application rate, however only 2% of the amount applied left the paddock via runoff. This result is consistent with Walton (2000), who reported that a tilled soil with small aggregates produced very little solute in surface runoff. Paddocks that have been freshly finely tilled at planting have a minimal risk to lose herbicides via runoff.

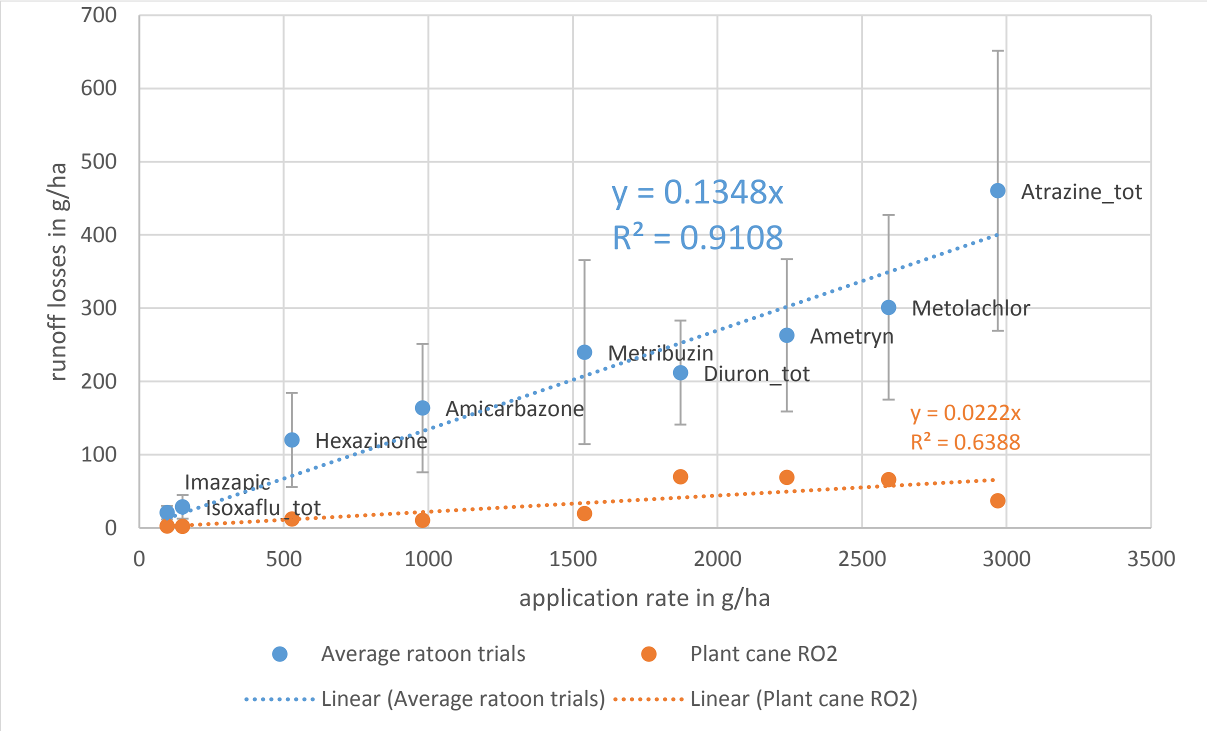


Figure 38 Loads of active ingredients in runoff compared to their application rate.

Trash blanket does not reduce herbicide runoff

The herbicide loss coming from trash blanketed plots was similar to the bare soil plots, suggesting no impact of trash blanket on herbicide runoff. Cowie *et al.*(2013) carried out rainfall simulations on trash versus bare soil in ratoons in Ingham and concluded that cane trash blanket reduced the runoff loss of PSII herbicides from 15% of applied to 9 %. Aslam *et al.* (2013) concluded that the degree of mulch decomposition enhanced the adsorption of non-ionic pesticides (all tested residual herbicides in our study are non-ionic except imazapic). The variation in the decomposition stage of the trash and the amount of trash between our RO4 and the Ingham experiments may explain why different conclusions were reached. The results on trash and soil when herbicides were sprayed on trash highlight trash as a confounding factor in herbicide movement dynamic and one that would require significant research on trash to better understand (Dang *et al.*, 2016).

Combination of environmental, efficacy and economic data

Efficacy, economic and environmental data can be combined for each site. Combined data for ratoon trials were presented at the 2017 conference of the ASSCT, a Meringa grower field day and the 2017 meeting of the Pesticide Working Group. They appear to be a good way to communicate with growers as they display a full picture of pros and cons of alternative strategies to diuron in trash blanketed ratoons.

Table 34 presents the combined data for runoff trials RO1 and efficacy trial R6. Calculations of the relative risk to diuron were performed using the latest toxic equivalent factors supplied by Rachael Smith (DES) and the runoff data relative to diuron from our trials (see Lewis *et al.* (2013) on how relative risk factor to diuron is calculated). The best option for this weedy block was Bobcat® i-MAXX, which was twelve times less toxic than using Barrage full rate. However it still contains a PSII herbicide and it is an expensive option at $86/ha. Flame® (imazapic), Balance® (isoxaflutole) and Amitron® would be more effective if used in a mixture to extend their efficacy spectrum, they were environmentally 30 to 250 times less toxic than diuron full rate at this site. A combination of Flame®

+ Balance® or Balance® + Amitron® may be cheaper options with a slightly lower environmental impact than Bobcat® i-MAXX.

Table 35 presents the combined data for runoff trial RO3 and efficacy trial R5. The best option for this block with moderate weed pressure was also Bobcat® i-MAXX. It was six times less toxic than using Barrage full rate. However it contains a PSII herbicide and it is an expensive option at $86/ha. Barrage low rate, Flame® and Amitron® would be more effective if used in a mixture to extend their efficacy spectrum. A combination of Barrage low rate + Flame® may be a cheaper option and half as toxic as Barrage full rate. Flame® + Amitron® could also be a potential option in the future with a lower environmental impact (10 times less toxic than Barrage full rate at this site).

Table 36 presents the combined data for runoff trial RO2 and efficacy trial PC1. With the exception of the treatment with ametryn that presented significant environmental risk compared to diuron, and the treatment with isoxaflutole alone or mixed with metribuzin that generated phytotoxicity on cane (due to the unsuitable soil type for Balance® at these application rates at this site), all other treatments achieved very good weed control with lower impact than diuron on the environment. From an economic perspective, the treatment imazapic + isoxaflutole would be the preferred option. The lack of robust ecotoxicity data currently available for flumioxazin prevents a more definitive comparison for this active ingredient.

All scenarios converge to similar conclusions despite different weed types and pressure and different soil types. These results are being used by the Pesticide Working Group to inform policies in relation to herbicide runoff impact. Relative toxicity factor to diuron (calculated by Smith *et al.,* 2017) combined with runoff properties of the tested herbicides will help create a decision risk matrix for growers to take into account runoff contamination when selecting an herbicide strategy.

Table 34 Summary of relative risk, efficacy and cost for each treatments at RO1/R6 trial site[1]

T	Treatment	Active per ha	Runoff mean concentration in ppb at RO1	Relative toxicity to diuron	Total relative risk to diuron[2]	Indicative cost per ha	Efficacy on weeds at R6
T1[3]	Barrage high rate	diuron 1872 g hexazinone 528 g	722 310	1 0.19	1.08	$74	Very efficient
T2[3]	Barrage low rate	diuron 421.2 g hexazinone 118.8 g	105 51	1 0.19	0.159	$17	Inefficient
T3	Flame®	imazapic 96 g	41	0.062	0.004	$10	Moderate efficacy
T4	Balance®	isoxaflutole 150 g	49	0.34	0.023	$35	Moderate efficacy
T5	Clincher®Plus	metolachlor 2592 g	550	0.19	0.145	$49	Moderate efficacy on grass only
T6[33]	Amitron®	amicarbazone 980 g	267	0.087	0.032	TBA	Very efficient on broadleaves only
T7[3]	Bobcat® i-MAXX	imazapic 95 g hexazinone 475 g	41 279	0.062 0.19	0.077	$86	Very efficient

[1] Toxicity data relative to diuron and mean surface runoff concentrations from the runoff trial were used to calculate the treatment relative risk to diuron. Note: no herbicide treatments had adverse impact on cane
[2] Total risk relative to diuron = Σ(individual active runoff mean concentration relative to diuron x individual relative toxicity to diuron)
[3] Treatment including a PSII herbicide

Table 35 Summary of relative risk, efficacy and cost for each treatment at RO3/R5 trial site [1]

T	treatment	Active per ha	Runoff mean concentration in ppb at RO3	Relative toxicity to diuron	Total relative risk to diuron[2]	Indicative cost per ha	Efficacy on weeds at R5
T1[3]	Barrage high rate	diuron 1872 g hexazinone 528 g	563 533	1 0.19	1.18	$74	Very efficient
T2[3]	Barrage low rate	diuron 421.2 g hexazinone 118.8 g	210 150	1 0.19	0.424	$17	Moderate efficacy
T3	Flame®	imazapic 96 g	63	0.062	0.007	$10	Very efficient on grasses
T4	Balance®	isoxaflutole 150 g	110	0.34	0.066	$35	Good efficacy on grasses only
T5	Clincher®Plus	metolachlor 2592 g	1017	0.19	0.343	$49	Moderate efficacy on grass only
T6[3]	Amitron®	amicarbazone 980 g	603	0.087	0.093	TBA	Very efficient on broadleaves
T7[33]	Bobcat® i-MAXX	imazapic 95 g hexazinone 475 g	63 479	0.062 0.19	0.169	$86	Very efficient

Table 36 Summary of relative risk, efficacy and cost for each treatments at RO2/PC1 trial site[1]

treatment	Active per ha	Runoff mean concentration in ppb at RO2	Relative toxicity to diuron	Total relative risk to diuron[2]	Indicative cost per ha	Efficacy on weeds/phytotoxicity on cane at PC1
Pend/atraz[3]	pendimethalin 1410 g atrazine 1980 g	13[4] 148[4]	0.20 0.036	0.040	$81	Very efficient
Meto/atraz[3]	metolachlor 2400 g atrazine 1980 g	240[4] 148[4]	0.19 0.036	0.190	$57	Very efficient
Amet/metrib[3]	Ametryn 1600 g metribuzin 1125 g	195[4] 85[4]	1.44 0.085	1.08	$109	Very efficient
Meto/metrib[3]	metolachlor 2400 g metribuzin 1125 g	240[4] 85[4]	0.19 0.085	0.197	$88	Very efficient
Flumio	flumioxazin 175 g	7[4]	3.17-52.2[5]	0.03-0.5	$87	Very efficient
Isox	isoxaflutole 150 g	15	0.34	0.019	$40	Less efficient on vines, phyto on cane
Isox/metrib[3]	isoxaflutole 112.5 g metribuzin 1125 g	11[44] 85[4]	0.34 0.085	0.041	$80	Very efficient, phyto on cane
Imaz/Bal	imazapic 48 g isoxaflutole 75 g	4.5[4] 7.5[4]	0.062 0.34	0.011	$28	Very efficient

[1] Toxicity data relative to diuron and mean surface runoff concentrations from the runoff trial were used to calculate the treatment relative risk to diuron. Note: no herbicide treatments had adverse impact on cane.
[2] Total risk relative to diuron = Σ(individual active runoff mean concentration relative to diuron x individual relative toxicity to diuron)
[3] Treatment including a PSII herbicide
[4] Runoff concentration calculated from RO4 trial (relative to diuron concentrations) and adjusted to application rate in PC1
[5] As no proposed ecotoxicity threshold values were released in the 2017 scientific consensus statement, algae (acute 72 hour EC50, growth mg L-1) and aquatic plants (acute 7 day EC50, biomass mg L-1) values from the pesticide properties database for diuron and flumioxazin were used to determine the relative toxicity to diuron.

6.1.5 Field trials on strategies to reduce the use of herbicides in fallow

6.1.5.1 Preliminary trials CC1 and CC2: Results

Preliminary small scale field trials were conducted in 2014-2015 to narrow down the options for cover crop strategies that would reduce the weed population in fallow.

6.1.5.1.1 Cover crop coverage

The results of the statistical analysis showed significant interactions for the effect = Species x Date and for the effect = Sowing rate x Date in both trials. Tests of the fixed effects are presented in Table 37. The percentage of cover crop ground coverage is presented in Figure 39 and Figure 40 for trial CC1 and in Figure 41 and Figure 42 for trial CC2. Mean comparisons for each date are included in the graphs.

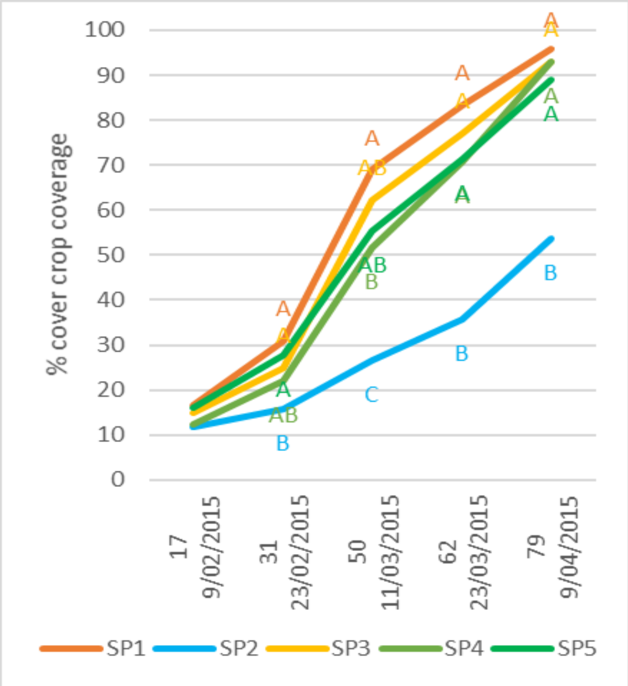
Table 37 Test of the fixed effect on cover crop coverage in trials CC1 and CC2

Effect	Num DF	Trial CC1 P value	Trial CC2 P value
Herbicide	1	0.4839	0.3755
Species	4	<.0001	<.0001
Sowing_rate	1	<.0001	<.0001
DAP	4	<.0001	<.0001
Species x Sowing_rate	4	0.6739	0.6980
Species x DAP	16	<.0001	0.0001
Sowing_rate x DAP	4	<.0001	0.0435
Species x Sowing_rate x DAP	16	0.6978	0.9723
Herbicide x Species	4	0.2870	0.5767
Herbicide x Sowing_rate	1	0.1189	0.3210
Herbicide x DAP	4	0.4495	0.3587
Herbicide x Species x Sowing rate	4	0.7212	0.4360
Herbicide x Species_ x DAP	16	0.6763	0.8790
Herbicide x Sowing_rate x DAP	4	0.8976	0.5949
Herbicide x Species x Sowing_rate x DAP	16	0.9180	0.7712

Cover crop coverage of cowpea alone (SP1) was higher than lablab alone (SP2) throughout the assessment period in both trials. The cover crop coverage of cowpea alone (SP1) was higher than the mix with Jack bean (SP4) at certain dates in both trials (Figure 39 and Figure 41).

At most assessment dates, the high sowing rate (R2) resulted in a significantly higher crop cover than the normal sowing rate (R1) in both trials (Figure 40 and Figure 42).

There was no significant difference in crop cover with or without herbicide in both trials.



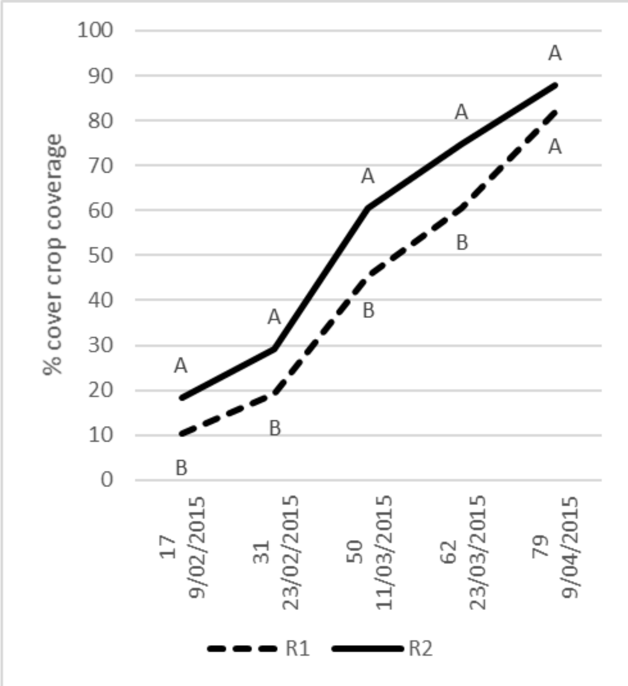
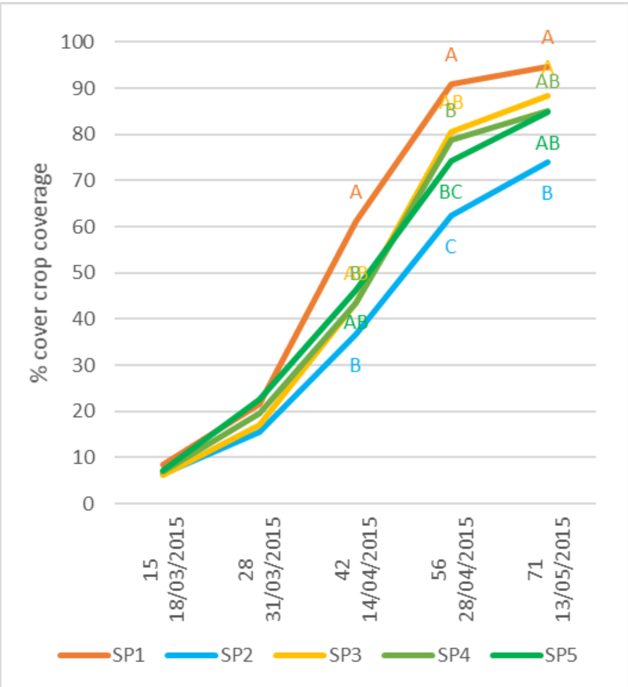


Figure 39 Percentage legume coverage in trial CC1 grouped by species[1,2].

Figure 40 Percentage legume coverage in trial CC1 grouped by sowing rate[1,2]



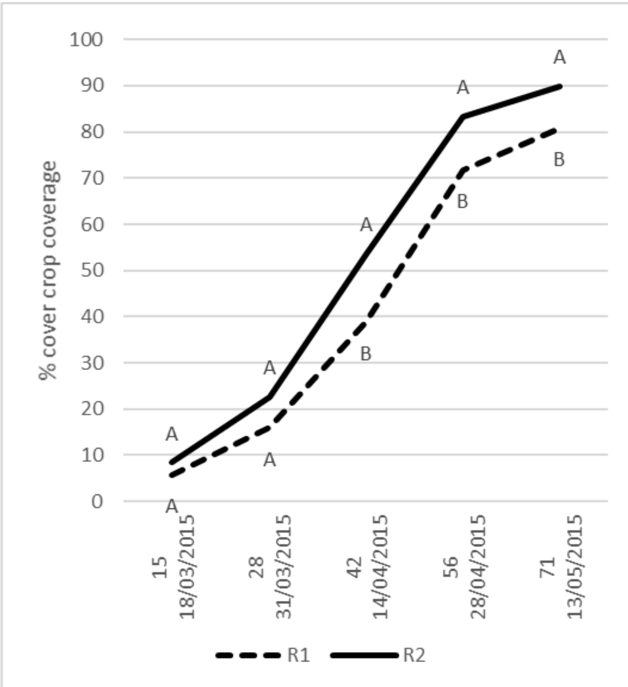


Figure 41 Percentage cover crop coverage in trial CC2 grouped by species[1,2].

Figure 42 Percentage cover crop coverage in trial CC2 grouped by sowing rate[1,2].

[1] Similar letters are not significantly different.

[2] SP1 Ebony cowpea, SP2 Rongai lablab, SP3 Cowpea + lablab, SP4 Cowpea + lablab + Jack bean, SP5 Cowpea + lablab + millet, R1 normal sowing rate, R2 double sowing rate.

6.1.5.1.2 Weed coverage

The results of the statistical analysis showed significant interactions for the effect = Species x Date, effect = Herbicide x Date and for the effect = Sowing rate x Date in both trials. Tests of the fixed effects are presented in Table 38. The percentage weed coverage is presented in

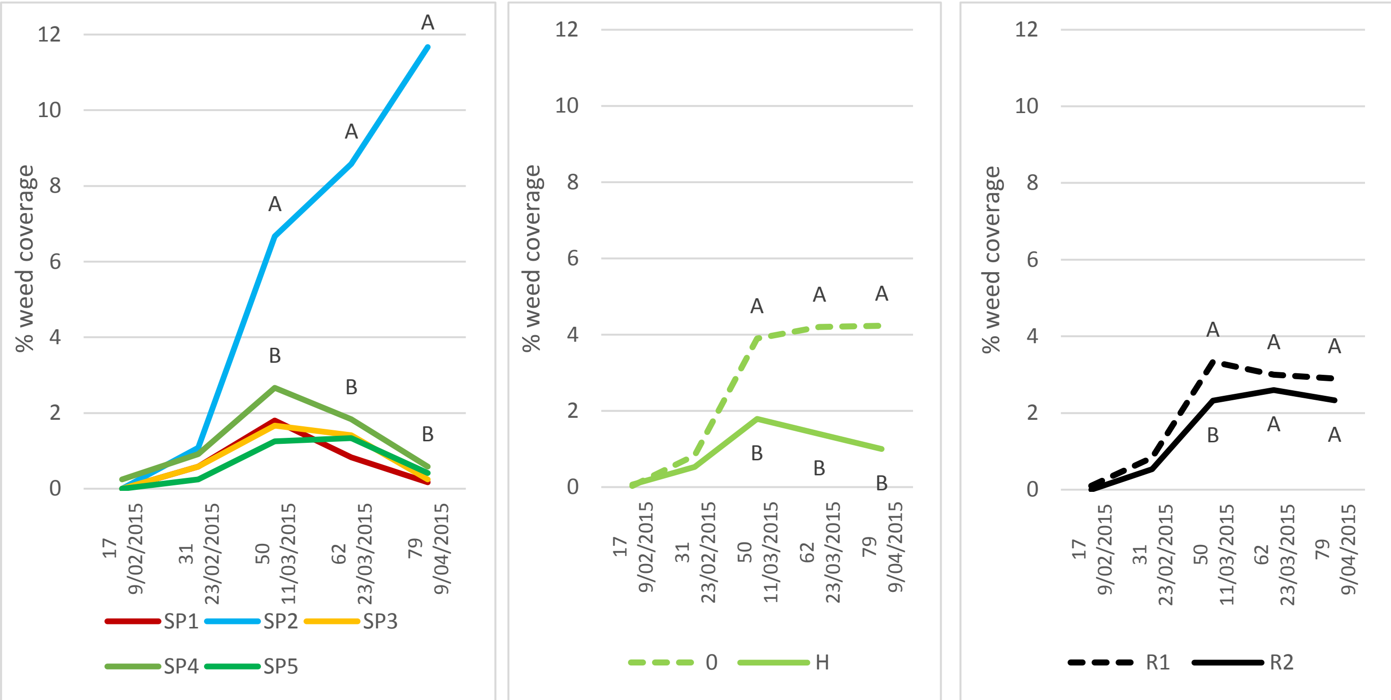
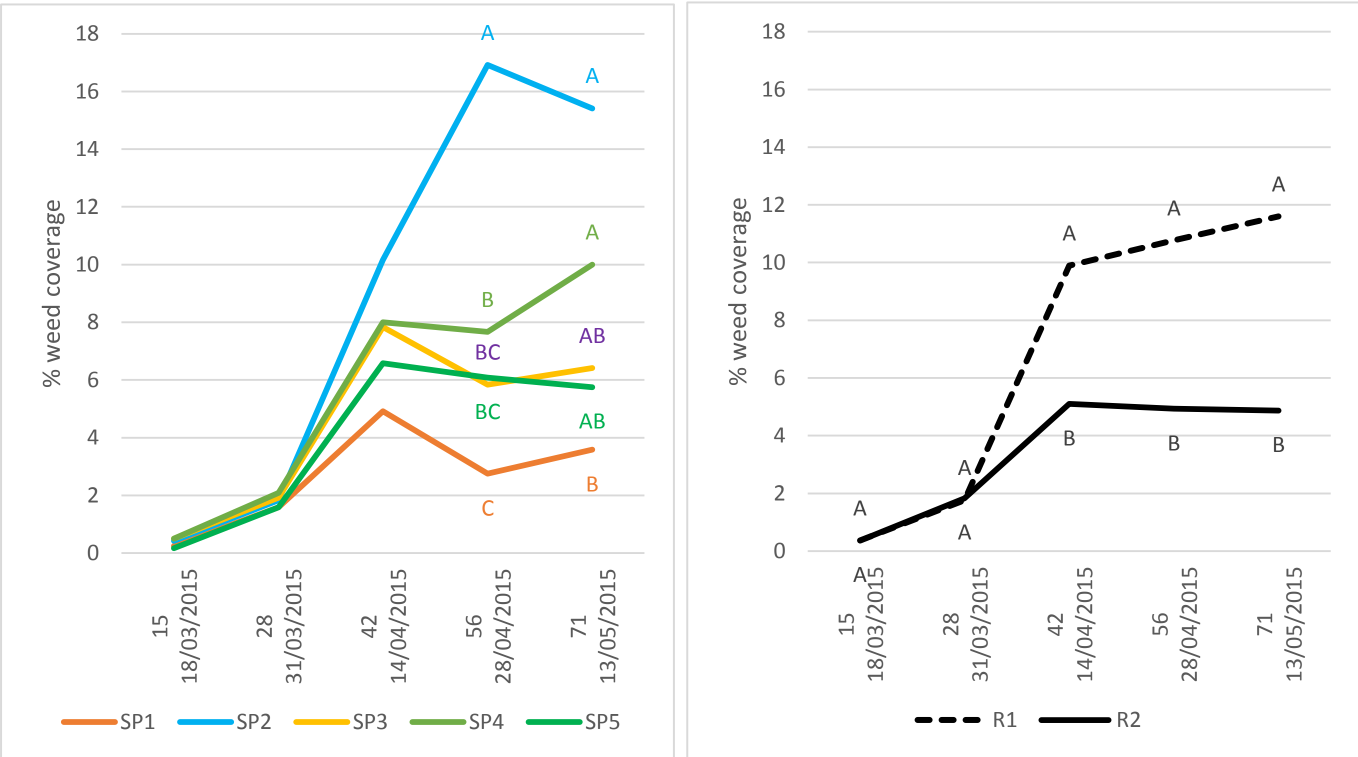


Figure 43 and



Figures 44. Mean comparisons for each date are included in the graphs.

Table 38 Test of the fixed effect on weed coverage in trials CC1 and CC2

Effect	Num DF	Trial CC1 P value	Trial CC2 P value
Herbicide	1	<.0001	0.6578
Species	4	<.0001	<.0001
Sowing_rate	1	0.0249	<.0001
DAP	4	<.0001	<.0001
Species x Sowing_rate	4	0.4240	0.7985

Effect	Num DF	Trial CC1 P value	Trial CC2 P value
Species x DAP	16	<.0001	0.0003
Sowing_rate x DAP	4	0.0374	<.0001
Species x Sowing_rate x DAP	16	0.2108	0.7052
Herbicide x Species	4	0.8651	0.7051
Herbicide x Sowing_rate	1	0.6292	0.6801
Herbicide x DAP	4	0.0124	0.3727
Herbicide x Species x Sowing_rate	4	0.3374	0.6893
Herbicide x Species x DAP	16	0.9585	0.4334
Herbicide x Sowing_rate x DAP	4	0.9029	0.8063
Herbicide x Species x Sowing_rate x DAP	16	0.7577	0.6578

Expectedly the weed coverage in lablab alone (SP2) -which had the lowest cover crop coverage – was higher than in other treatments at some assessment dates in both trials. In trial CC2 only, the weed coverage in cowpea alone (SP1) was lower than in the mix with Jack bean (SP4) for the last two assessment dates. In both trials, the mix with millet (SP5) tended to provide better weed suppression for one month after sowing.

The high sowing rate reduced the weed coverage in both trial, however differences were more obvious in trial CC2 with weed coverage reduced from 12% to 5%.

Applying herbicide resulted in lower weed coverage from 50 days after sowing in trial CC1 only; however this significant reduction was only from 4% to 2% weed coverage.

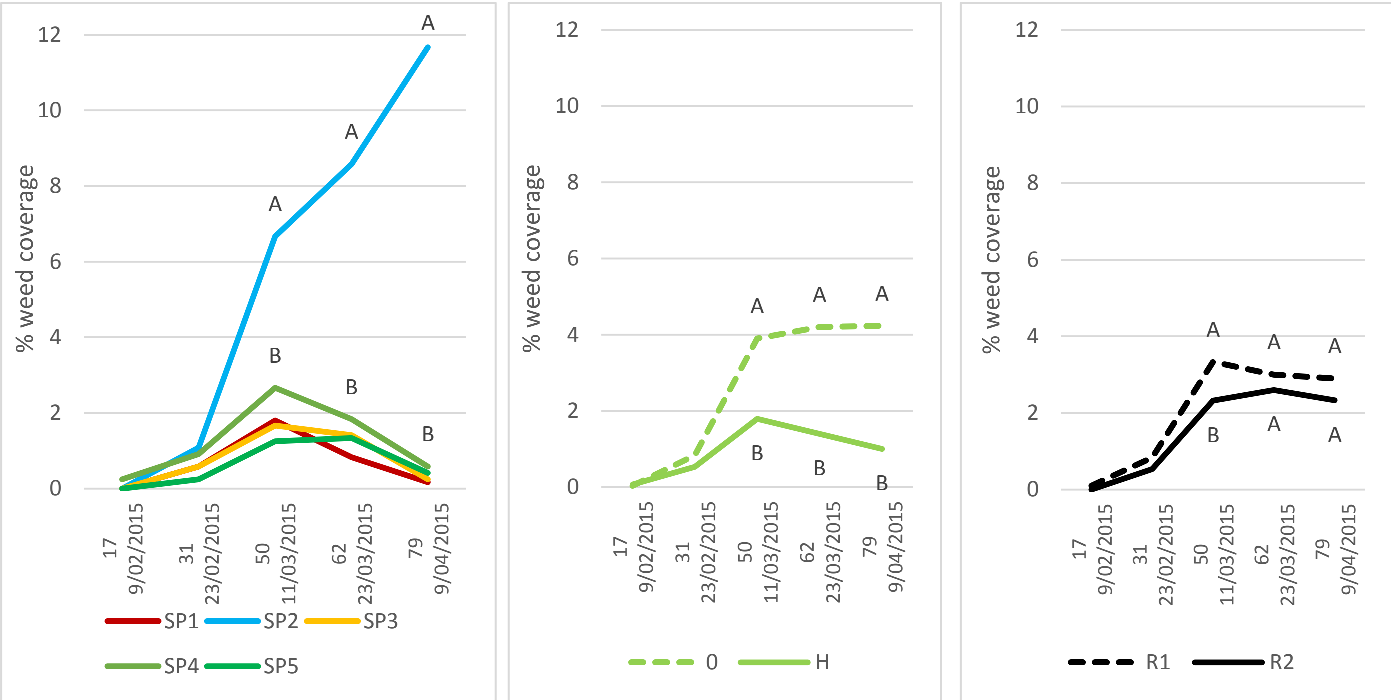
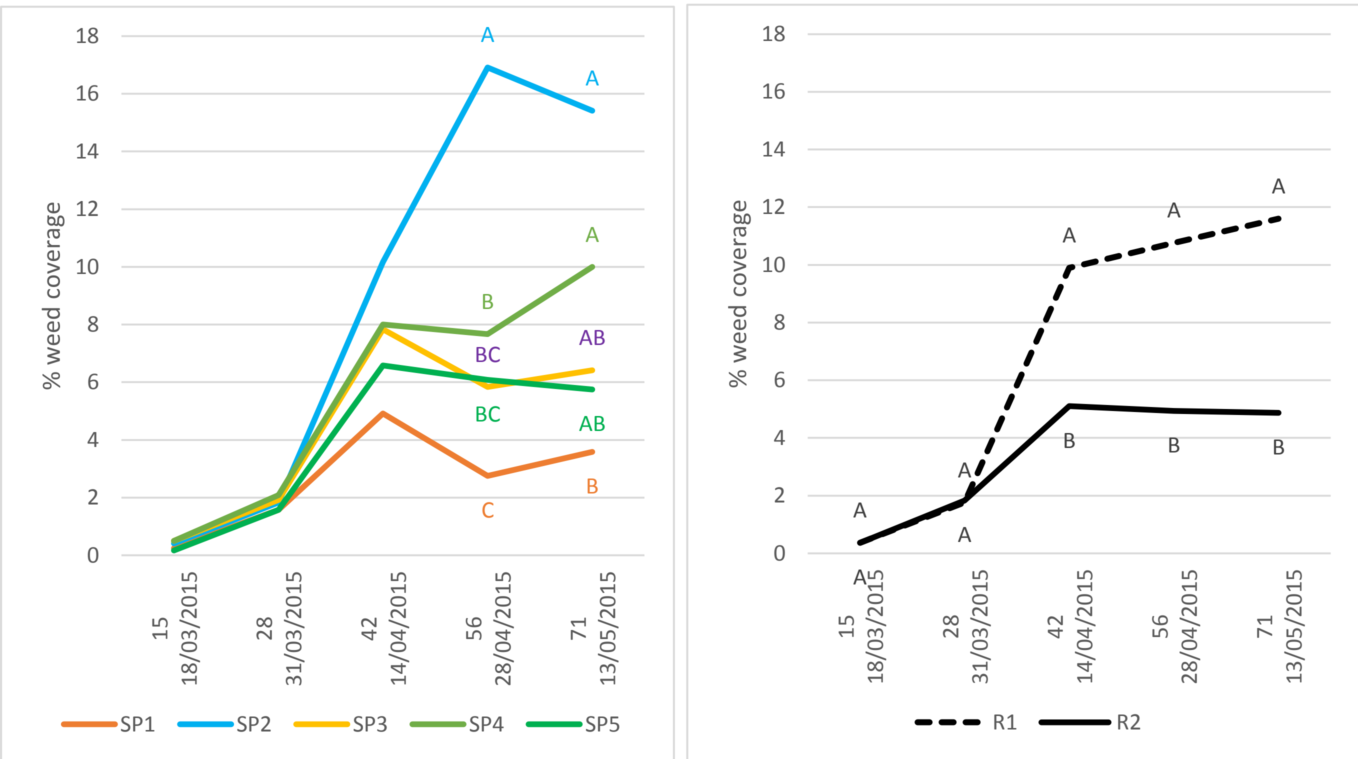


Figure 43 Percentage weed coverage in trial CC1 grouped by species (left graph), herbicide regime (centre graph) and sowing rate (right graph)[1,2].



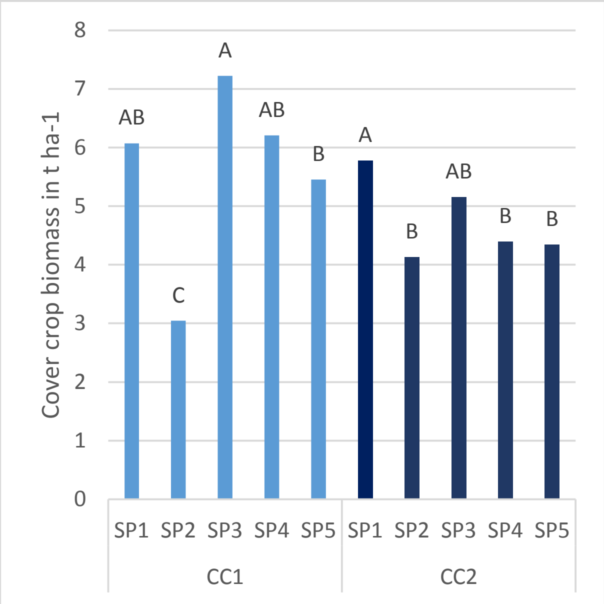
Figures 44 Percentage weed coverage in trial CC2 grouped by species (left graph) and sowing rates (right graph)[1, 2]

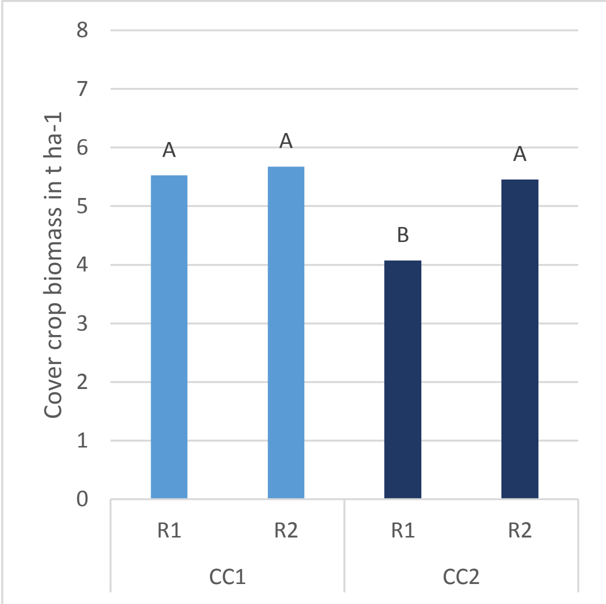
[1] Similar letters within each graph are not significantly different.

[2] SP1 Ebony cowpea, SP2 Rongai lablab, SP3 Cowpea + lablab, SP4 Cowpea + lablab + Jack bean, SP5 Cowpea + lablab + millet, R1 normal sowing rate, R2 double sowing rate, 0 no herbicide, H herbicide applied.

6.1.5.1.3 Biomass results

The cover crop biomass data for the two trials were grouped for analysis. The results of the statistical analysis showed significant interactions for the effect = Site x Species and for the effect = Site x Sowing rate. Tests of the fixed effects are presented in Table 39. The biomass results are presented in





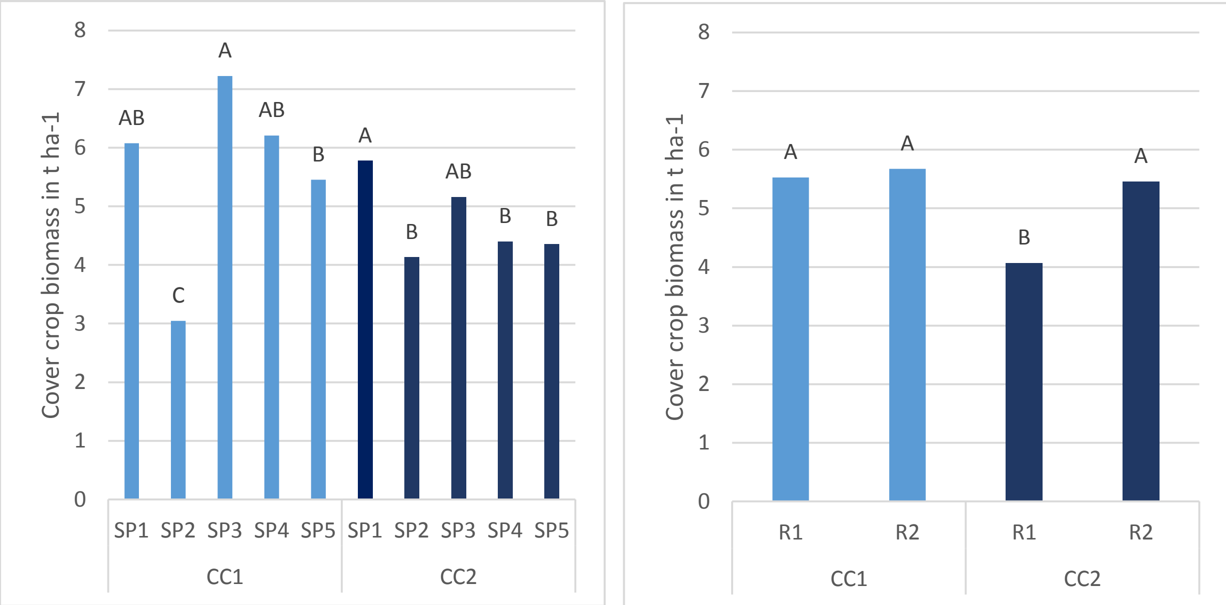
Figures 45. Mean comparisons are included in the graphs.

Table 39 Test of the fixed effect on biomass (trials CC1 and CC2 combined)

Effect	Num DF	P value
site	1	0.3306
Herbicide	1	0.4559
Site x Herbicide	1	0.9364
Species	4	<.0001
Site x Species	4	0.0075
Herbicide x Species	4	0.7164
Site x Herbicide x Species	4	0.9564
Sowing_rate	1	0.0110
Site x Sowing_rate	1	0.0386
Herbicide x Sowing_rate	1	0.3377
Site x Herbicide x Sowing_rate	1	0.4796
Species x Sowing_rate	4	0.1233
Site x Species x Sowing_rate	4	0.2378
Herbicide x Species x Sowing_rate	4	0.5069
Site x Herbicide x Species x Sowing_rate	4	0.9671

The combined analysis showed that cowpea alone (SP1) in trial CC2 or mixed 50% with lablab (SP3) in trial CC1 gave the best final biomass. Biomasses obtained on lablab alone (SP2) were the lowest in both trials but particularly in trial CC1. This poor result for SP2 (lablab only) was due to a severe attack of loopers and heliothis that defoliated the lablab plants in trial CC1. Even if the plants were sprayed by insecticide, the insect damage impeded their growth and the final biomass. Lablab mixes in SP3, SP4 and SP5 were far less affected as if the other legume species repelled the insects. In trial CC2 only, the addition of Jack bean (SP4) significantly decreased the biomass compared to the best treatment. The addition of millet (SP5) significantly reduced the biomass compared to the best treatments in both trials.

The highest sowing rate (R2) gave significantly more biomass than the normal sowing rate (R1) in trial CC2 only.



Figures 45 Average of dry biomass at harvest in trial CC1 and CC2 grouped by species (left graph) and by sowing rate (right graph)[1,2].

There was no significant difference in final biomass between plots sprayed with herbicide and unsprayed plots, however the plots sprayed with herbicide tended to generate lower yield (4.9 t ha^{-1}) than the unsprayed plots (5.5 t ha^{-1}), likely due to some phytotoxic herbicide effect on the cover crop.

6.1.5.1.4 Available N results

The measurements of available N per ha for the two trials were grouped for analysis. The results of the statistical analysis showed significant interactions for the effect = Species and for the effect = Site x Sowing rate. Tests of the fixed effects are presented in Table 40. The available N per ha is presented in Figures 46. Mean comparisons are included in the graphs.

Table 40 Test of the fixed effect on biomass (trials CC1 and CC2 combined)

Effect	Num DF	P value
Site	1	0.9906
Herbicide	1	0.4894
Site x Herbicide	1	0.8044
Species	4	<.0001
Site x Species	4	0.0572
Herbicide x Species	4	0.7289

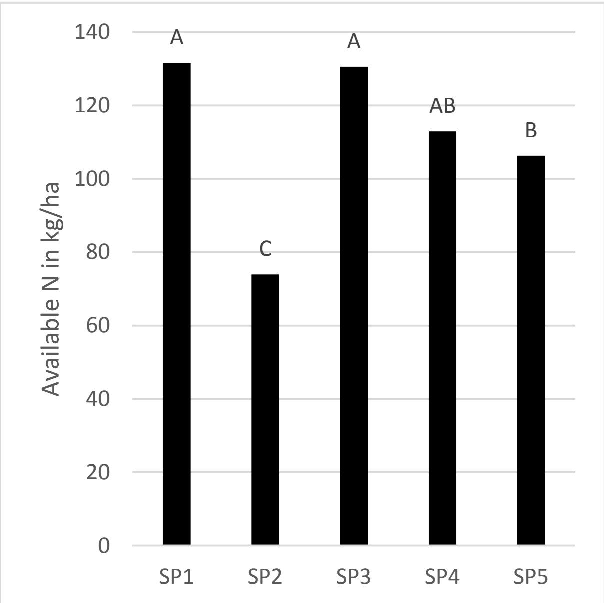
[1] Similar letters within each graph are not significantly different.

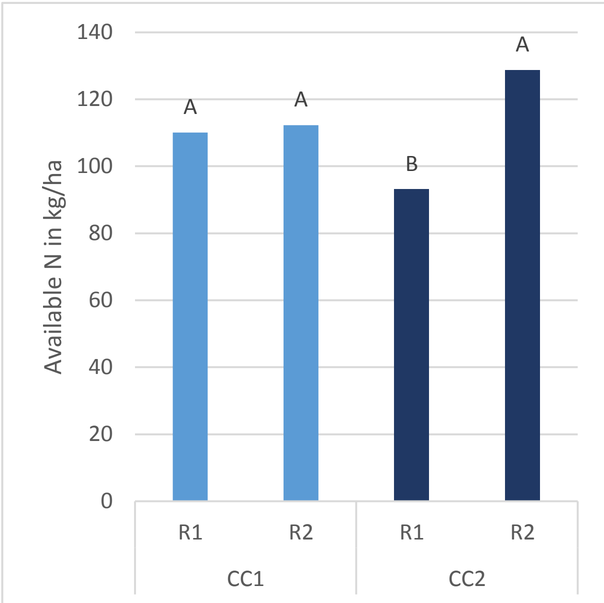
[2] SP1 Ebony cowpea, SP2 Rongai lablab, SP3 Cowpea + lablab, SP4 Cowpea + lablab + Jack bean, SP5 Cowpea + lablab + millet, R1 normal sowing rate, R2 double sowing rate.

Effect	Num DF	P value
Site	1	0.9906
Site x Herbicide x Species	4	0.9192
Sowing_rate	1	0.0056
Site x Sowing_rate	1	0.0139
Herbicide x Sowing_rate	1	0.2477
Site x Herbicide x Sowing_rate	1	0.5001
Species x Sowing_rate	4	0.1800
Site x Species x Sowing_rate	4	0.2200
Herbicide x Species x Sowing_rate	4	0.4913
Site x Herbicide x Species x Sowing_rate	4	0.9693

Around 130 kg N ha^{-1} were supplied by the residues of cowpea alone (SP1) and mixed with lablab (SP3), whereas 106 kg N ha^{-1} was supplied by the mix with millet (SP5) and only 74 kg N ha^{-1} by lablab alone (SP2).

In trial CC2, the high sowing rate supplied higher N compared to the low sowing rate (129 kg versus 93 kg N ha^{-1}respectively).





Figures 46 Available N in kg/ha grouped by species (mean of trials CC1 and CC2) left graph and grouped by sowing rate (right graph)[1,2].

6.1.5.2 Preliminary trials CC1 and CC2: Discussion

The best cover crops to reduce weed coverage were either cowpea alone or mixed 50% with lablab. They were also the best yielding crops, supplying around 130 kg N ha^{-1}. Adding millet to the mix was beneficial to early weed suppression. Adding Jack bean to the mix reduced the biomass and did not improve the ground coverage and weed control. Lablab alone did not cover the ground enough to ensure efficient weed control (up to 17% weed coverage). It also generated less biomass, supplied

[1] Similar letters within each graph are not significantly different

[2] SP1 Ebony cowpea, SP2 Rongai lablab, SP3 Cowpea + lablab, SP4 Cowpea + lablab + Jack bean, SP5 Cowpea + lablab + millet, R1 normal sowing rate, R2 double sowing rate.

only 74 kg N ha^{-1} and was particularly sensitive to insect damage so it makes sense to use it only in a mixed crop scenario.

The high sowing rate increased the speed of cover crop establishment and coverage and decreased the amount of weeds. It also resulted in a higher supply of nitrogen compared to the low sowing rate.

Using herbicide decreased the weed pressure to a small extent (from 4% to 1.5% on average) but tended to reduce the crop biomass, likely due to herbicide phytotoxicity on the cover crop.

Based on these conclusions, treatments selected for the 2015-2016 trials were cowpea alone, cowpea + lablab and cowpea + lablab + millet (for early weed suppression). All were tested at a high sowing rate and without herbicide.

6.1.5.3 Trials CC3 and CC4: Results

All data related to trial CC3 and CC4 were grouped for statistical analysis.

6.1.5.3.1 Cover crop coverage

The results of the statistical analysis showed a range of significant interactions. For ease of interpretation, we will concentrate on the significant Effect = Site x Tillage and Site x Species. Tests of the fixed effects are presented in Table 41. Mean comparisons are included in the graphs (Figure 47).

Table 41 Test of the fixed effect on cover crop coverage (trials CC3 and CC4 combined)

Effect	Num DF	P value
Site	1	0.175
Tillage	2	0.000
Species	2	0.000
Tillage x Species	3	0.302
Date	6	0.000
Site x Tillage	2	0.000
Site x Species	1	0.023
Site x Tillage x Species	2	0.262
Tillage x Date	12	0.001
Species x Date	9	0.000
Tillage x Species x Date	15	0.081

The ground coverage of cowpea alone (T1) was higher than cowpea + lablab (T2) in both trials across the assessment period, however the differences were bigger in trial CC3 due to the poor establishment of lablab in some wet plots with poor drainage. The smaller differences in trial CC4 were only due to the normal slower growth development of lablab as no waterlogging stress occurred.

In trial CC3, the coverage of cowpea + lablab + millet (T3) was as high as cowpea alone (T1), thanks to the early germination and coverage of the millet (data not shown). The cover crop ground coverage was lower in no tillage compared to the other treatments in trial CC4, which was due to the presence of cane residues and weeds at the time of sowing that impeded the quick establishment of the legume crop.

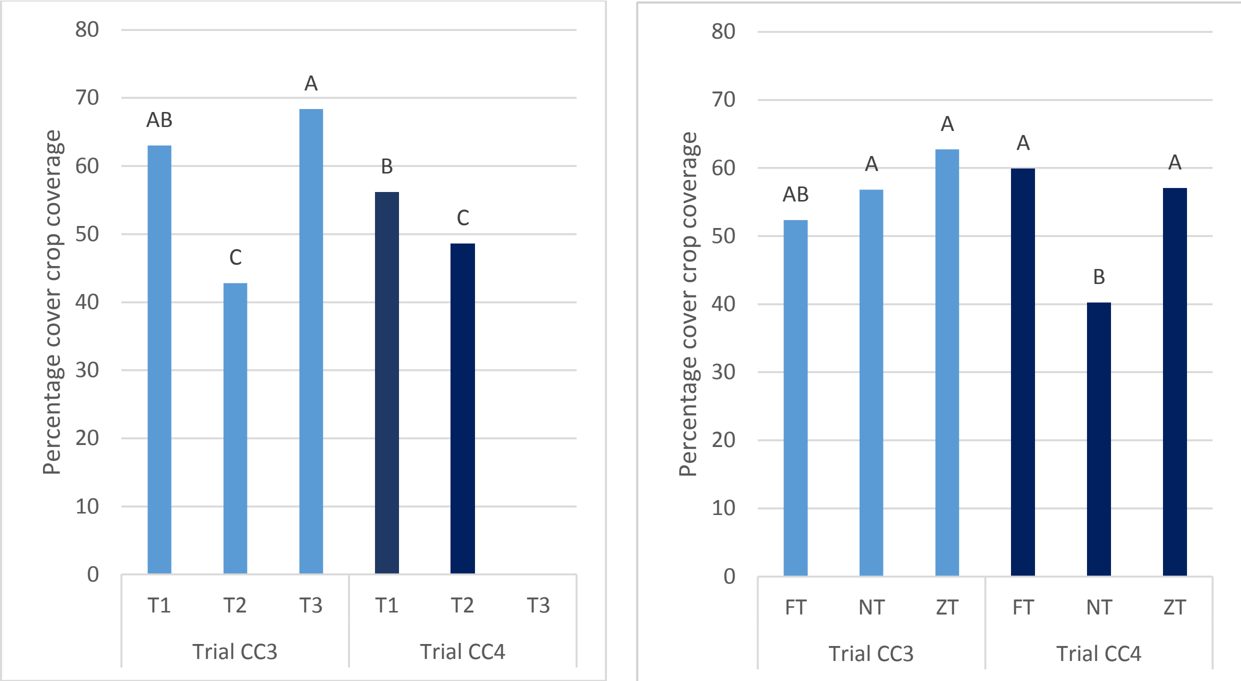


Figure 47 Percentage cover crop coverage in trials CC3 and CC4 grouped by crop species (left graph) and tillage system (right graph)[1,2].

6.1.5.3.2 Weed coverage

The results of the statistical analysis showed a range of significant interactions. For ease of interpretation, we will concentrate on the significant Effect = Site x Tillage x Species. Tests of the fixed effects are presented in Table 42.

The percentage weed coverage is presented in Figure 48. Mean comparisons are included in the graph.

Table 42 Test of the fixed effect on weed coverage (trials CC3 and CC4 combined)

Effect	Num DF	P value
Site	1	0.324
Tillage	2	0.000
Species	3	0.000
Tillage x Species	5	0.005
Date	6	0.000
Site x Tillage	2	0.000
Site x Species	2	0.000
Site x Tillage x Species	4	0.017
Tillage x Date	12	0.000
Species x Date	15	0.000
Tillage x Species x Date	27	0.271

[1] Similar letters within each graph are not significantly different

[2] T1 Ebony cowpea, T2 Cowpea + Rongai lablab, T3 Cowpea + lablab + millet, T4 no cover crop, NT no tillage, ZT zonal tillage, FT full tillage

The difference in weed coverage in the bare soil treatment (T4) between trial CC3 (38 to 48% weed coverage) and CC4 (6 to 13% weed coverage) was due to the type of weeds and the weed pressure (Figure 48). Both trials were sprayed but the grasses dominant in trial CC3 covered up to 80% of the ground at time of spraying. Broadleaves, dominant in trial CC4, were more scattered at time of spraying. There was no significant difference when comparing the effect of the farming system on the weed coverage on bare soil (T4) at each site.

Cowpea alone (T1) and cowpea + lablab +millet (T3) reduced the weed coverage compared to cowpea + lablab (T2) and bare soil (T4) by more than 50% in all tillage systems in trial CC3. In zonal and full till where the millet could be sown, the blend with millet (T3) significantly reduced the weed coverage compared to cowpea alone (T1) by more than 73%. The lack of competition from the blend cowpea + lablab (T2) was due to the poor establishment of the lablab species in this trial. Rongai lablab did not perform as well as Ebony cowpea in wet conditions.

In trial CC4, the plots with the highest weed coverage were the no till plots where small weeds were already present at time of sowing the legume (up to 70% weed coverage in cowpea alone (T1)). Cowpea + lablab (T2) significantly reduced the weed coverage by 46% compared to cowpea alone (T1). In zonal till, cowpea + lablab (T2) also reduced the weed coverage 70% better then cowpea alone (T1), however differences were not significant. This result highlights the use of cover crop blends to achieve maximum weed suppression. If all species in the blend develop successfully, they control the weeds better due to the combination of competition effects of each cover crop species.

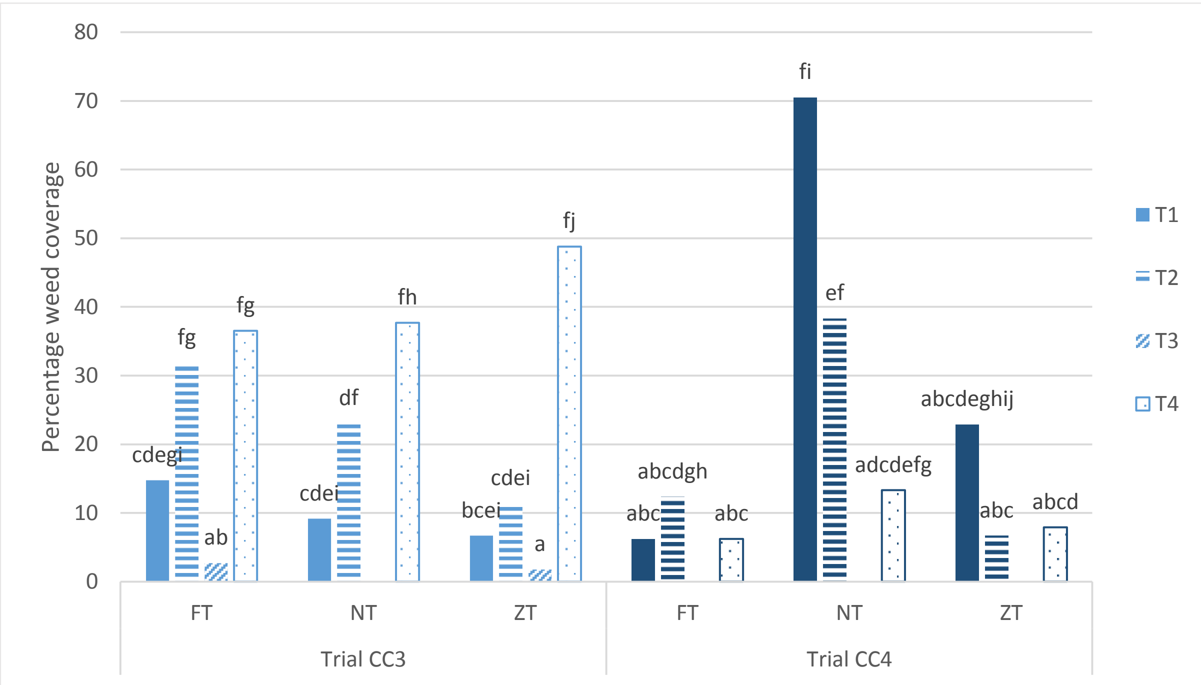


Figure 48 Percentage weed coverage in trials CC3 and CC4[1,2]

6.1.5.3.3 Biomass results

The cover crop biomass data for the two trials were grouped for analysis. The results of the statistical analysis showed a significant interaction for the Effect = Species. Tests of the fixed effects are presented in

[1] Similar letters are not significantly different

[2] NT no tillage, ZT zonal tillage, FT full tillage

Table 43. The biomass results are presented in Figure 49. Mean comparisons for each date are included in the graphs.

Table 43 Test of the fixed effect on biomass (trials CC3 and CC4 combined)

Effect	Num DF	P value
Site	1	0.000
Tillage	2	0.333
Species	3	0.000
Site x Tillage	2	0.203
Tillage x Species	6	0.110
Site x Species	1	0.648
Site x Tillage x Species	2	0.902

Cowpea alone (T1) produced the most biomass in both trials. Dry matter yield of lablab is usually reported higher than cowpea, particularly under drought conditions; however lablab only tolerates short periods of flooding but is intolerant of poor drainage and prolonged inundation (http://www.tropicalforages.info/key/forages/Media/Html/entities/lablab_purpureus.htm)

The lower biomass observed with lablab in our trials was likely due to wetter environmental conditions than experienced in the literature reviews.

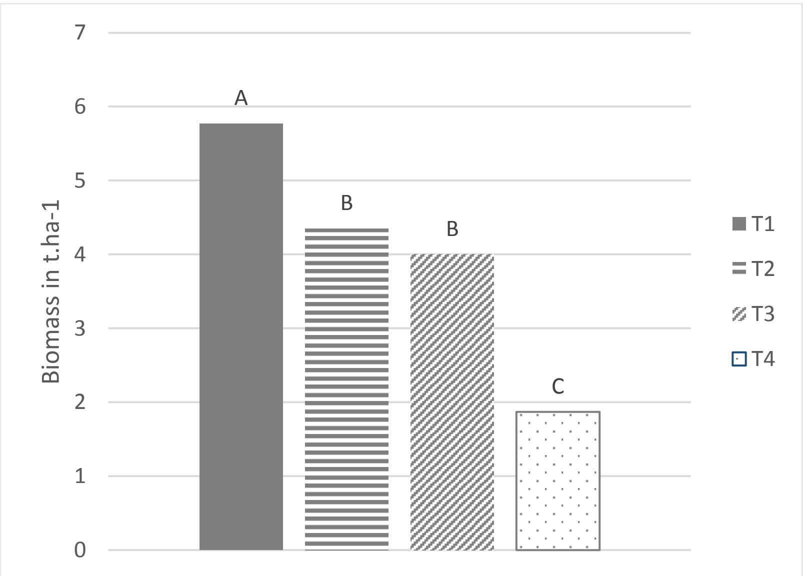


Figure 49 Cover crop biomass (mean of trials CC3 and CC4)[1,2].

6.1.5.3.4 Available N per ha results

The measurements of available N per ha for the two trials were grouped for analysis. The results of the statistical analysis showed significant interactions for the Effect = Species. Tests of the fixed effects are presented in Table 44. The results for available N per ha are presented in Figure 50. Mean comparisons are included in the graph.

[1] Similar letters are not significantly different

[2] T1 Ebony cowpea, T2 Cowpea + Rongai lablab, T3 Cowpea + lablab + millet, T4 no cover crop, NT no tillage, ZT zonal tillage, FT full tillage

Table 44 Test of the fixed effect on available N (trials CC3 and CC4 combined)

Effect	Num DF	P value
Site	1	0.000
Tillage	2	0.593
Species	3	0.000
Site x Tillage	2	0.506
Tillage x Species	6	0.064
Site x Species	1	0.994
Site x Tillage x Species	2	0.986

All cover crop treatments produced between 72 and 98 kg N ha^{-1} without a significant difference between them. Cowpea alone (T1) tended to produce the most N available, as the biomass is the main driver of the nitrogen produced.

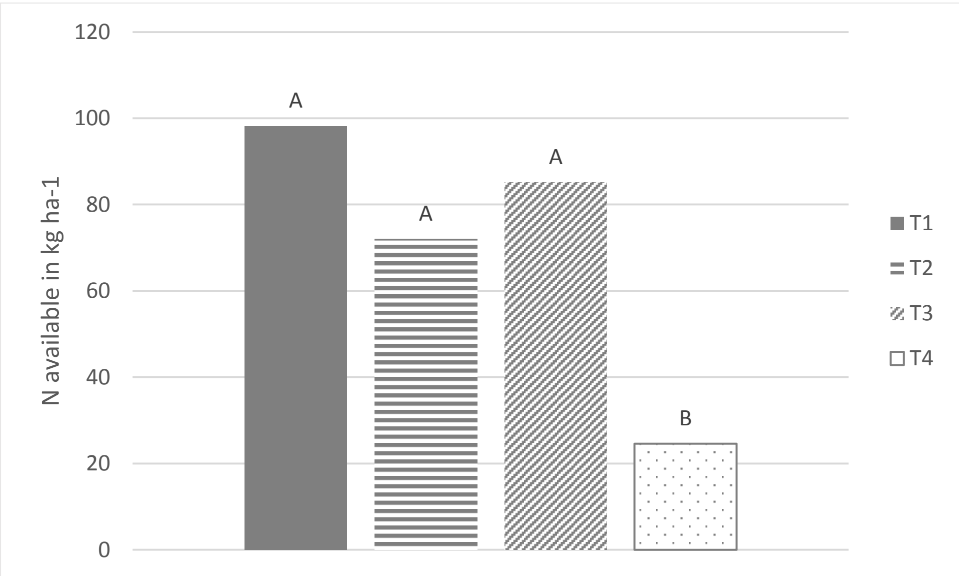


Figure 50 N available (mean of trials CC3 and CC4)[1,2].

6.1.5.3.5 Weed coverage in the following plant cane

Weed coverage was measured in untreated areas in the following plant cane to assess the long term effect of the fallow system on weed control. It is important to mention that the whole block was fully tilled to prepare the ground for planting cane at both trial sites. It is anticipated the full tillage would resurface buried seeds, therefore reducing the impact of the fallow treatments. The data for the two trials were grouped for analysis. The results of the statistical analysis showed significant interactions for the Effect = Site x Species and Effect = Tillage. Tests of the fixed effects are presented in Table 45. The results in terms of weed coverage in plant cane are presented in Figure 51. Mean comparisons are included in the graphs.

[1] Similar letters are not significantly different

[2] T1 Ebony cowpea, T2 Cowpea + Rongai lablab, T3 Cowpea + lablab + millet, T4 no cover crop, NT no tillage, ZT zonal tillage, FT full tillage

Table 45 Test of the fixed effect on weed coverage in plant cane (trials CC3 and CC4 combined)

Effect	Num DF	P value
Site	1	0.019
Tillage	2	0.018
Species	3	0.161
Tillage x Species	5	0.271
Date	2	0.000
Site x Tillage	2	0.102
Site x Species	2	0.035
Site x Tillage x Species	4	0.177
Tillage x Date	4	0.633
Species x Date	5	0.163
Tillage x Species x Date	9	0.276

Weed coverage in plant cane was higher in trial CC3 (maximum 47%) than CC4 (maximum 9%), likely due to a very high grass seed bank. The weed coverage in T2 and T4 (43 and 47% coverage) was higher than the other treatments (around 30%) in trial CC3, however the results are not significantly different. Results in plant cane in both trials correlate well with the weed coverage in fallow. Weed spraying in the bare fallow (T4) was carried out a bit late and some weeds started to seed, thus increasing the weed seed bank.

In plant cane, the weed coverage was higher in the full tillage treatment (40% weed coverage) compared to the zonal tillage (26% weed coverage) across both sites. This result does not correlate well with weed coverage measurements in fallow. The full tillage operation in fallow could have buried the surface seeds that were unearthed during the second tillage operation before plant cane.

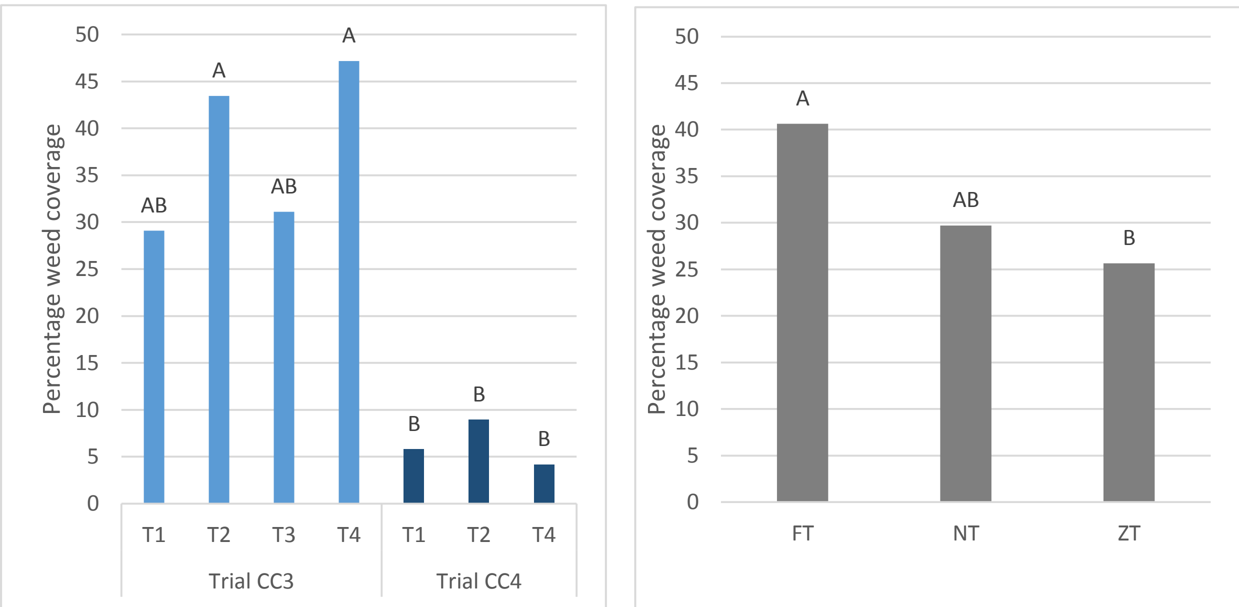


Figure 51 Percentage weed coverage in plant cane for trials CC3 and CC4 grouped by species (left graph) and mean of trials CC3 and CC4 grouped by tillage system (right graph)[1]

[1] T1 Ebony cowpea, T2 Cowpea + Rongai lablab, T3 Cowpea + lablab + millet, T4 no cover crop, NT no tillage, ZT zonal tillage, FT full tillage

6.1.5.3.6 Plant cane yield

Yield data for the two trials were grouped for analysis. The results of the statistical analysis showed a significant interaction for the Effect = Site x Tillage. Tests of the fixed effects are presented in Table 46. Cane yield results are presented in Figure 52. Mean comparisons are included in the graph.

Table 46 Test of the fixed effect on weed coverage in plant cane (trials CC3 and CC4 combined)

Effect	Num DF	P value
Site	1	0.042
Tillage	2	0.062
Species	3	0.745
Site x Tillage	2	0.020
Tillage x Species	6	0.907
Site x Species	2	0.885
Site x Tillage x Species	4	0.645

In trial CC3, cane yield was higher in the full tillage treatment compared to the zonal tillage treatment (71 t ha^{-1} versus 63 t ha^{-1}). Yields were similar in the three farming systems in trial CC4 (Figure 52).

In plant cane, weed and nutrient management was conducted at the paddock scale at each trial site. Nutrients were added according to results of the soil analysis in bare fallow and weeds were controlled using pre and post emergent throughout the season. This whole paddock management would have cancelled any potential difference between cover crop treatments. In a real scenario, the nitrogen provided by the cover crop needs to be taken in consideration for the nutrition of the following plant cane.

Differences related to tillage systems obtained in trial CC3 are not linked to cover crop results in fallow. They are likely related to a better soil preparation that was more favourable for cane germination and growth in this soil type.

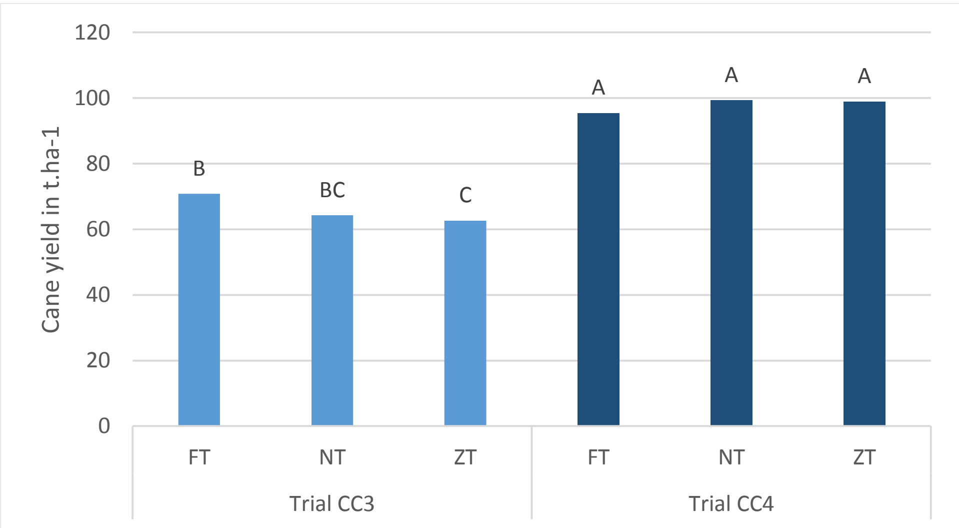


Figure 52 Plant cane yield (grouped by tillage system). Similar letters are not significantly different[1].

[1] NT no tillage, ZT zonal tillage, FT full tillage

6.1.5.4 Trials CC3 and CC4: Discussion

Cowpea alone or cowpea mixed with lablab and millet were the best weed control options and seemed adequate for the three tested tillage systems, as long as the cover crops were sown before any weeds germinated. Bare soil fallow was also an effective management alternative as long as the weeds were sprayed before they set seeds. Keeping a bare fallow during the wet season has the disadvantage of requiring multiple herbicide applications prone to contaminate watercourses or, alternatively, multiple tillage operations that put the paddock at high risk of erosion.

In wet conditions, the full tillage system was more challenging for mixes with Rongai lablab species whereas Ebony cowpea was fully adapted to extreme wet conditions. The weeds took advantage of the poor establishment of lablab.

Japanese millet performed well in all farming systems (including fully tilled wet conditions -as long as there was no prolonged waterlogging). The early germinating millet outcompeted the weeds in the early stages after planting, while the legumes emerged and competed with the weeds a few weeks later. It is to note that millet seeds are likely to attract rats and assist breeding. In areas where rats are an issue, the addition of millet should be considered carefully to avoid millet seeding simultaneously with the rat breeding period.

Cover crop costing

Using our trial data, we compared the cost of establishing cover crops (at twice the sowing rate) without the use of herbicides versus cover crops at the normal sowing rate that will also require the use of herbicides. Table 47 presents a few scenarios that were tested in 2014-15 and 2015-16 trials as well as in 2016-17 demonstrations.

The potential herbicide cost in fallow was based on the application of Stomp®Xtra as a pre-emergence followed by Verdict. The total cost per ha was alleviated by the N supplied by the cover crop (available N data are mean of 2014-15 and 2015-16 trials). The adjusted cost was the total cost minus the N savings.

Scenarios 6 and 7 combining cowpea + lablab (high sowing rate) with or without millet were the cheapest of the non- herbicide strategies, but they were still \$60 to \$90 ha^{-1} more expensive than traditional legume scenarios (1, 2 and 3) that relied on herbicides. This costing did not take into account additional soil benefits:

- no plant back effect in the following plant cane from herbicide residues used during fallow
- mixes of cover crop species in fallow are beneficial to soil structure
- high green manure biomass provides more organic matter.

Soybean is currently the most planted legume fallow in Queensland but it does not provide an early ground coverage (25% of growers acknowledge planting soybean in their fallow according to the results of the 2017 SRA grower survey). Further research is necessary to look into the potential to use soybean in blends that would achieve acceptable weed control.

Table 47 Costing scenario for establishing cover crops and mixes with or without herbicides.

Scenario	1	2	3	4	5	6	7	
	cowpea with herbicide	**lablab with herbicide**	**cowpea + lablab with herbicide**	**cowpea (HSR[1])**	**cowpea + millet (HSR[1])**	**cowpea + lablab (HSR[1])**	**cowpea + lablab + millet (HSR[1])**	***cost seed/kg***
Cowpea kg/ha	35		17.5	70	60	35	28	***$4.81***
Lablab kg/ha		35	17.5			35	28	***$3.50***
Millet kg/ha					10		10	***$6.50***
Seed cost $/ha	$168	$123	$145	$337	$354	$291	$298	
Potential herbicide cost $/ha	$47	$47	$47	$0	$0	$0	$0	
Total cost $/ha	$215	$170	$192	$337	$354	$291	$298	
N available kg/ha	135	59	110	127	115	149	120	
Saving cost of N $/ha	$88	$38	$72	$83	$75	$97	$78	
Adjusted cost $/ha	$128	$131	$121	$254	$279	$194	$220	

6.2 Part B: Varietal susceptibility to herbicides (phytotoxicity screening)

6.2.1 Pot trial results

6.2.1.1 Greenseeker results

The interaction Product x Variety x Week was significant (P 0.0481), however the only significant difference in colour between treatments within a week was Rattler® decreasing the Greenseeker value of Q249[Φ] compared to Amicide® 625 sprayed on KQ228[Φ] in week 6 (data not shown).

The use of the Greenseeker indicator did not seem fully suited to this trial, because the plants developed rapidly mixing up the cane leaves of adjacent pots. More space between pots would have been more suitable to achieve a correct measurement. A different device like a chlorophyll meter SPAD 502 that measures the chlorophyll content at the leaf level was tested in later trials.

6.2.1.2 Phytotoxicity rating results

The point of having a factorial trial is to learn how the factors interact and affect a trait. In this case the model was: Colour = overall mean + block + variety + product + date + variety x product + variety x date + variety x product x date.

Unfortunately, there was not at least 5% of the observations (per value colour) for each combination of factors and none of the models applied did work when combining all factors together using the raw data. A subset of the data was analysed by fitting a Poisson distribution to each week of data.

The output of the analysis for the first three weeks showed significant differences between products ($P<0.0001$). There were no significant differences in phytotoxicity rating for the interaction Product x Variety and no differences between varieties for any of the assessments.

The mean comparisons for the first three weeks showed that all herbicide treatments received a higher phytotoxicity rating than the controls (Table 48). At week 1, Monopoly and Clincher® generated a higher phytotoxicity rating than the other herbicides. By week 2, only Monopoly had a higher phytotoxicity rating than the other herbicides. Krismat® had a higher phytotoxicity rating than Rattler® in week 1 only.

[1] HSR : high sowing rate

Table 48 Mean comparison of phytotoxicity rating in pot trial for the first three weeks[1].

product	Estimate for colour rating	Letter Group	product	Estimate for colour rating	Letter Group	product	Estimate for colour rating	Letter Group
Week 1			**Week 2**			**Week 3**		
Mono	0.7618	A	**Mono**	0.7638	A	**Krism**	0.6931	A
Clinch	0.6867	A	**Krism**	0.6931	B	**Clinch**	0.6931	A
Krism	0.3969	B	**Clinch**	0.6931	B	**Mono**	0.6931	A
Amic	0.3726	BC	**Rattl**	0.6755	B	**Socc**	0.6579	A
Socc	0.3639	BC	**Socc**	0.6634	B	**Rattl**	0.6512	A
Actri	0.3559	BC	**Amic**	0.6634	B	**Amic**	0.645	A
Rattl	0.2563	C	**Actri**	0.6567	B	**Actri**	0.6431	A
control	0.01008	D	**control**	0.0524	C	**control**	0.01067	B

6.2.1.3 HTVD results

The interaction Product x Variety x Week was significant (P<0.0001). Only some mean comparisons for week 4 are presented in Table 49 to improve the report readability. Values are estimates of HTVD. Same letters within a row are not statistically different.

Monopoly was the product that impacted the earliest on the growth of many varieties like SP80, Q238$^{\phi}$, Q232$^{\phi}$ and Q249$^{\phi}$. Its impact lasted up to week 7 (data not shown).

Soccer® impacted as early as week 2 on a couple of varieties like SP80 and Q238$^{\phi}$ (data not shown).

Clincher® impacted quite late (week 4) on the growth of a wide range of varieties like SP80, Q250$^{\phi}$, Q238$^{\phi}$ and Q249$^{\phi}$.

Rattler® also impacted rather late (week 4) on the growth on some varieties like SP80, Q238$^{\phi}$ and Q249$^{\phi}$.

Short varieties seemed particularly impacted by these herbicides. Q242$^{\phi}$ seemed the least susceptible variety to the tested herbicides.

[1] Means followed by the same letter within a column are not significantly different.

Table 49 Mean comparisons of the effect Product x Variety at week 4 (data extract only)[1]

Week 4	Control	Letter group	Clinch	Letter group	Mono	Letter group	Rattl	Letter group	Socc	Letter group
Q208$^{\phi}$	3.1	AB	2.94	ABCDEFGHIJKLMNOPR	2.84	BCDEFGHIJKLMNOPQRST	3.01	ABCDEFGHIJK	2.93	ABCDEFGHIJKLMNOPQRS
Q232$^{\phi}$	2.96	ABCDEFGHIJKLMNO	2.89	ABCDEFGHIJKLMNOPQRS	2.66	RSTU	2.99	ABCDEFGHIJKLM	2.97	ABCDEFGHIJKLMNO
Q238$^{\phi}$	2.82	CDEFGHIJKLMNOPQRST	2.78	GHIJKLMNOPQRST	2.65	ST	2.8	DEFGHIJKLMNOPQRST	2.77	HIJKLMNOPQRST
Q242$^{\phi}$	3.08	ABCD	3.07	ABCDE	2.96	ABCDEFGHIJKLMNO	3.1	ABC	3.05	ABCDEFGH
Q249$^{\phi}$	2.89	ABCDEFGHIJKLMNOPQRS	2.83	BCDEFGHIJKLMNOPQRST	2.66	RSTU	2.78	GHIJKLMNOPQRST	2.91	ABCDEFGHIJKLMNOPQRS
Q250$^{\phi}$	2.93	ABCDEFGHIJKLMNOPQRS	2.72	LMNOPQRST	2.73	KLMNOPQRST	2.9	ABCDEFGHIJKLMNOPQRS	2.84	BCDEFGHIJKLMNOPQRST
Q252$^{\phi}$	3.14	A	2.99	ABCDEFGHIJKLM	2.91	ABCDEFGHIJKLMNOPQRS	3.05	ABCDEFG	2.99	ABCDEFGHIJKLM
Q253$^{\phi}$	3.02	ABCDEFGHIJ	3.02	ABCDEFGHI	2.84	BCDEFGHIJKLMNOPQRST	2.99	ABCDEFGHIJKL	2.86	ABCDEFGHIJKLMNOPQRST
SP80	2.86	BCDEFGHIJKLMNOPQRST	2.74	JKLMNOPRST	2.6	T	2.77	GHIJKLMNOPQRST	2.72	LMNOPQRST

6.2.1.4 Biomass results

The analysis showed a significant difference for the interaction Variety x Product (P 0.018). In the untreated plots, the varieties Q253$^{\phi}$ produced more biomass than SP80 and Q238$^{\phi}$ (data not shown). If SP80 or Q238$^{\phi}$ produced less biomass than Q253$^{\phi}$ after a treatment application, the loss of biomass was not attributed to the variety being more susceptible to the herbicide treatment as there was a confounding varietal factor.

Mean comparisons between Products x Variety are presented in Table 50. Krismat® reduced KQ228$^{\phi}$ biomass more than Clincher®, Amicide®625 or Rattler®. Krismat® reduced Q232$^{\phi}$ biomass more than Actril®DS. Q208$^{\phi}$ was impacted by Clincher®, whereas Clincher® and Rattler® did not impact on KQ228$^{\phi}$ and Q242$^{\phi}$ biomass. Rattler® did not impact on Q252$^{\phi}$, nor Soccer® on Q249$^{\phi}$ and Q250$^{\phi}$.

[1] Means followed by the same letter in the table are not significantly different

Table 50 Mean comparisons of biomass by herbicide in pot trial[1].

Variety	Product	Estimate	Standard Error	Letter Group
KQ228ɸ	Clinch	132.15	8.3657	A
KQ228ɸ	Rattl	122.62	8.3657	A
KQ228ɸ	Amic	121.67	8.3657	A
KQ228ɸ	control	115.1	8.3657	AB
KQ228ɸ	Mono	105.22	8.3657	AB
KQ228ɸ	Actri	101.1	8.3657	AB
KQ228ɸ	Socc	99.95	8.3657	AB
KQ228ɸ	Krism	68.85	8.3657	B

Variety	Product	Estimate	Standard Error	Letter Group
Q232ɸ	Actri	124.17	8.3657	A
Q232ɸ	Amic	117.35	8.3657	AB
Q232ɸ	control	106.58	8.3657	AB
Q232ɸ	Rattl	106.47	8.3657	AB
Q232ɸ	Socc	100.53	8.3657	AB
Q232ɸ	Clinch	96.55	8.3657	AB
Q232ɸ	Mono	87.95	8.3657	AB
Q232ɸ	Krism	69.475	8.3657	B

Variety	Product	Estimate	Standard Error	Letter Group
Q253ɸ	Amic	144.9	8.3657	A
Q242ɸ	Amic	122.37	8.3657	AB
KQ228ɸ	Amic	121.67	8.3657	AB
Q232ɸ	Amic	117.35	8.3657	AB
Q250ɸ	Amic	114.47	8.3657	AB
Q240ɸ	Amic	110.17	8.3657	AB
Q208ɸ	Amic	106.42	8.3657	AB
Q249ɸ	Amic	100	8.3657	AB
Q252ɸ	Amic	95.425	8.3657	AB
SP8018	Amic	88.475	8.3657	B
Q238ɸ	Amic	84	8.3657	B

Variety	Product	Estimate	Standard Error	Letter Group
Q253ɸ	Clinch	147.1	8.3657	A
KQ228ɸ	Clinch	132.15	8.3657	AB
Q242ɸ	Clinch	127.02	8.3657	AB
Q240ɸ	Clinch	125.05	8.3657	ABC
Q249ɸ	Clinch	116	8.3657	ABC
Q252ɸ	Clinch	113.05	8.3657	ABC
Q250ɸ	Clinch	103.27	8.3657	ABC
Q232ɸ	Clinch	96.55	8.3657	ABC
Q208ɸ	Clinch	83.425	8.3657	BC
Q238ɸ	Clinch	81.625	8.3657	BC
SP8018	Clinch	75.85	8.3657	C

Variety	Product	Estimate	Standard Error	Letter Group
Q242ɸ	Rattl	135.32	8.3657	A
Q253ɸ	Rattl	126.75	8.3657	A
Q252ɸ	Rattl	126.12	8.3657	A
KQ228ɸ	Rattl	122.62	8.3657	A
Q208ɸ	Rattl	117.07	8.3657	AB
Q232ɸ	Rattl	106.47	8.3657	AB
Q240ɸ	Rattl	104.65	8.3657	AB
Q250ɸ	Rattl	101.12	8.3657	AB
SP80	Rattl	99.2	8.3657	AB
Q249ɸ	Rattl	93.725	8.3657	AB
Q238ɸ	Rattl	66.5	8.3657	B

Variety	Product	Estimate	Standard Error	Letter Group
Q250ɸ	Socc	118.8	8.3657	A
Q249ɸ	Socc	118.3	8.3657	A
Q253ɸ	Socc	111.5	8.3657	AB
Q242ɸ	Socc	110.72	8.3657	AB
Q240ɸ	Socc	103.62	8.3657	AB
Q232ɸ	Socc	100.53	8.3657	AB
KQ228ɸ	Socc	99.95	8.3657	AB
Q208ɸ	Socc	94.75	8.3657	AB
Q252ɸ	Socc	91.125	8.3657	AB
Q238ɸ	Socc	72.75	8.3657	AB
SP80	Socc	67.075	8.3657	B

[1] The values are estimates of biomass. Only sets with significant differences between treatments are presented. Same letters within a table means no significant difference.

Variety	Product	Estimate	Standard Error	Letter Group
Q253$^{\phi}$	control	146	8.3657	A
Q250$^{\phi}$	control	130.7	8.3657	AB
Q249$^{\phi}$	control	119.93	8.3657	AB
Q240$^{\phi}$	control	116.18	8.3657	AB
KQ228$^{\phi}$	control	115.1	8.3657	AB
Q242$^{\phi}$	control	112.43	8.3657	AB
Q208$^{\phi}$	control	107.23	8.3657	AB
Q232$^{\phi}$	control	106.58	8.3657	AB
Q252$^{\phi}$	control	103.03	8.3657	AB
Q238$^{\phi}$	control	93.325	8.3657	B
SP801816	control	87.6	8.3657	B

6.2.2 Pot trial discussion

We trust the biomass sampling to be the most reliable indicator of the impact of the treatment on yield. Other indicators rarely predicted the biomass results. The HTVD measurement may in a couple of instances have indicated a growth issue that seemed to be later overcome (i.e. Q250$^{\phi}$ with Clincher®, Q232$^{\phi}$ with Monopoly).

Assessing the colour (visually or using machine vision) did not reflect well with final biomass results, except in a couple of instances with Krismat® or Clincher® that both affected the colour and the biomass of some varieties.

Early visual colour rating is still a pertinent indicator for growers if visual damage is to be expected on the cane leaves. Visual damage is to be expected when using product like Clincher®, Krismat® or Monopoly, without a significant difference between varieties.

According to these results we would recommend caution when using Krismat® on Q232$^{\phi}$ and KQ228$^{\phi}$, Clincher® on Q208$^{\phi}$ and Q250$^{\phi}$, and Monopoly on Q232$^{\phi}$.

The variety Q242$^{\phi}$ seemed to particularly tolerate herbicide treatments: Q242$^{\phi}$ HTVD and biomass were not affected by herbicide treatments. The variety Q242$^{\phi}$ could be used as a reference variety as it received minimum impact instead of Q208$^{\phi}$, which has been commonly chosen as reference variety in recent variety trials.

The varieties and herbicides justifying further field trial testing were:

- Four varieties: Q232$^{\phi}$, Q238$^{\phi}$ and Q250$^{\phi}$. Q242$^{\phi}$ used as a reference variety because it received minimum impact in the pot trial.
- Four herbicides: Krismat®, Clincher®, Monopoly and Soccer®

6.2.3 Field trial results

6.2.3.1 Phytotoxicity rating results

The interactions Product x Date, Variety x Date and Variety x Product were significant (P<0.0001, P 0.0021 and P 0.0258 respectively).

Table 51, Table 52 and

Table 53 only display the mean comparisons that presented significant differences. Results showed that:

Q250Φ and Q242Φ displayed more phytotoxicity symptoms than Q232Φ when sprayed with Soccer® (Table 51).

Between 40 and 72 DAT (from 5 Nov until 7 Dec 2015), the variety Q232Φ displayed the least phytotoxicity symptoms (Table 52).

prod	date	Estimate	Std Error	backtr	Letter Group
Daco	10/22/15	0.583	0.051	2.722	A
Clin	10/22/15	0.402	0.051	1.729	AB
Kris	10/22/15	0.363	0.051	1.611	B
Socc	10/22/15	0.293	0.052	1.435	B
cont	10/22/15	0.227	0.052	1.303	B

At 15 DAT (8 Oct 2015), Daconate® displayed stronger symptoms than Krismat®, Soccer® and the control. Clincher® displayed significantly stronger symptoms than the control. At 29 DAT (22 Oct 2015), only Daconate® still displayed stronger symptoms than the control (

Table 53).

Table 51 Mean comparisons of variety by product[1].

var	prod	Estimate	Std Error	backtr	Letter Group
Q250	Socc	0.357	0.052	1.593	A
Q242	Socc	0.290	0.053	1.427	A
Q238	Socc	0.212	0.056	1.277	AB
Q232	Socc	0.0824	0.052	1.091	B

prod	date	Estimate	Std Error	backtr	Letter Group
Daco	10/22/15	0.583	0.051	2.722	A
Clin	10/22/15	0.402	0.051	1.729	AB
Kris	10/22/15	0.363	0.051	1.611	B
Socc	10/22/15	0.293	0.052	1.435	B
cont	10/22/15	0.227	0.052	1.303	B

Table 52 Mean comparisons of variety by date[1]

var	date	Estimate	Std Error	backtr	Letter Group
Q238	11/05/15	0.348	0.049	1.570	A
Q242	11/05/15	0.249	0.049	1.345	A
Q250	11/05/15	0.224	0.048	1.299	AB
Q232	11/05/15	0.055	0.049	1.058	B

var	date	Estimate	Std Error	backtr	Letter Group
Q238	11/19/15	0.325	0.049	1.510	A
Q250	11/19/15	0.277	0.048	1.400	A
Q242	11/19/15	0.213	0.049	1.279	AB
Q232	11/19/15	0.0774	0.049	1.085	B

var	date	Estimate	Std Error	backtr	Letter Group
Q242	12/07/15	0.241	0.050	1.329	A
Q250	12/07/15	0.188	0.048	1.237	AB
Q238	12/07/15	0.180	0.050	1.225	AB
Q232	12/07/15	0.0146	0.049	1.015	B

prod	date	Estimate	Std Error	backtr	Letter Group
Daco	10/22/15	0.583	0.051	2.722	A

[1] Means followed by the same letter within a column within a table are not significantly different.

Table 53 Mean comparisons of product by date[1]

prod	date	Estimate	Std Error	backtr	Letter Group
Daco	10/08/15	0.673	0.051	3.944	A
Clin	10/08/15	0.470	0.051	1.996	AB
Kris	10/08/15	0.445	0.051	1.889	BC
Socc	10/08/15	0.300	0.052	1.450	BC
cont	10/08/15	0.260	0.052	1.366	C
Clin	10/22/15	0.402	0.051	1.729	AB
Kris	10/22/15	0.363	0.051	1.611	B
Socc	10/22/15	0.293	0.052	1.435	B
cont	10/22/15	0.227	0.052	1.303	B

6.2.3.2 HTVD results

The interaction Variety*Product*Date was significant (P<0.0001). The cane stage at spraying (added as a covariate) had a significant impact on the variable HTVD (P 0.0329), which was always suspected as a limitation for field trials. All varieties are planted on the same day in a field trial, however some varieties emerge earlier than others. As a result, different varieties are sprayed at different growth stage, which affects the severity of herbicide symptoms.

Tables 54 only displays the mean comparisons that presented significant differences between products within one variety. Results showed that:

Q242$^{\phi}$

At 29 DAT (22 Oct 2015), Clincher® reduced cane growth. Daconate® reduced cane growth even further.

At 40 DAT (19 Nov 2015), Clincher®, Soccer® and Daconate® reduced cane growth.

At 72 DAT (22 Dec 2015), only Daconate® still reduced cane growth compared to the control and the plots treated with Krismat®.

Q238$^{\phi}$

At 29 DAT (22 Oct 2015), Daconate® reduced cane growth compared to the control and the plots treated with Soccer®.

At 40 DAT (19 Nov 2015), Daconate® reduced cane growth compared to the control and the plots treated with Soccer® or Clincher®.

At 72 DAT (22 Dec 2015), only Daconate® still reduced cane growth compared to the control.

Q250$^{\phi}$

Daconate® reduced cane growth compared to the plots treated with Krismat® only at 29 DAT (22 Oct 2015)

Q232$^{\phi}$

At 40 DAT (19 Nov 2015), Daconate® reduced cane growth compared to the plots treated with Soccer®.

At 72 DAT (22 Dec 2015), Daconate® reduced cane growth compared to the plots treated with Krismat® and Soccer®.

There were also differences in height across varieties throughout the assessment with Q242$^{\phi}$ significantly taller than the other varieties and Q238$^{\phi}$ taller than Q250$^{\phi}$ (data not shown).

[1] Means followed by the same letter within a column within a table are not significantly different.

Tables 54 Mean comparisons of Variety x Product x Date[1].

var	prod	date	Estimate	Std Error	Letter Group
Q242	cont	10/22/15	3.507	0.029	A
Q242	Clin	10/22/15	3.312	0.030	B
Q238	cont	10/22/15	3.112	0.037	C
Q242	Daco	10/22/15	3.065	0.049	CDE
Q238	Socc	10/22/15	3.055	0.041	CD
Q250	Kris	10/22/15	2.832	0.028	EFGH
Q238	Daco	10/22/15	2.824	0.031	FGH
Q250	Daco	10/22/15	2.593	0.034	I

var	prod	date	Estimate	Std Error	Letter Group
Q242	cont	11/19/15	4.100	0.026	A
Q242	Clin	11/19/15	3.907	0.035	BC
Q242	Socc	11/19/15	3.839	0.035	BCD
Q242	Daco	11/19/15	3.736	0.047	CDE
Q238	cont	11/19/15	3.713	0.040	CDE
Q238	Socc	11/19/15	3.664	0.041	DEF
Q232	Socc	11/19/15	3.650	0.026	EF
Q238	Clin	11/19/15	3.630	0.035	EF
Q238	Daco	11/19/15	3.414	0.024	GHI
Q232	Daco	11/19/15	3.358	0.030	HIJ

var	prod	date	Estimate	Std Error	Letter Group
Q242	cont	12/22/15	4.658	0.027	A
Q242	Kris	12/22/15	4.548	0.031	AB
Q232	Socc	12/22/15	4.370	0.023	CD
Q242	Daco	12/22/15	4.315	0.044	CDEF
Q238	cont	12/22/15	4.272	0.035	DEF
Q232	Kris	12/22/15	4.208	0.031	DEFG
Q238	Daco	12/22/15	4.088	0.020	GHJ
Q232	Daco	12/22/15	3.968	0.037	HJ

6.2.3.3 Yield results

As the trial site was known for its yield variation, it was decided to record the yield for every 15 m of unsprayed guard row planted with Q200$^{\Phi}$. Q200$^{\Phi}$ guard rows yield variation is represented in Figure 53. The average plot yields for adjacent guard rows have been used as a covariate for the treated plot.

[1] Means followed by the same letter within a column within a table are not significantly different

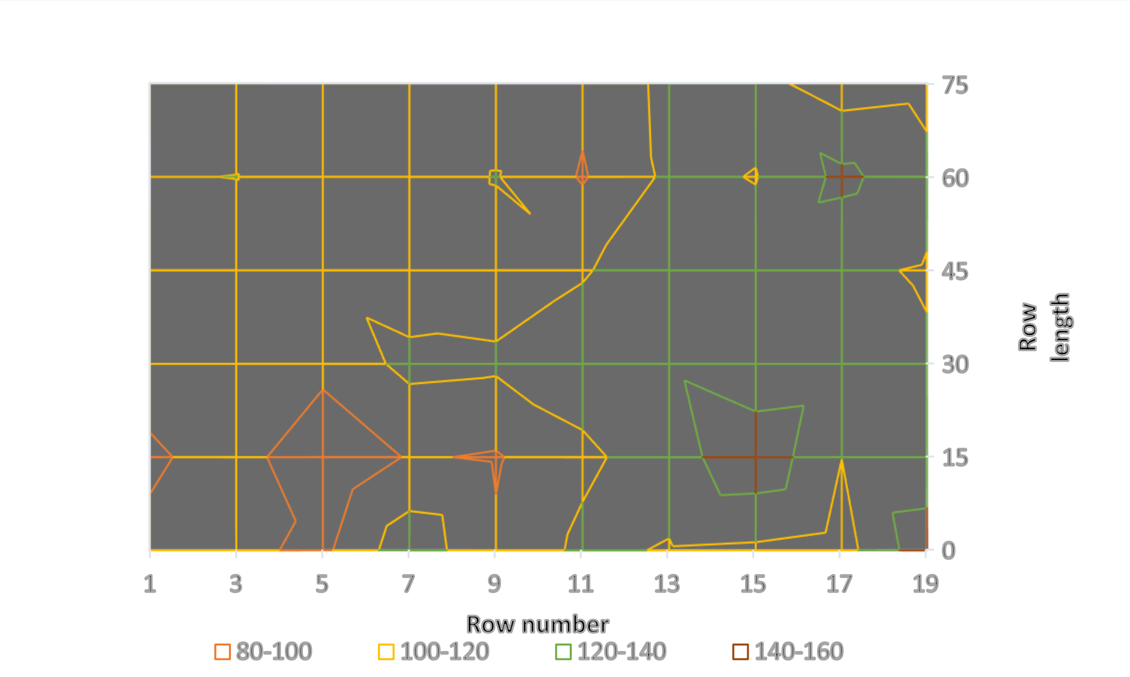


Figure 53 Representation of the yield variation in field trial (in t ha^{-1}) in the untreated guard rows planted with Q200$^{\phi}$

Yield data for each combination of Product x Variety are presented in Figure 54. The results of the statistical analysis only showed significant yield differences between cane varieties in the trial (P 0.0012), Q242$^{\phi}$ yielding more than the other three tested varieties. There were no significant differences for the interaction Product x Variety (P 0.37) and no significant differences between products (P 0.064). Yield data by product are represented in Table 55. Daconate® seemed to impact on yield more than any other products with up to 22% yield reduction in Q238$^{\phi}$ compared to the untreated control.

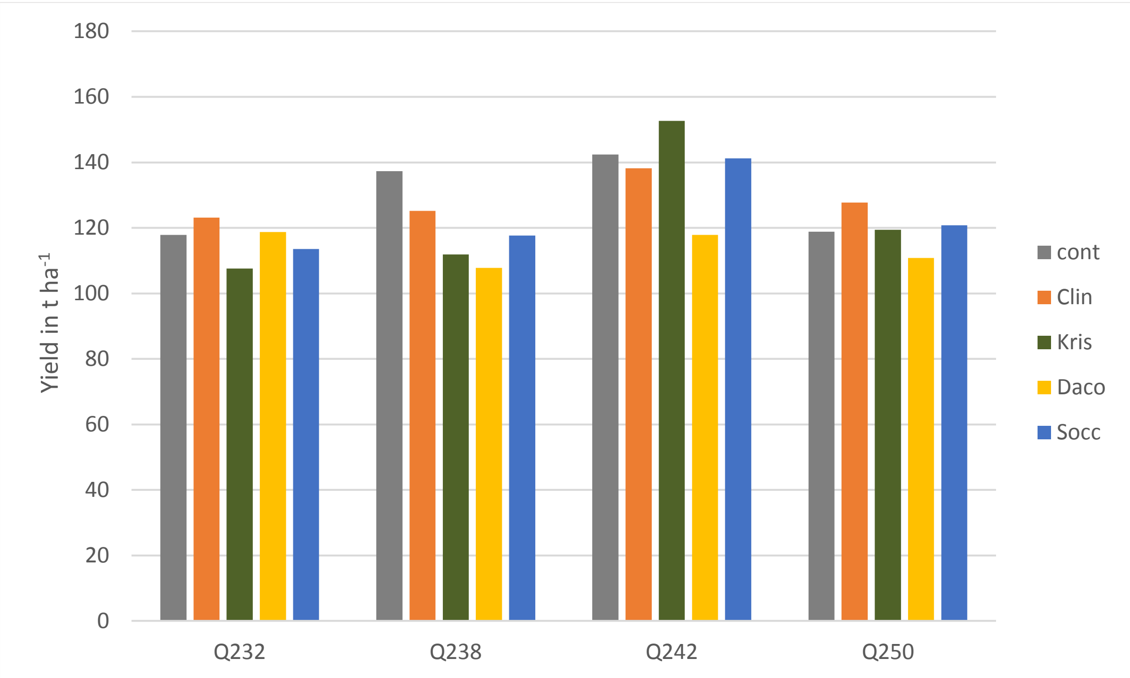


Figure 54 Average of yield obtained in the field trial for each combination of Product x Variety

Table 55 Mean comparisons of the Effect = Variety for yield in the field trial

var	Estimate	Standard Error	Letter Group
Q242	137.86	4.342	A
Q250	119.84	4.297	B
Q238	119.81	4.452	B
Q232	115.93	4.296	B

6.2.4 Field trial discussion

None of the varieties tested had their yield significantly impacted by any herbicide treatment. Daconate® was the treatment that produced the maximum foliar damage and up to 21 % yield reduction in one variety, although the yield difference was not significant (P 0.064).

Soccer® application resulted in foliar symptoms on Q250$^{\phi}$ and Q242$^{\phi}$; Clincher® and Soccer® temporarily reduced the growth of Q242$^{\phi}$; however these reactions did not result in any tangible yield penalty.

6.2.5 Methodology discussion and report to industry

Very similar trends between the biomass in the pot trial and the yield in the field trial were observed for the varieties Q232$^{\phi}$ and Q238$^{\phi}$. For the varieties Q242$^{\phi}$ and Q250$^{\phi}$ trends were different between the pot and the field trial. These two varieties were quite susceptible to some herbicide treatments like Krismat® in the pot trial but not in the field trial. Q242$^{\phi}$ germinated quickly and had a rapid growth, making it more advanced at time of spraying compared to the other varieties and potentially more susceptible to some herbicide treatments (Figure 55). This variation in the growth stage in the field trial creates an artefact in the field trial results, which can explain the differences between field and pot trials.

The pot trial remains a reliable way to screen for variety susceptibility to detect any potential dramatic phytotoxicity for a combination of Variety x Product. Field trials are always expected to give different results due to the growth stage of the variety and the environmental conditions at time of spraying. It is very likely that growers will still observe incidences of phytotoxicity that have not been revealed by pot or field trials because the conditions at spraying were different to the ones in the trials.

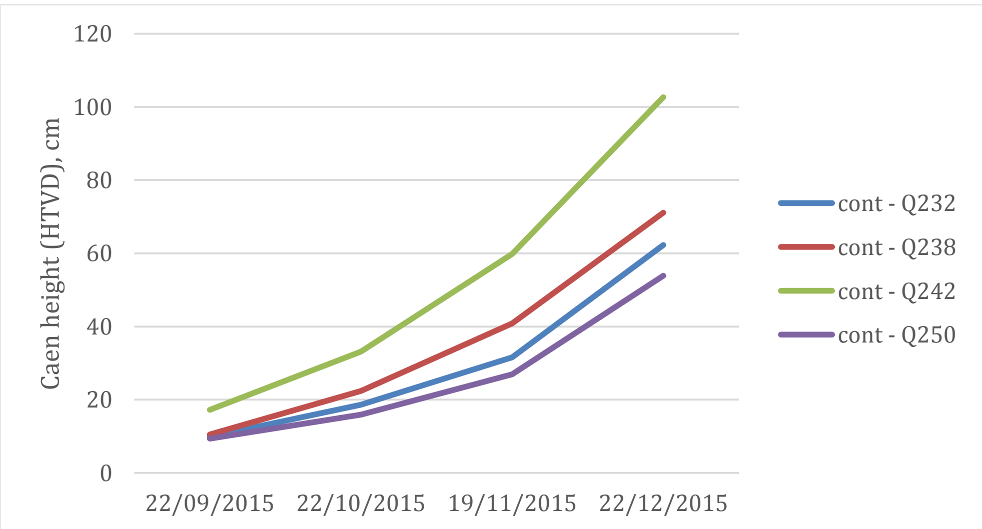


Figure 55 Growth curve of the varieties tested in the field trial (untreated control)

A report to the industry was prepared and submitted to the SRA Board. The report can be found in Appendix 8. This report includes a detailed methodology and costing for a routine herbicide tolerance screening activity.

The board decided that routine herbicide tolerance screening would be funded as part of core plant breeding activities at SRA from 2016. In 2016, a pot trial was established followed by a field trial in 2017. A new pot trial will be established in 2018.

The following media release was emailed to productivity services CEO, managers and boards.

Variety x herbicide phytotoxicity screening – update for future screening

Current SRA weed management research includes the one-off screening of varieties for phytotoxic reactions to herbicides and development of a suitable screening protocol (Project 2014050).

Part of this project is to develop an agreed model with industry to conduct ***ongoin**g* phytotoxicity screening.

SRA is pleased to advise that from 2016 phytotoxicity screening will be carried out by SRA as part of the variety release program.

This screening program will utilise the protocols developed as part of the existing project. Screening of new varieties will be conducted biennially, in a two-step process:

Year 1: Pre-screening

A pot trial will pre-screen new varieties against a range of herbicides. Productivity Service Companies will be asked to nominate herbicides of interest.

There will be a maximum of 50 variety/herbicide combinations, e.g. 5 varieties x 10 herbicides (including 1 control) = 50 treatments. If more than 50 combinations are nominated then Productivity Services' herbicide preferences will be weighted proportionally to their district area, to shortlist the top preferences. This pot trial will be conducted in Mackay, as southern material can be sourced without the need for a quarantine period.

Year 2: Field trial

Combinations of variety x herbicide that show the strongest effects (visual, biomass) will be field tested to determine potential yield reductions.

For practical purposes, the maximum number of varieties x herbicide combinations will be twenty (including controls).

Results will be provided as part of the variety release package.

Timing of results in relation to variety release

Varieties will be screened following release by the VACs. This will make the results of the pre-screening pot trial available either in the year of commercial release or one year after commercial release (as pre-screening will be every second year). This will ensure growers have the results before commercial planting occurs.

Results of the field trials will lag one year behind but will still be available to growers before commercial planting; unless the use of tissue culture for commercial planting occurs.

We would be pleased to discuss any queries you may have:

Emilie Fillols: 0438711613

Andrew Ward: 0401564312

Phil Ross: 0477318897

7 PUBLICATIONS

Fillols E, Staier T (2016) Efficacy of alternative pre-emergent herbicides applied in trash-blanketed ratoons in the Wet Tropics. In Proceedings of the 38th Australian Society of Sugarcane Conference Technology, Mackay, 27-29 April 2016.

Fillols E, Staier T (2016) Use of cover crops as weed management tools in sugarcane fallow. In Proceedings of the 7th International Weed Science Congress, Czech Republic, 19-25 June, 2016.

Fillols E, Staier T (2016) Use of cover crops as weed management tools in sugarcane fallow. In Proceedings of the 20th Australasian Weeds Conference, Perth, 11-15 September 2016.

Ross P, Fillols E, Billing B (2017) The water quality conundrum. In Proceeding of 39th Australian Society of Sugarcane Conference Technology, Cairns, 3-5 May 2017.

Fillols E, Lewis S, Davis A (2018) Efficacy and environmental impact of alternative pre-emergent herbicides to diuron applied on trash blanketed ratoons. In Proceeding of the 40th Australian Society of Sugarcane Conference Technology, Mackay, 18-20 April 2018.

8 REFERENCES

Arévalo RA, Bertoncini EI (2008) Sustainable weed management in *Saccharum* spp. En: Congreso Nacional de la Ciencia de la Maleza-asomecima, 29; Simposium Internacional sobre la Maleza acuática, 5; Simposium internacional sobre resistencia y tolerancia a herbicidas, 1; Simposium Internacional sobre la Enseñanza de la Ciencia de la Maleza, 1.Tapachula, Chiapas. México, Memorias Asomecima. Cd-rom, p. 72-109.

Beltran E, Fenet H, Cooper JF, Coste CM (2003) Fate of isoxaflutole in soil under controlled conditions. J Agric Food Chem, 51: 146-51.

Butler, D. (2009) asreml: asreml() fits the linear mixed model [Computer software manual]. Retrieved from www.vsni.co.uk (R package version 3.0).

Chabalier M, Arhiman E, Marion D (2013) Inter-cropping legume and sugarcane, a way to reduce treatment frequency index? AFPP – 22nd conférence du Columa, 10pp.

Cowie B, Shaw M, Davison L, Tang W, Di Bella L, Benson A, Nash M (2013) Comparing runoff loss of knockdown and residual herbicides in the Herbert catchment. Paddock case study report, Reef Water Quality Protection Plan secretariat, 2pp.

Davis AM, Pradolin J (2016) Precision herbicide application technologies to decrease herbicide losses in furrow irrigation outflows in a north eastern Australian cropping system. Journal of Agriculture and food chemistry, 64, 4021-4028.

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

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

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

Garside AL (2006) Final report - SRDC project YDV002 : Sugar yield decline joint venture : phase 2 (July 1999 - June 2006). Sugar Research Australia Limited. eLibrary, 68pp.

Graymore M, Stagnitti F and Allinson G. (2001) Impacts of atrazine in aquatic ecosystems. Environmental International 26, 483-495.

Kenward, M., & Roger, J. (1997) Small sample inference for fixed effects from restricted maximum likelihood. Biometrics, 53, 983 – 997.

Lewis SE, Silburn DM, Davis A, O'Brien DS, Oliver D, Brodie JE, Shaw M, Andersen JS, Kookana R, Fillols E, Rojas-Ponce S, McHugh A, Baillie C (2013) Pesticides in the sugar industry: an evaluation of improved management practices. Report to the Reef Rescue Water Quality Research & Development Program. Reef and Rainforest Research Centre Limited, Cairns, 34pp.

Loch RJ, Robotham BG, Zeller L, Masterman N, Orange DN, Bridge BJ, Sheridan G, Bourke JJ (2001) A multi-purpose rainfall simulator for field infiltration and erosion studies. Aust. J. Soil Res., 39, 599–610.

Masters B; Rohde K; Gurner N; Reid D (2013) Reducing the risk of herbicide runoff in sugarcane farming through controlled traffic and early-banded application. Agric., Ecosyst. Environ., 180, 29−39.

McMahon G, Lawrence P, and O'Grady T. (2000) Weed control in sugarcane. In: Manual of cane growing. (eds Hogarth DM and Allsopp PG), pp 241-261, BSES Brisbane,Qld.

Melland AR., Silburn DM , McHugh AD., Fillols E, Rojas-Ponce S, Baillie C, Lewis S (2016) Spot spraying reduces herbicide concentrations in runoff. Journal of Agricultural and Food Chemistry, 60 (20). 4009-4020.

Mitra S, Bhowmik PC, Xing BS. (1999) Sorption of isoxaflutole by five different soils varying in physical and chemical properties. Pest Sci, 55: 935–42.

Pallett KE, Cramp SM, Little JP, Veerasekaran P, Crudace AJ, Slater AE. (2001) Isoxaflutole: the background to its discovery and the basis of its herbicidal properties. Pest Management Science, 57: 133–42.

Smith RA, Warne MSJ, Mengersen K, Turner R (2017) An Improved Method for Calculating Toxicity-Based Pollutant Loads: Part 2. Application to Contaminants Discharged to the Great Barrier Reef, Queensland, Australia. Integr Environ Assess Manag 13-4, 754-764.

Soares MBB, Finoto EL, Bolonhezi D, Carrega WC, Anchieta Alves J (2012) Weeds in raw sugarcane renovation area with different systems of management on soil and green manure succession. Revista Agro@mbiente On-line, v. 6, n. 1, p. 25-33.

Tixier C, Bogaerts P, Sancelme M, Bonnemoy F, Twagilimana L, Cuer A, Bohatier J and Veschembre H. (2000) Fungal biodegradation of a phenylurea herbicide, diuron: structure and toxicity of metabolites. Pest Management Science 56, 455-462.

Walton RS, Volker RE, Bristow KL, Smettem KRJ (2000) Experimental examination of solute transport by surface runoff from low-angle slopes. Journal of hydrology 233, 19-36.

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10 APPENDICES

Appendix 1 **METADATA DISCLOSURE**

Table 56 Metadata Disclosure 1

Data	All
Stored Location	SRA Meringa server
Access	On request
Contact	Emilie Fillols

Appendix 2 **MONKEY SURVEY RESULTS**

Appendix 2 - Survey results

Appendix 3 **RAINFALL DATA**

Appendix 3 - Rainfall data.pdf

Appendix 4 **SOIL ANALYSIS DATA**

Appendix 4 - Soil analysis data.pdf

Appendix 5 **MULGRAVE PROJECT REPORT UPDATE 2015**

Appendix 5 - Mulgrave project re|

Appendix 6 **MOSSMAN PROJECT REPORT UPDATE 2015**

Appendix 6 - Mossman project re|

Appendix 7 **TULLY PROJECT REPORT UPDATE 2015**

Appendix 7 - Tully project upda

Appendix 8 **HERBICIDE TOLERANCE INDUSTRY REPORT**

Appendix 8 - Herbicide tolerance