Department of Natural Resources and Mines

Paddock to Sub-catchment Scale Water Quality Monitoring of Sugarcane Management Practices

Interim Report
2012/13 Season

Mackay Whitsunday Region

Queensland Government

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List of Acronyms

ACS	Analytical Consulting Services Laboratories (Australia)
APHA	American Public Health Association
BSES	Bureau of Sugar Experiment Stations (now Sugar Research Australia)
DIN	Dissolved inorganic nitrogen
EC	Electrical conductivity
FRP	Filterable reactive phosphorus
GBR	Great Barrier Reef
KCl	Potassium chloride
LCMS	Liquid chromatography mass spectrometry
N	Nitrogen
NO_x-N	Oxidised nitrogen, mainly nitrate
NTU	Nephelometric Turbidity Units
P2R	Paddock to Reef Integrated, Monitoring, Modelling and Reporting Program
P	Phosphorus
PRS	Percent recoverable sugar
QHFSS	Queensland Health Forensic and Scientific Services laboratory
R&D	Research and development
TFN	Total filterable nitrogen
TKN	Total Kjeldahl nitrogen
TFP	Total filterable phosphorus
TKP	Total Kjeldahl phosphorus
TN	Total nitrogen
TP	Total phosphorus
TropWATER	Centre for Tropical Water and Aquatic Ecosystem Research
TSS	Total suspended solids

List of Units

cm	centimetres
cumecs	cubic metres per second
g	grams
g/ha	grams per hectare
ha	hectares
kg/ha	kilograms per hectare
kg N/ha	kilograms of nitrogen per hectare
kg P/ha	kilograms of phosphorus per hectare
kg/km^2	kilograms per square kilometre
L	litres
L/ha	litres per hectare
L/s	litres per second
m	metres
mg	milligrams
mg/kg	milligrams per kilogram
mg/L	milligrams per litre
mL	milliltres
mm	millimetres
mm/hr	millimetres per hour
t/ha	tonnes per hectare
µg/kg	micrograms per kilogram
µg/L	micrograms per litres
µg N/L	micrograms of nitrogen per litre
µg P/L	micrograms of phosphorus per litre
µm	micrometre

EXECUTIVE SUMMARY

The *Reef Protection Research and Development (R&D) Program* aims to support sugarcane growers to improve the quality of water leaving their farms, and ensure advice given to land managers is based on sound, well-reviewed science. In 2011, the Queensland Government funded an extensive portfolio of research and development projects totaling $7.6 million to identify sources of reef pollutants and the best ways to manage them. Of the funds, more than $300,000 was allocated to extend existing efforts by growers and support organisations in the Wet Tropics, Burdekin Dry Tropics and Mackay Whitsunday regions (http://www.reefwisefarming.qld.gov.au/information/science.html; July 2013). One project was funded in the Mackay Whitsunday region – *Validation and extension of the water quality, productivity and economic benefits of adopting improved nutrient and chemical management in sugarcane in the Central region.* This funding builds on three years of funding as part of the *Paddock to Reef Integrated, Monitoring, Modelling and Reporting (P2R) Program*.

Two sugarcane farms in the Mackay Whitsunday region were selected for paddock scale monitoring. Different sugarcane management strategies were investigated, with the emphasis on improving water quality with improved management practices. The Victoria Plains site (cracking clay) was divided into four treatments with differing soil, nutrient and herbicide management practices. The Marian site (duplex soil) was divided into five treatments of differing soil, nutrient and herbicide management practices (only yield reported for this site). The table below provides an overview of the treatments implemented. Sampling for sediment, nutrient and herbicide concentrations in runoff were undertaken at the Victoria Plains site.

Summary of the treatments applied at the Victoria Plains and Marian sites

	ABCD Classification	Soil Management	Nutrient Management	Herbicide Management
Victoria Plains site – uniform cracking clay				
Treatment 1	CCC[1]	1.5 m current practice	Generalised recommendation	Regulated[3]
Treatment 2	BBB	1.8 m controlled traffic	Six Easy Steps[2]	Non-regulated[4]
Treatment 3	BCC	1.8 m controlled traffic	Generalised recommendation	Regulated
Treatment 4	BBB	1.8 m controlled traffic	Six Easy Steps	Regulated (banded)
Marian site - duplex soil				
Treatment 1	CCC	1.5 m current practice	Generalised recommendation	Non-regulated
Treatment 2	BCC	1.8 m controlled traffic	Generalised recommendation	Non-regulated
Treatment 3	BBB	1.8 m controlled traffic	Six Easy Steps	Non-regulated
Treatment 4	BAB	1.8 m controlled traffic	Nitrogen replacement	Non-regulated
Treatment 5	ABB	1.8 m controlled traffic, skip row	Six Easy Steps	Non-regulated

[1] – ABCD classifications for soil/sediment, nutrients and herbicides, respectively
[2] – Farm-specific nutrient management plan designed by BSES
[3] – Herbicides identified in the Chemical Usage (Agricultural and Veterinary) Control Regulation 1999
[4] – Herbicides not identified in the Chemical Usage (Agricultural and Veterinary) Control Regulation 1999

An additional site (Multi-farm scale) was used to measure the effects of changes in management strategies at larger scales (~3000 ha). The Victoria Plains and Multi-farm sites were instrumented to measure runoff and collect samples for water quality analyses (total suspended solids, total and filtered nutrients, and total (unfiltered) herbicides).

Results from the 2012/13 wet season are reported.

Controlled traffic (matching machinery wheel spacing to crop row width) reduced runoff by 20% when compared to mis-matched spacings. Due to the high ground cover provided by the green cane trash blanket, soil erosion rates were low and consistent between treatments (~0.2 t/ha). These findings are consistent with previous seasons.

Nitrogen concentrations in runoff were driven by the application rate of fertiliser, and the period between application and first runoff. Dissolved concentrations in the initial runoff events were the highest of the season, and then declined through the season as the nutrient supply was exhausted. Runoff losses this season (NO_x-N and urea-N; mainly sourced from applied fertiliser) were relatively consistent between treatments and represented 0.7-1.0% of the applied nitrogen to each treatment. This is similar to the previous season when runoff first occurred 75 days after application (39 days this season), but is approximately one-tenth of that measured in the 2010/11 season when runoff occurred with 10 days of application.

Similar to nutrients, the loss of herbicides in runoff was also driven by the timing of rainfall after herbicide application and the amount of product applied. Where herbicides (diuron) were applied as a blanket application, losses were 0.7% of the applied product (first runoff 63 days after application). These losses are higher than the previous season (<0.2%) when runoff first occurred 128 days after application. Imazapic (applied at a much lower application rate than diuron) was generally not detected in runoff. Where herbicides were banded (approximately 33% band on the cane stool), runoff losses of diuron were half those of the blanket applied treatments (this season only). These results show that the most effective practice to reduce herbicide losses will be to allow time for the herbicides to dissipate before runoff occurs (through time or infiltrating rainfall) and applying less product (by banding or product selection).

At both sites, row spacing had little impact on cane yield, and applying higher rates of nitrogen (above Six Easy Steps) had no impact on cane yield. At the Marian site, the lower rate of nitrogen applied to the N replacement treatment (56% less than Six Easy Steps) reduced cane yield by 30%, and the skip row treatment yielded 73% of the solid plant, despite only 56% of the area planted to cane.

In summary, results from the 2012/13 season showed similar trends between treatments as those observed in previous seasons: controlled traffic reduced runoff, higher rates of nitrogen application lead to higher losses of nitrogen in runoff, banded spraying reduced herbicide losses in runoff (this season only), and maximising the time between the application of nutrients and herbicides and first runoff will reduce losses in runoff. All of these practices which result in improved water quality of runoff had little/no impact on crop productivity.

1 INTRODUCTION

Several water quality monitoring and modelling studies in the past decade have shown that regions with sugarcane as a major land use export high concentrations (compared to pre-European or "natural" state) of dissolved inorganic nitrogen (DIN or NO_x-N, consisting primarily of nitrate). In a modelling study, estimates show that DIN exports from the Mackay Whitsunday region has increased 4.6 times since pre-European condition, and the Wet Tropics increased 6.4 times, with increases in other regions of 1.8-2.2 times (Kroon *et al.* 2012). Catchment scale monitoring during the 2009/10 wet season showed the load of DIN in the high rainfall coastal catchments (Pioneer, Plane, North Johnstone, South Johnstone and Tully catchments) ranged from 245-321 kg/km^2 (Turner *et al.* 2012). These catchments also contain a high proportion of irrigated cropping (mainly sugarcane). The load from all other catchments was considerably lower (<1-130 kg/km^2). The herbicides most commonly found in surface waters in the Great Barrier Reef (GBR) region where sugarcane is grown (ametryn, atrazine, diuron and hexazinone) are largely derived from sugarcane farming land-use (Bainbridge *et al.* 2009, Rohde *et al.* 2008, Lewis *et al.* 2009). Sediment fluxes from sugarcane farming land-use has been shown to be relatively low (Prove *et al.* 1995), which is a result of the industry adopting improved management practices (e.g. green cane trash blanketing) over the past twenty years.

To address the issue of declining water quality entering the GBR lagoon, the Reef Water Quality Protection Plan (Reef Plan) was first endorsed by the Prime Minister and Premier in 2003. It was updated in 2009 to provide clear and measurable targets, improved accountability and more comprehensive and coordinated monitoring and evaluation. A key action and outcome of the Reef Plan 2009 was the development and implementation of the *Paddock to Reef Integrated, Monitoring, Modelling and Reporting (P2R) Program*. The P2R program used multiple lines of evidence to report on the effectiveness of investments and whether targets were being met (Carroll *et al.* 2012). Results from the paddock monitoring component of the P2R Program in the Mackay Whitsunday region have been reported previously (Rohde *et al.* 2013), with further funding for the 2012/13 wet season provided as part of the *Reef Protection Research and Development (R&D) Program*.

The Reef Protection R&D program aims to support sugarcane growers to improve the quality of water leaving their farms, and ensure advice given to land managers is based on good, well-reviewed science. In 2011, the Queensland Government funded an extensive portfolio of research and development projects totaling $7.6 million to identify sources of reef pollutants and the best ways to manage them. Of the funds, more than $300,000 was allocated to extend existing efforts by growers and support organisations in the Wet Tropics, Burdekin Dry Tropics and Mackay Whitsunday regions (http://www.reefwisefarming.qld.gov.au/information/science.html; July 2013). One project was funded in the Mackay Whitsunday region – *Validation and extension of the water quality, productivity and economic benefits of adopting improved nutrient and chemical management in sugarcane in the Central region.* This project report summarises the findings of the water quality component of this project.

The key objectives of the project for the 2012/13 season were to:

- Assess the runoff, water quality, productivity and economic impacts of differing soil, nutrient and herbicide management practices in sugarcane (Victoria Plains site)
- Assess the productivity and economic impacts of differing soil, nutrient and herbicide management practices in sugarcane (Marian site)

- Assess the water quality at a small catchment scale dominated by sugarcane production (Multi-farm site)

2 METHODOLOGY

2.1 Paddock-scale

2.1.1 Victoria Plains site

The selected block (Farm 3434A, Block 14-1; Figure 1) is located near Mount Vince, west of Mackay (21° 11' 3"S 148° 58' 7"E). The block drains to the south and has a slope of 1.0-1.1% on the eastern side (Treatments 1-3) and decreases to 0.9% on the western side (Treatment 4). The site has previously been mapped (1:100,000) on the change between a Victoria Plains ("Vc") and Wollingford ("Wo") soil (Holz and Shields 1984). A Victoria Plains soil is a uniform clay derived from quaternary alluvium, and a Wollingford soil is a soil of uplands derived from acid to volcanic rocks on 2-8% slopes.

Uniform clay soils of the alluvial plains comprise 16% of the sugarcane growing area in the Mackay district, with Victoria Plains soils occupying 7% of the growing area. Soils of uplands derived from acid to intermediate volcanics on 2-8% slopes comprise a further 7%, with Wollingford soils occupying 3% of the growing area (Holz and Shields 1985).

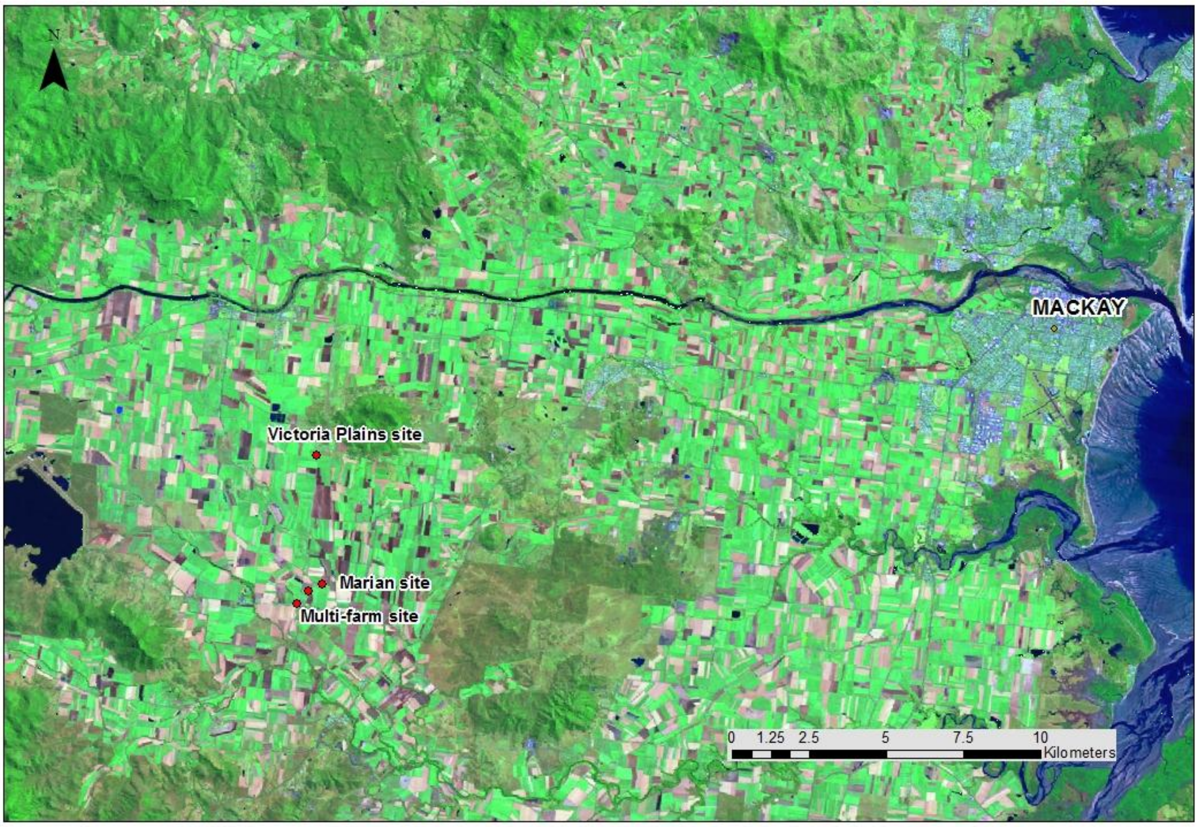

Figure 1 Locality map of monitoring sites

The soil across the monitoring site can be generally described as a deep (>1.6 m) black to dark grey self-mulching medium clay. Details of soil properties can be found in the 2009/10 report (Rohde and Bush 2011). Prior to planting this trial in August 2009 (when row spacing treatments were established), soybeans were grown and sprayed out using glyphosate. Trash from the previous cane crop was not burnt and was worked into the soil. The block was initially divided into two treatments each 45 m wide (30 x 1.5 m rows, 25 x 1.8 m rows), with an additional two treatments each 18 m wide (10 x 1.8 m rows) included after the 2012 harvest (Figure 2; Table 1). Row length across the entire block ranged from approximately 225-300 m.

Figure 2 Treatment layout of the Victoria Plains site

Table 1 Summary of treatments applied at the Victoria Plains site

	ABCD Classification	Soil Management	Nutrient Management	Herbicide Management
Treatment 1	CCC[1]	1.5 m current practice	Generalised recommendation	Regulated[3]
Treatment 2	BBB	1.8 m controlled traffic	Six Easy Steps[2]	Non-regulated[4]
Treatment 3	BCC	1.8 m controlled traffic	Generalised recommendation	Regulated
Treatment 4	BBB	1.8 m controlled traffic	Six Easy Steps	Regulated (banded)

[1] – ABCD classifications for soil/sediment, nutrients and herbicides, respectively
[2] – Farm-specific nutrient management plan designed by BSES
[3] – Herbicides identified in the Chemical Usage (Agricultural and Veterinary) Control Regulation 1999
[4] – Herbicides not identified in the Chemical Usage (Agricultural and Veterinary) Control Regulation 1999

2.1.1.1 Management practices

All treatments were harvested on 17th October 2012 (second ratoon). The cane was harvested green, the trash blanket was left on the soil surface and no cultivation was undertaken. Herbicide treatments were applied on 22nd October 2012 as a boom spray to the entire area of Treatments 1-3, and as a ~33% band to the cane stool (top of mound) of Treatment 4 (Table 2). Nutrient treatments were applied on 15th November 2012 as a liquid mix to the cane stool using a contractor tractor and boom (Table 3).

The site was flood irrigated over a period of three days from 26th to 28th November 2012, in sets of approximately 20 rows. Estimated depths of irrigation applied to each treatment varied due to the different wetting patterns; 80 mm for Treatment 1, 70 mm for Treatment 2 and 60 mm for Treatments 3 and 4. The source water was sampled and sent to the various laboratories for analysis.

Table 2 Application of herbicide treatments to the Victoria Plains site

Treatment	Date	Product (rate applied)	Active ingredients (rate applied)
1	22nd October 2012	Bobcat (3.8 kg/ha)	diuron (1778 g a.i./ha) hexazinone (502 g a.i./ha)
2	22nd October 2012	Flame (0.4 L/ha)	imazapic (96 g a.i./ha)
3	22nd October 2012	Bobcat (3.8 kg/ha)	diuron (1778 g a.i./ha) hexazinone (502 g a.i./ha)
4	22nd October 2012	Bobcat (3.8 kg/ha) on 33% band	diuron (593 g a.i./ha) hexazinone (167 g a.i./ha)

Table 3 Application of nutrient treatments to the Victoria Plains site

Treatment	Product	Nutrient analysis (%)				Nutrient applied (kg/ha)			
	(rate applied)	N	P	K	S	N	P	K	S
1	MKY200P (3800 kg/ha)	5.19	0.66	2.62	0.86	197	25	97	33
2	PMR2 (3700 kg/ha)	3.66	0.68	2.69	0.82	135	25	100	30
3	MKY200P (3800 kg/ha)	5.19	0.66	2.62	0.86	197	25	97	33
4	PMR2 (3700 kg/ha)	3.66	0.68	2.69	0.82	135	25	100	30

(Note – Products applied are from the Sucrogen AgServices BioDunder™ Liquid Fertiliser range of products)

The third ratoon cane crop was harvested on 14th October 2013. The cane was harvested green, the trash was left on the soil surface and no cultivation was undertaken.

2.1.2 Marian site

The selected block (Farm 3120, Block 2-2; Figure 1) is located near North Eton, SW of Mackay (21° 13' 37"S 148° 58' 17"E). Slope is 0.4%, draining to the north. The soil is a duplex derived from quaternary alluvium and has been previously mapped as mapping unit "Ma1" (Marian, yellow B horizon variant) (Holz and Shields 1984), which is a Brown Chromosol (Great Soil Group) (Isbell 1996).

Duplex soils (of the alluvial plains) comprise 28% of the sugarcane growing area in the Mackay district, with Marian soils (Ma and Ma1) occupying 6% (Holz and Shields 1985).

The soil across the monitoring site can be generally described as a 0.3 m deep, very dark brown (sometimes greyish) to black sandy or silty clay loam A horizon; there is a sharp change to a dark to yellowish or black medium clay B horizon with a generally strong prismatic structure. The surface of the soil is hard setting, imperfectly drained and slowly permeable. Details of soil properties can be found in the 2009/10 report (Rohde and Bush 2011).

Prior to cane being planted in August 2009 (when row spacing treatments were established), this block was in its final ratoon from a previous cane rotation which was subsequently ploughed out and replanted, with no fallow. Trash from the previous cane crop was burnt before replanting for ease of cultivation. This is not typical of current cane practice in the Mackay region with most growers choosing to fallow between crop cycles; however suitable sites and co-operators for this level of study were limited. The block was divided into five treatments (Figure 3; Table 4) of 18 rows each with an approximate row length of 260 m.

Figure 3 Treatment layout of the Marian site

Table 4 Summary of treatments applied at the Marian site

	ABCD Classification	Soil Management	Nutrient Management	Herbicide Management
Treatment 1	CCC[1]	1.5 m current practice	Generalised recommendation	Non-regulated[3]
Treatment 2	BCC	1.8 m controlled traffic	Generalised recommendation	Non-regulated
Treatment 3	BBB	1.8 m controlled traffic	Six Easy Steps[2]	Non-regulated
Treatment 4	BAB	1.8 m controlled traffic	Nitrogen replacement	Non-regulated
Treatment 5	ABB	1.8 m controlled traffic, skip row	Six Easy Steps	Non-regulated

[1] – ABCD classifications for soil/sediment, nutrients and herbicides, respectively
[2] – Farm-specific nutrient management plan designed by BSES
[3] – Herbicides not identified in the Chemical Usage (Agricultural and Veterinary) Control Regulation 1999

2.1.2.1 Management practices

All treatments were machine harvested on 18th September 2012 (second ratoon). The cane was harvested green, the trash blanket left on the soil surface and no cultivation was undertaken. Nutrient treatments were applied to Treatments 1-4 on 1st October 2012 as a liquid mix to the cane stool using a contractor tractor and boom (Table 5). Nutrients were applied to Treatment 5 on 22nd October 2012 as a stool-split granular mix (Table 5).

The same herbicide applications were applied to all treatments. Flame was applied as a broadcast blanket application (0.3 L/ha; active ingredient 72 g/ha imazapic) immediately after harvest. In mid-December, Amicide 625 (1 L/ha; active ingredient 625 g/ha 2,4-D amicide) was applied using a high clearance tractor. The site was irrigated a number of times (records not kept) during the season using a low pressure centre pivot irrigator.

The third ratoon cane crop was harvested on 7th October 2013. The cane was harvested green, the trash was left on the soil surface and no cultivation was undertaken.

Table 5 Application of nutrient treatments to the Marian site

Treatment	Product (rate applied)	Nutrient analysis (%) N	P	K	S	Nutrient applied (kg/ha) N	P	K	S
1	LOS+P (4200 kg/ha)	4.7	0.48	2.66	0.73	197	20	112	31
2	LOS+P (4200 kg/ha)	4.7	0.48	2.66	0.73	197	20	112	31
3	MKY170 (4200 kg/ha)	3.78	0	2.74	0.41	159	0	115	17
4	MKY80 (3900 kg/ha)	1.81	0	2.84	0.34	70	0	110	13
5	160S (650 kg/ha)	25.5	2.4	15.5	2.8	165	15	100	18

(Note – Products applied to Treatments 1-4 are from the Sucrogen AgServices BioDunder™ Liquid Fertiliser range of products)

2.1.3 Soil and cane trash sampling

2.1.3.1 Soil nutrients

Soil profile samples were collected to 1.5 m depth from four locations (row and interspace, top and bottom of paddock) post-harvest (second ratoon) in each treatment. Samples were collected from the Marian site on 19th September 2012 and from the Victoria Plains site (Treatments 1 and 2 only) on 17th October 2012. Depth increments for all samplings were at 0.1 m depth intervals to 0.3 m, and then 0.3 m intervals to 1.5 m.

Samples were chilled to 4ºC and sent to the laboratory for prompt analysis of mineral nitrogen (ammonium-N and nitrate-N) and phosphorus in the field wet samples. The results were adjusted to air dry values, with analytical methods described elsewhere (Rayment and Lyons 2011).

2.1.3.2 Soil and cane trash herbicides

Samples of soil (0-2.5 cm) and cane trash were collected on six occasions 3-147 days after herbicide application. Three cane trash samples (using 8x12 cm quadrats) were taken from beside the cane stool, and three from the interspace (bottom of furrow). The six samples were bulked, and placed into alfoil lined bags. Samples were immediately stored on ice, and then refrigerated before being transported to the laboratory on ice.

The soil samples were collected from immediately below where the cane trash samples were taken, using a 10 cm diameter bulk density ring. The samples were mixed and bulked to produce one composite sample for each treatment. The bulk sample was then sub-sampled into 500 mL solvent rinsed glass jars with teflon lined lids. As with the cane trash samples, soil samples were immediately placed on ice and then refrigerated before being transported to the laboratory overnight on ice.

2.1.3.3 Soil moisture

Continuous soil moisture monitoring was undertaken directly below the cane stool within the two original treatments (Treatments 1 and 2). Moisture content was recorded at one hourly intervals (using EnviroSCAN systems) and logged using the CR800 data loggers. Six sensors were used in each treatment, distributed at 20 cm intervals to 1 m, with the final sensor at 1.5 m.

EnviroSCAN sensors consist of two brass rings (50.5 mm diameter and 25 mm high) mounted on a plastic body and separated by a 12 mm plastic ring. The sensors are designed to operate inside a PVC access tube. The frequency of oscillation depends on the permittivity of the media surrounding the tube. Sensitivity studies show that 90% of the sensor's response is obtained from a zone that stretches from about 3 cm above and below the centre of the plastic ring to about 3 cm in a radial direction, starting from the access tube (Kelleners *et al.* 2004).

2.1.4 Rainfall, runoff and water quality

Sampling at each treatment monitoring site was controlled using a Campbell Scientific CR800 data logger housed in a weatherproof container. The logger was programmed to read all sensors every 60 seconds. When runoff water began to flow through the San Dimas flumes (see following), the station commenced the pre-programmed sampling routine.

Rainfall was measured at each site using a Hydrological Services TB4 tipping bucket rain gauge, with 0.2 mm bucket. Bucket tips were recorded by the data logger allowing for measurements of rainfall volume and intensity. A volumetric rain gauge (250 mm) was also installed at each site as a backup, but these overtopped periodically.

San Dimas flumes (300 mm; Figure 4) were used to measure the runoff discharge from each treatment. The galvanised steel flumes were manufactured to standard specifications as outlined by Walkowiak (2006). The flumes were installed approximately five metres beyond the end of the sugarcane rows (outside of the actual cropped area), and rubber belting was used as bunding to collect runoff from four furrows and direct the runoff water into the flume for discharge measurement and sample collection. The standard discharge calibration equation (Walkowiak 2006) for converting water depth into discharge is:

$$Q\ (L/s) = 0.110925 \times \text{depth (mm)}^{1.285788}$$

Water depth was measured using a Campbell Scientific CS450 stainless steel SDI-12 pressure transducer, installed in a stilling well at the side of the San Dimas flume, with a connection to the main chamber. The pressure transducer has an accuracy of approximately 0.1% at full scale. Standard equations programmed into the logger automatically converted pressure into water height.

Event integrated water samples were collected using an ISCO Avalanche refrigerated auto-sampler containing four 1.8 L glass bottles. The refrigeration system was activated after collection of the first sample. The sampler was triggered by the CR800 logger. Using the flume discharge equation above, the logger was programmed to take a sub-sample (~160 mL) every 3 mm of runoff, filling each bottle consecutively and allowing for 120 mm of runoff to be sampled. The integrated "bulked" samples were sub-sampled and analysed for total suspended solids (TSS; Section 2.4.2.1), nutrients (total and filtered; Section 2.4.2.3), and herbicides (Section 2.4.2.4) where possible (depending on volume collected). Following smaller rainfall events with limited volume of sample collected, priority was given to analysis in the order of nutrients, herbicides and then TSS.

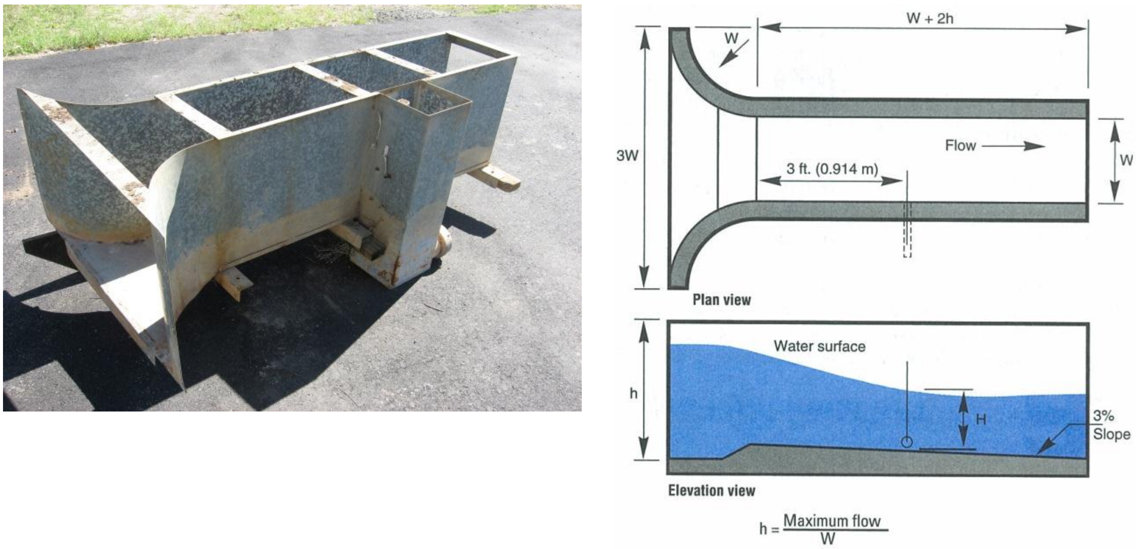

Figure 4 A 300 mm San Dimas flume (left) and critical design dimensions (right)

A radio telemetry network was established between the treatments to enable remote communications through one "base station" (Treatment 2). A Next G modem was installed to enable communication and download/upload of information from offsite.

Separate power supply systems were installed for the data logger and instrumentation, and for the auto-sampler. The logger power and charging system consists of an 18 A/hr deep cycle battery, a 10 W solar panel with a power regulator, while the auto-sampler power system is four 100 A/hr sealed, deep cycle batteries, a 40 W solar panel and a power regulator.

2.1.5 Agronomic sampling

Pre-harvest sampling of the Victoria Plains site (only) was undertaken on 9th September 2013. A 5 m row of standing cane (top and bottom of treatment) was hand cut and separated into leaf and stalk. Whole stalks were weighed and then processed through a garden mulcher in the paddock. Sub-samples were taken and fresh weights recorded. All samples were dried at 60^{o}C for 14 days, and dry weights recorded. Samples were then sent to Sugar Research Australia for nutrient analysis of the dry matter. Only nitrogen results are reported.

Cane was mechanically harvested at the Marian site on 7th October 2013 and at the Victoria Plains site on 14th October 2013. All bin numbers were recorded and treatments remained in separate rakes (group of bins) to allow for yield and percent recoverable sugar (PRS) measurements to be calculated for each treatment during cane processing.

2.2 Multi-farm scale

At the Multi-farm scale (21^{o} 13' 49"S 148^{o} 57' 45"E; Figure 1), runoff was measured within a natural drain (catchment area approximately 2965 ha) using a 1 in 20 flat vee crest weir, with depth of flow again being recorded by a pressure transducer at one minute intervals.

The standard discharge calibration equations (Cooney *et al.* 1992) for converting water depth into discharge are shown in Table 6.

As with the paddock sites, rainfall (amount and intensity) was measured using a Hydrological Services TB4 tipping bucket rain gauge. A Campbell Scientific CR800 data logger collected outputs from sensors and triggered the ISCO Avalanche refrigerated auto-sampler (with a four

1.8 L glass bottle configuration). While submerged, an Analite NEP9510 turbidity probe continuously measured turbidity (data not reported), and water depth was measured via a Campbell Scientific CS450 SDI-12 pressure transducer to calculate flow.

Table 6 Discharge equations used at the Multi-farm site

Water Depth (m)	Discharge equation	Notes
0 – 0.250 m	Q (cumecs) = 1.557 x 20 x depth$^{2.5}$	Within vee
0.251 – 0.500 m	Q (cumecs) = 1.557 x 20 x [depth$^{2.5}$ – (depth – 0.250)$^{2.5}$]	Within wing walls
0.501 – 2.000 m	Q (cumecs) = (1.3085 x depth^{2}) + (5.726 x depth) + 1.3114	Within drain

Using the weir discharge equation above, the logger was programmed to sub-sample (~160 mL) every 3 mm of runoff allowing for a total of 120 mm of runoff to be sampled. The bulked sample was sub-sampled and analysed for nutrients (total and filtered), herbicides and sediments (Section 2.4.2). In addition to the rainfall runoff events, two grab samples were collected from two separate minor irrigation runoff events on 18th and 21st December 2012.

At the time of reporting, details of specific management practices undertaken within the Multi-farm catchment during 2012/13 were not known.

2.3 Water quality load calculations

To estimate the total water quality loads for the wet season, constituent concentrations were required for every runoff event. This was not possible due to occasional equipment failure, insufficient sample volume or samplers being turned off during extreme weather events. Therefore, water quality concentrations need to be estimated for those events that were not sampled.

2.3.1 Victoria Plains

Regression curves were fitted to known concentrations (TSS, nutrients and herbicides) with time after application of nutrients or herbicides, or in the case of TSS, maximum rainfall intensity (Table 7) to estimate concentrations in non-sampled runoff events. Various outliers (high values for unknown reasons) were excluded from these regressions, but are noted on the regressions plots shown in Section 7.1. Event water quality loads were calculated by multiplying the total event discharge by the concentration. At the Victoria Plains site, only 40-50% of the seasonal flow was sampled for TSS and 55-65% for nutrients and herbicides. As a result of the low proportion of runoff sampled, **there is low confidence in the estimated concentrations and subsequent water quality loads.**

2.3.2 Multi-farm site

For the Multi-farm site, the first and last rainfall runoff events were not sampled. Combined, these runoff events only represent 0.2% of the seasonal flow. As a result, concentrations for the first event were set to be the same as the second event (~5% of the seasonal flow). Concentrations of the last event were estimated to be the same as the last sampled event (~15% of the seasonal flow).

Table 7 Regression equations used to estimate missing water quality concentrations in runoff, Victoria Plains site

Parameter	Treatment 1	Treatment 2	Treatment 3	Treatment 4
TSS (mg/L)	y=0.0507x+20.882 (R^2=0.06)	y=0.3037x-13.423 (R^2=0.59)	y=0.3439x-5.7953 (R^2=0.62)	y=0.0537x+25.943 (R^2=0.62)
TKN (µg N/L)	$y=3184.1e^{-0.008x}$ (R^2=0.11)	$y=1020.5e^{-0.002x}$ (R^2=0.11)	$y=1362.1e^{-0.006x}$ (R^2=0.59)	$y=2195.1e^{-0.008x}$ (R^2=0.49)
NO_x-N (µg N/L)	$y=18370e^{-0.061x}$ (R^2=0.94)	$y=6351.6e^{-0.045x}$ (R^2=0.82)	$y=826.59e^{-0.044x}$ (R^2=0.60)	$y=532.21e^{-0.033x}$ (R^2=0.59)
Urea-N (µg N/L)	$y=146.25e^{-0.01x}$ (R^2=0.17)	$y=522.18e^{-0.018x}$ (R^2=0.70)	$y=117.52e^{-0.002x}$ (R^2=0.03)	$y=154.24e^{-0.002x}$ (R^2=0.02)
TKP (µg P/L)	$y=592.81e^{-0.012x}$ (R^2=0.64)	$y=377.95e^{-0.011x}$ (R^2=0.76)	$y=407.45e^{-0.008x}$ (R^2=0.22)	$y=493.41e^{-0.012x}$ (R^2=0.34)
FRP (µg P/L)	$y=713.16e^{-0.02x}$ (R^2=0.70)	$y=473.35e^{-0.022x}$ (R^2=0.82)	$y=466.19e^{-0.014x}$ (R^2=0.34)	$y=387.83e^{-0.019x}$ (R^2=0.36)
Diuron (µg/L)	$y=343.49e^{-0.049x}$ (R^2=0.96)		$y=533.23e^{-0.051x}$ (R^2=0.95)	$y=471.39e^{-0.056x}$ (R^2=0.96)
Hexazinone (µg/L)	$y=68.026e^{-0.041x}$ (R^2=0.89)		$y=57.162e^{-0.039x}$ (R^2=0.95)	$y=128.66e^{-0.047x}$ (R^2=0.90)

(Note – for TSS, x = maximum rainfall intensity (mm/hr); for all other parameters, x = days after application (of nutrients or herbicides). Regression plots are shown in Section 7.1)

2.4 Laboratory methodologies

2.4.1 Soil nutrients

Air-dried soil samples were analysed for ammonium- and nitrate-N by method 7C2a (Rayment and Lyons 2011) using a 1 M KCl extracting solution. Similarly, soil phosphorus was analysed on air-dried samples by method 9A3a using a 1 M KCl extracting solution.

2.4.2 Water analyses

Analysis of TSS, turbidity, electrical conductivity, and nutrients (filtered and unfiltered) were conducted by the Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) laboratory, James Cook University, Townsville. Unfiltered herbicide samples were analysed by the Queensland Health Forensic and Scientific Services (QHFSS) laboratory, Brisbane and ACS Laboratories (Australia), Kensington.

2.4.2.1 Total suspended solids and turbidity

To determine the mass per volume of TSS, a known volume of sample was filtered through a pre-weighed standard glass fibre filter and oven dried (APHA 1998).

Laboratory turbidity measurements (APHA 2130B) were based on a comparison between the intensity of light scattered by the water sample under defined conditions, and the intensity of light scattered by a standard reference suspension under the same defined conditions (APHA 1998). A formazin polymer was used as the primary standard reference suspension (turbidity of 4000 NTU).

2.4.2.2 Electrical conductivity

Electrical conductivity was measured directly using a calibrated conductivity cell rinsed with sample at a known temperature. The conductivity cell was calibrated with known standards of potassium chloride solution prior to analysis (APHA 1998).

2.4.2.3 Nutrients

Nutrient samples from surface water runoff and drainage soil solution were analysed for ammonium-N, urea-N, oxidised nitrogen (NO_x-N, consisting of nitrate and nitrite), total filterable nitrogen (TFN), total Kjeldahl nitrogen (TKN), total filterable phosphorous (TFP), filterable reactive phosphorous (FRP) and total Kjeldahl phosphorous (TKP). Samples for TFN and TFP were digested in an autoclave using an alkaline persulphate technique (Hosomi and Sudo 1987) and the resulting solution simultaneously analysed for NO_x-N and FRP with a segmented flow auto-analyser. The analyses of NO_x-N, ammonium-N and FRP were also conducted using segmented flow auto-analysis techniques following standard methods (APHA 2005).

For TKN and TKP, the samples were digested prior to analysis in the presence of sulphuric acid, potassium sulphate and a mercury catalyst. Total Kjeldahl nitrogen was then determined using the indophenol reaction (Searle 1984) on a segmented flow analyzer. Total Kjeldahl phosphorus was determined using the phosphomolybdic blue reaction (Murphy and Riley 1962) on a segmented flow analyser.

2.4.2.4 Herbicides

Water samples were analysed (unfiltered) by liquid chromatography mass spectrometry (LCMS) at the Queensland Health and Forensic Scientific Services (QHFSS) laboratory. Urea and triazine herbicides and polychlorinated biphenyls were extracted from the sample with dichloromethane. The dichloromethane extract was concentrated prior to instrumentation quantification by LCMS (QHFSS method number 16315).

Imazapic analyses were conducted by ACS Laboratories (Australia). Samples were filtered through a 0.45 µm nylon filter to remove particulate matter before being extracted through a solid phase extraction (SPE) cartridge which was eluted using acetonitrile. The extracted sample was analysed by LCMS using standard blanks, matrix spikes and duplicates for quality control.

2.4.3 Soil and cane trash herbicide analysis

Analysis of samples for atrazine, diuron and hexazinone were conducted at QHFSS. Samples were extracted using routine procedures and analysed by LCMS.

Imazapic analyses were conducted by ACS Laboratories. Samples were homogenized by freezing with dry ice and blending to a fine powder. Five grams of homogenized sample was extracted with acetonitrile and passed through an SPE cartridge which was eluted using acetonitrile. The extracted sample was analysed by LCMS using standard blanks, matrix spikes and duplicates for quality control.

2.5 Spatial rainfall variability

In addition to the tipping bucket rain gauges located at each monitoring site, five were located in the surrounding area, with one located near the top of the Multi-farm catchment. The annual rainfall (October 2012 to September 2013) was spatially assessed and interpolated using the Spatial Analyst extension in ArcMap™ 10.1.

2.6 Data management

All data is stored in the DARTS (DAta Recording Tool for Science) database, available at http://darts.information.qld.gov.au/darts/.

DARTS enables the capture of scientific data in a format that is suitable for long-term storage, easy discovery, retrieval and reuse. Only pre-processed data is entered into DARTS after it has been checked for accuracy.

3 RESULTS

3.1 Overview of annual rainfall

Rainfall around the region for 2012/13 (October-September) was similar to, or above, the long-term average of 1679 mm (median 1513 mm) (Te Kowai Research Station, 1889/90-2009/10; data extracted in April 2011 from http://www.bom.gov.au/climate/data/). The highest rainfall was recorded at the Victoria Plains site (1939 mm), with the lowest (1630 mm) recorded in the south-east of the region (Figure 5). A typical rainfall intensity-frequency-duration graph is contained in Appendix 7.3.

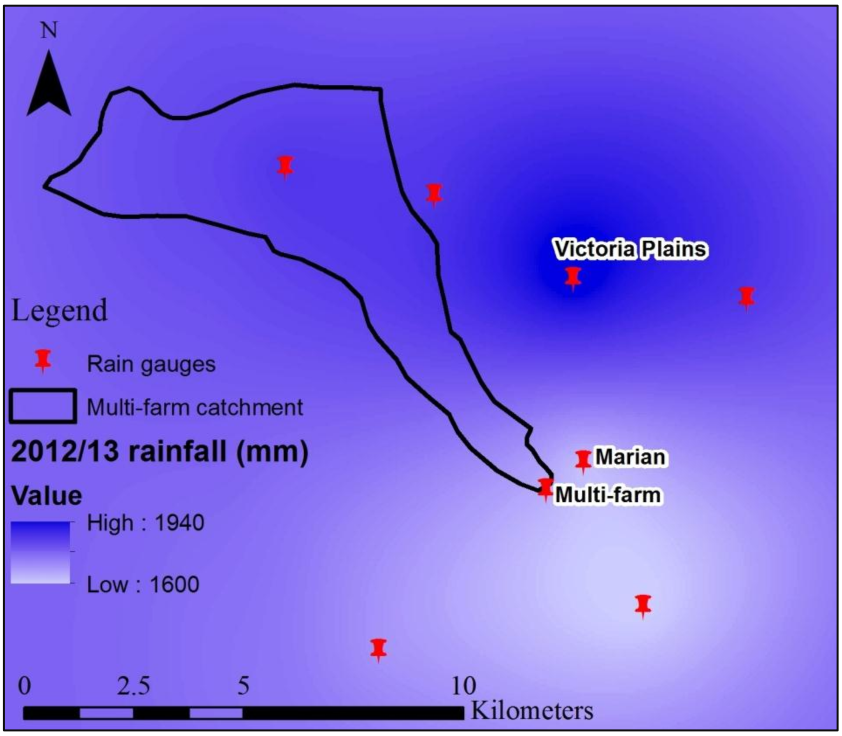

Figure 5 Annual (October-September) rainfall for 2012/13

3.2 Overview of runoff events

3.2.1 Paddock scale (Victoria Plains)

Eleven rainfall runoff events were recorded at each treatment of the Victoria Plains site. The first runoff event occurred on 24th December 2012, and the final event commenced on 9th April 2013. Due to the magnitude of the wet season, the automatic samplers were turned off for six days in March (events 8 and 9); hence not all runoff events have associated water quality data.

The site was flood irrigated once in late November 2012, producing a runoff event from Treatment 2 only.

3.2.2 Multi-farm scale

Two small irrigation runoff events were manually sampled in mid-December 2012 (one sample collected from each). The first rainfall runoff event commenced on 23rd December 2012, with seven events recorded for the season. The final runoff event commenced on 5th May 2013 (no samples collected from this event). It was difficult to define individual runoff events at this site, as runoff was still in progress when the next rainfall event occurred. A flow event was therefore defined as the duration of one composite sample.

3.3 Victoria Plains site

3.3.1 Soil nutrients

After harvest (17th October 2012), soil nitrate-N concentrations (KCl extraction) were ≤ 2 mg/L in both treatments (row and interspace) at all depths. Ammonium-N concentrations were ≤ 1 mg/kg, except for Treatment 1 row at the surface (4 mg/kg).

Average soil phosphorus concentrations (KCl extraction) were similar between treatments (159 µg/kg), although distribution down the profile and between row/interspace was variable.

3.3.2 Soil and cane trash herbicides

On the cane trash, peak herbicide concentrations were generally detected at the initial sampling. These concentrations then rapidly declined until the end of sampling 147 days after application (e.g. Figure 6 for diuron) during which time 1571 mm of rainfall was recorded. Imazapic was not detected (<0.005 mg/kg) on the cane trash 147 days after application. As expected, diuron and hexazinone concentrations in Treatment 4 (banded application) were lower than Treatments 1 and 3 where a blanket application was applied. Diuron was detected in the three applied treatments 147 days after application (0.12-1.2 mg/kg), and hexazinone was only detected in treatments 3 and 4 (0.008-0.072 mg/kg).

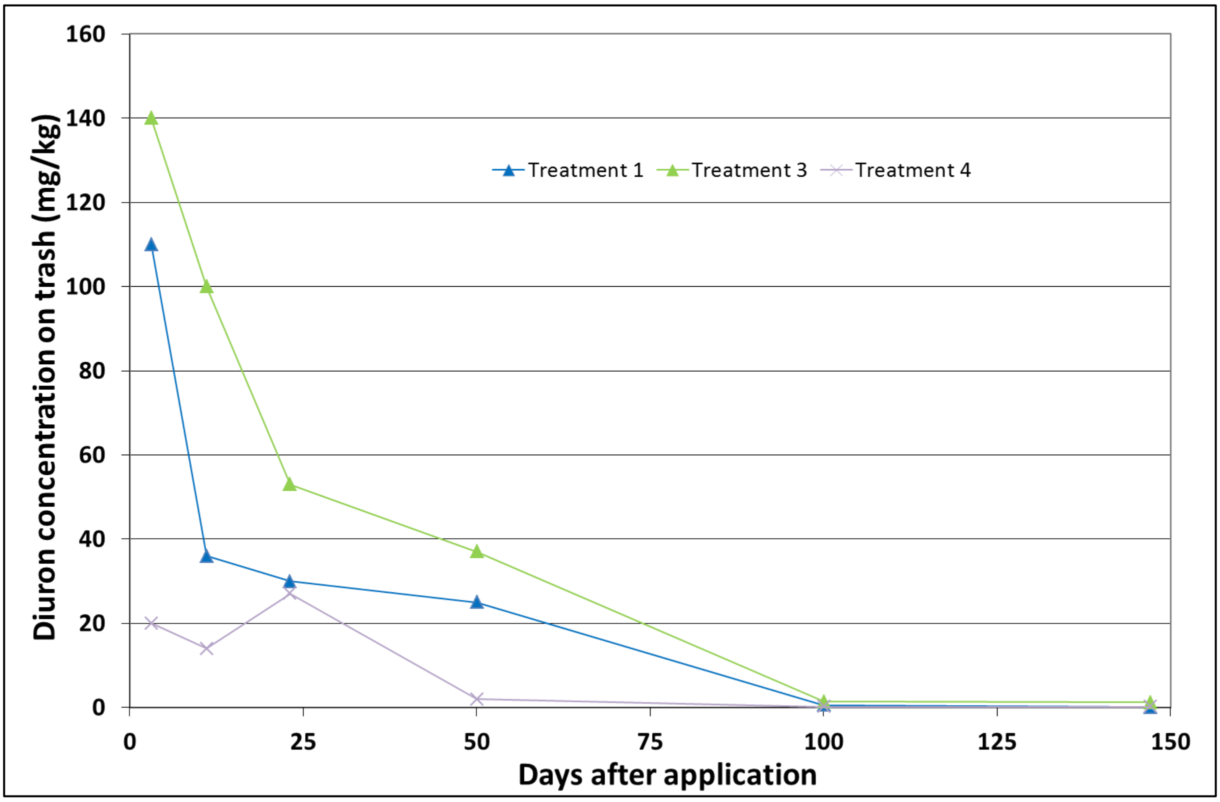

Figure 6 Concentration of diuron measured on the cane trash, Victoria Plains site

Using the field dissipation data, the calculated half-life for imazapic for cane trash and soil was 22 and 60 days, respectively. Despite the different application techniques for diuron and hexazinone (blanket or banded), the calculated half-lives for diuron and hexazinone were similar between treatments (Table 8); 16 and 12 days for diuron and hexazinone on cane trash, respectively; and 101 and 26 days for diuron and hexazinone in soil, respectively.

Table 8 Calculated field dissipation half-lives (days) of diuron, hexazinone and imazapic on cane trash and surface soil (0-2.5 cm), Victoria Plains site

		Diuron	Hexazinone	Imazapic
Cane trash (3-147 days)	Treatment 1	16 (r^2=0.91)	12 (r^2=0.91)	
	Treatment 2			22 (r^2=0.97)
	Treatment 3	15 (r^2=0.90)	11 (r^2=0.93)	
	Treatment 4	18 (r^2=0.92)	12 (r^2=0.93)	
	Average	**16 (r^2=0.94)**	**12 (r^2=0.96)**	
Surface soil (23-147 days)	Treatment 1	101 (r^2=0.93)	27 (r^2=0.95)	
	Treatment 2			60 (r^2=0.66)
	Treatment 3	79 (r^2=0.61)	25 (r^2=0.98)	
	Treatment 4	139 (r^2=0.61)	26 (r^2=0.98)	
	Average	**101 (r^2=0.89)**	**26 (r^2=0.98)**	

3.3.3 Soil moisture

Soil water extraction was evident throughout the season, with only a short period of saturation evident from mid-February to mid-March (Figure 7), although some extraction occurred during this period. Similar to previous seasons, Treatment 2 appeared wetter than Treatment 1, but it is unclear whether these differences were due to treatment differences or localised influences around the monitoring point (cracking patterns, root distribution, etc.).

Data from individual depth sensors shows water extraction at 150 cm in Treatment 1 was evident for approximately two weeks prior to the flood irrigation event (late November 2012), and there was no clear evidence of a shallow water table during the season (Section 7.2.1). Water extraction at 150 cm was not clearly evident in Treatment 2. A water table was evident at 150 cm until early September 2012, and again from early March to late June (Section 7.2.2).

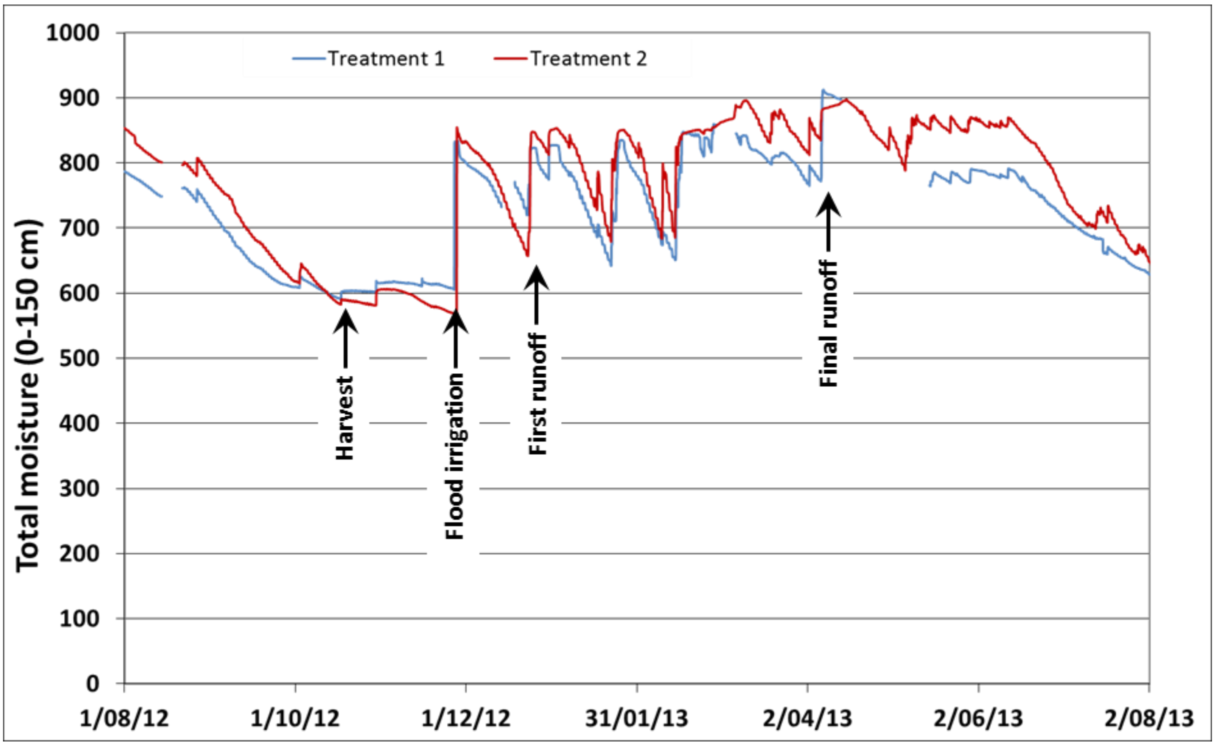

Figure 7 Total moisture in the soil profile (0-150 cm), Victoria Plains site

(Note – total moisture is uncalibrated volumetric water content)

3.3.4 Irrigation runoff and water quality

The only treatment that ran off from the flood irrigation in November 2012 was Treatment 2; 13 mm runoff from an estimated 70 mm applied. This irrigation was 36 days after herbicide application and 12 days after nutrient application. The quality of the source water (supplied from Kinchant Dam) indicated that it had relatively low concentrations of nitrogen and phosphorus, with no imazapic detected (Table 9), but atrazine was detected (0.06 µg/L). Concentrations of all parameters increased in the runoff water, as would be expected. Loads of nutrients in runoff were much larger than that applied in the source water, except for TKN (Table 10). The loss of imazapic (0.77 g/ha) represents only 0.8% of the applied product, 36 days after application.

Table 9 Selected water quality concentrations of the source water and runoff water (Treatment 2) of the flood irrigation event in November 2012, Victoria Plains site

	EC (µS/cm)	TSS (mg/L)	TKN (µg N/L)	NO_x-N (µg N/L)	Urea-N (µg N/L)	TKP (µg P/L)	FRP (µg P/L)	Imazapic (µg/L)
Source water	194	1.1	351	35	25	10	3	<1
Runoff water	IS	IS	1074	4421	724	342	299	6

(IS - insufficient sample volume for laboratory analysis)

Table 10 Nutrient and imazapic loads in source and runoff water (Treatment 2) of the flood irrigation event in November 2012, Victoria Plains site

	TKN (kg/ha)	NO_x-N (kg/ha)	Urea-N (kg/ha)	TKP (kg/ha)	FRP (kg/ha)	Imazapic (g/ha)
Source water	0.25	0.02	0.02	<0.01	<0.01	<0.01
Runoff water	0.14	0.57	0.09	0.04	0.04	0.77

3.3.5 Rainfall and runoff

A total of 1939 mm of rainfall was recorded at the Victoria Plains site between 1st October 2012 and 30th September 2013, which was above the long-term average of 1679 mm (median 1513 mm) (Te Kowai Research Station, 1889/90-2009/10; data extracted in April 2011 from http://www.bom.gov.au/climate/data/). The highest daily total recorded during 2012/13 was 221 mm on 4th March 2013.

Total wet season runoff (Table 11) from Treatment 2 (1.8 m row spacing) averaged 20% less than Treatment 1 (1.5 m row spacing) (671 mm and 841 mm, respectively). The additional treatments (Treatments 3 and 4; 1.8 m row spacing) also ran off less than Treatment 1 (17-31% less). Unlike previous years when the commencement of runoff from Treatment 2 was delayed by ~17 minutes (compared to Treatment 1), there was very little difference this season. The average peak runoff this season from Treatment 2 was 28% lower than Treatment 1, which was a greater difference than observed in previous seasons (~18%). Peak runoff from Treatments 3 and 4 was also lower than Treatment 1 (~25%).

Table 11 Event rainfall and runoff during the 2012/13 wet season, Victoria Plains site

Event	Start Date	Rainfall		Treatment 1 Runoff		Treatment 2 Runoff		Treatment 3 Runoff		Treatment 4 Runoff	
		Total (mm)	Max. I_{30} (mm/hr)	Total (mm)	Max. (mm/hr)	Total (mm)	Max. (mm/hr)	Total (mm)	Max. (mm/hr)	Total (mm)	Max. (mm/hr)
1	24/12/12	108	19	16	4.5	10	3.2	11	4.4	6.0	2.1
2	30/12/12	96	29	11	2.7	11	2.5	7.2	3.0	6.5	1.8
3	24/01/13	292	56	127	35	93	22	109	19	92	23
4	14/02/13	188	24	59	5.7	64	5.6	54	9.5	59	8.3
5	19/02/13	56	65	36	17	46	16	48	17	36	21
6	23/02/13	55	64	40	15	32	11	21	17	21	10
7	26/02/13	189	32	89	13	84	15	94	14	59	12
8	01/03/13	400	92	339	70	234	35	219	33	192	36
9	05/03/13	52	42	31	15	27	12	29	13	30	18
10	06/04/13	59	24	10	3.3	13	3.6	20	6.5	12	2.1
11	09/04/13	109	22	85	8.8	58	9.0	85	11	69	9.8
Total (mm)				**841**		**671**		**697**		**582**	

3.3.6 Rainfall runoff water quality

3.3.6.1 Total suspended solids, turbidity and electrical conductivity

Concentrations of TSS across all of the samples collected were low (<70 mg/L; Figure 8), excluding 475 mg/L from Treatment 4 (event 5 on 20th February 2013). This value is approximately 10-times higher than any other sample collected from any treatment, and has therefore been excluded from any analyses. There was a trend of increasing TSS concentration with increasing maximum rainfall intensity (and therefore peak runoff rate) (Section 7.1). The flow-weighted seasonal TSS concentration of each treatment was 22-33 mg/L (Table 12). Any difference in treatments is thought to be due to event sampling variability (and estimated concentrations) rather than treatment differences. The total estimated sediment load for the wet season from Treatment 1 (1.5 m row spacing) was 217 kg/ha, similar to the 1.8 m row spacing treatments (149-228 kg/ha) (Table 12). These concentrations were similar to the previous season (Treatments 1 and 2; 22-24 mg/L) but loads were higher (217-298 kg/ha) due to the higher runoff.

Similar to TSS concentrations, runoff turbidity was low and consistent between treatments (32-130 NTU, excluding 800 NTU from Treatment 4). When samples from each treatment were combined, there was a poor relationship (R^2=0.55, excluding the high value from Treatment 4) between TSS concentration and turbidity (data not shown). This is thought to be due to the low range in TSS concentrations.

Electrical conductivity (EC) values were very low and similar between treatments (34-65 µS/cm). This range is similar to the 2011/12 season (31-73 µS/cm, excluding 373 µS/cm measured in the first event of Treatment 1).

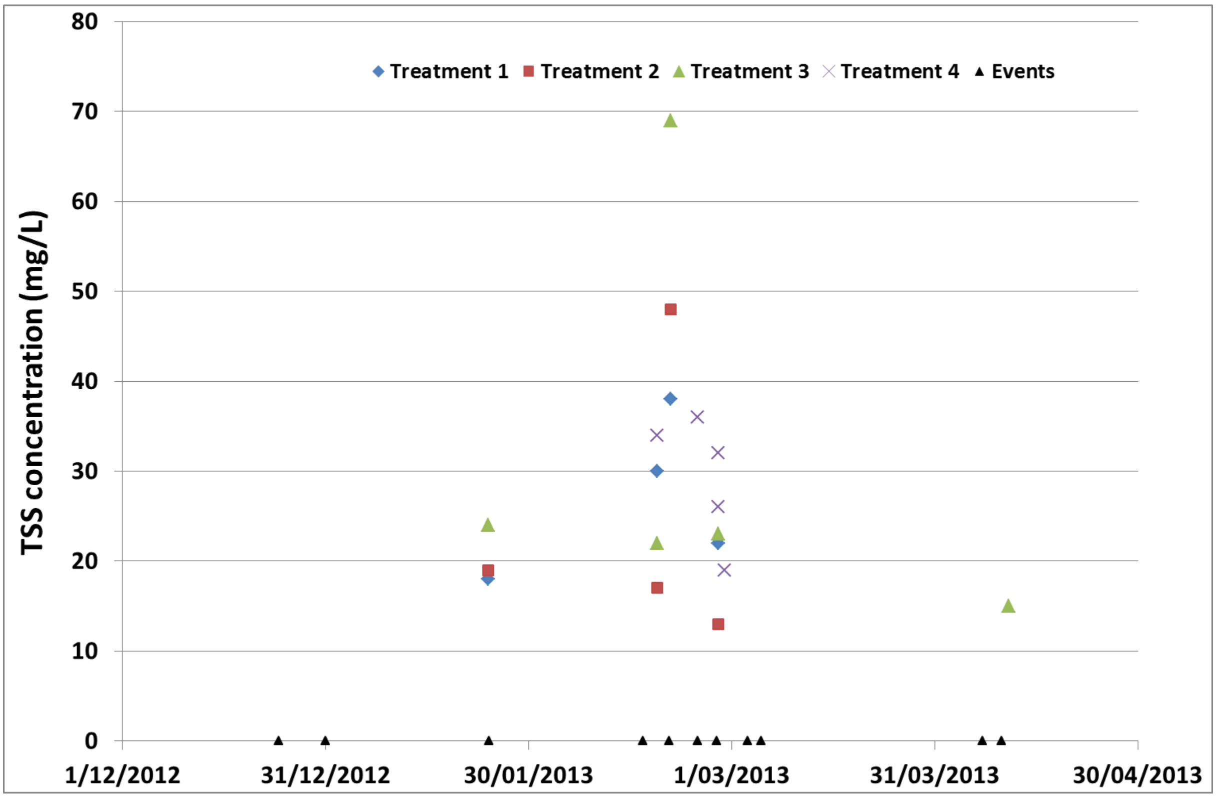

Figure 8 Concentrations of total suspended solids measured in rainfall induced runoff, Victoria Plains site

Table 12 Calculated event loads of sediment from rainfall induced runoff, Victoria Plains site

Event	Start Date	Treatment 1		Treatment 2		Treatment 3		Treatment 4	
		Load (kg/ha)	Conc. (mg/L)	Load (kg/ha)	Conc. (mg/L)	Load (kg/ha)	Conc. (mg/L)	Load (kg/ha)	Conc. (mg/L)
1	24/12/12	*4*	*24*	*1*	*5*	*2*	*15*	*2*	*29*
2	30/12/12	*3*	*27*	*3*	*23*	*3*	*35*	*2*	*32*
3	24/01/13	23	18	18	19	26	24	*31*	*34*
4	14/02/13	18	30	11	17	12	22	20	34
5	19/02/13	14	38	22	48	33	69	*13*	*35*
6	23/02/13	*12*	*29*	*11*	*34*	*10*	*48*	8	36
7	26/02/13	19	22	7	8	21	23	15	25
8	01/03/13	*95*	*26*	*71*	*22*	*96*	*33*	*65*	*32*
9	05/03/13	*8*	*26*	*4*	*16*	*8*	*27*	*9*	*31*
10	06/04/13	*2*	*25*	*2*	*12*	*5*	*23*	*4*	*30*
11	09/04/13	*20*	*23*	*1*	*1*	13	15	*20*	*29*
Total load (kg/ha)		**217**		**149**		**228**		**187**	
Flow-weighted seasonal av. conc. (mg/L)			**26**		**22**		**33**		**32**

(Note – figures in *italics* indicate estimations using the regression curves shown in Table 7 where samples were not collected)

3.3.6.2 Nitrogen

The first rainfall runoff event occurred 39 days after nutrient application, with samples collected from Treatment 4 only. The second event occurred 46 days after application, and samples were only collected from Treatment 1. As a result of the limited sampling in these initial events, there is **limited confidence** in the findings and loads calculated.

Concentrations of NO_x-N tended to decline throughout the season, and by February were <200 µg N/L (Figure 9). The proportion of NO_x-N to TN (TKN+ NO_x-N) also declined through the season; from ~33% in the initial events to generally <10% late in the season (average 22% across all samples collected). Concentrations of urea-N were low throughout the season, and remained below 200 µg N/L in all treatments, except for one sample collected from Treatment 4 (335 µg N/L in the first runoff event). Concentrations of TKN in each treatment were variable throughout the season, with Treatment 1 showing the highest seasonal flow-weighted average (Table 13).

The total loss of NO_x-N in runoff was quite consistent between treatments (0.7-0.9 kg/ha; Table 13), and the flow-weighted average concentration was 96-135 µg N/L. The total loss of urea-N was also quite consistent between treatments (0.6-0.7 kg/ha). The loss of NO_x-N plus urea-N represents 0.7-1.0% of the applied nitrogen to each treatment. This is similar to the previous season (0.9-1.2%; first runoff 75 days after application), but much lower than the ~10% measured in the 2010/11 season when runoff occurred three days after nutrient application.

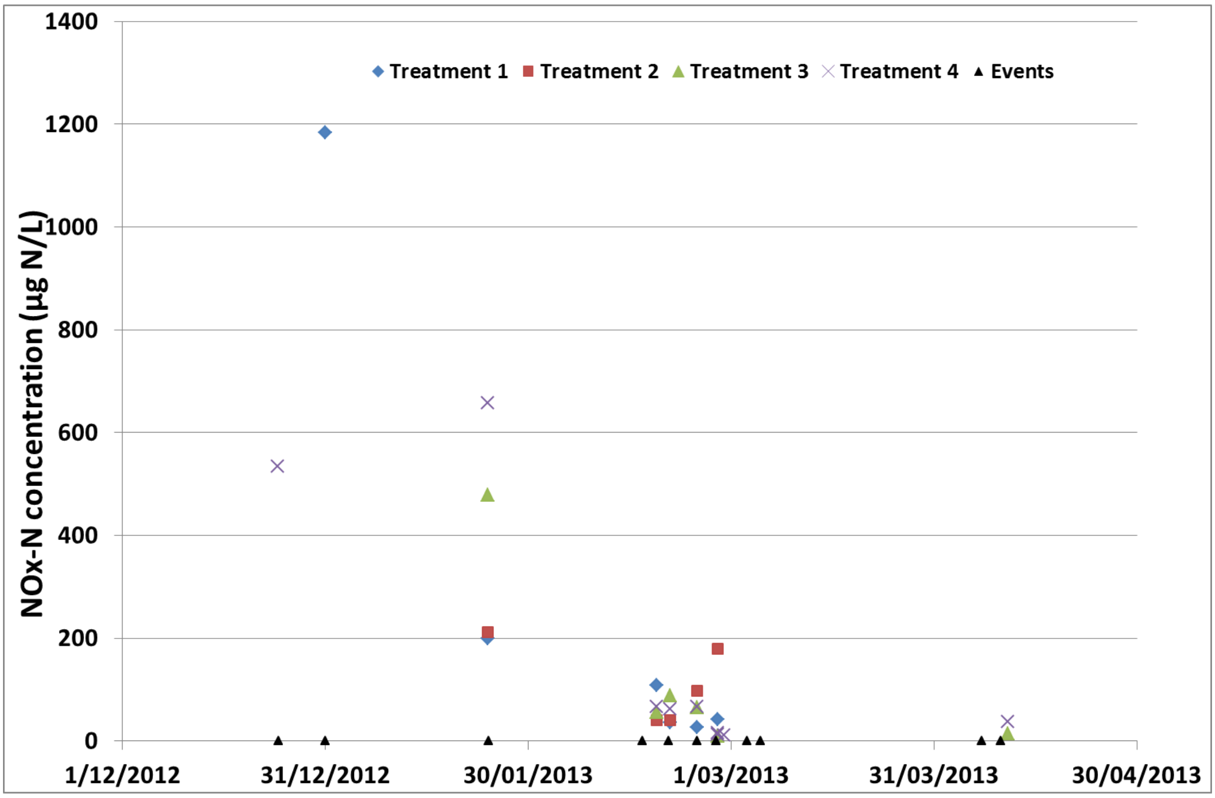

Figure 9 Concentrations of NO_x-N in rainfall induced runoff, Victoria Plains site

Table 13 Calculated event loads of nitrogen from rainfall induced runoff, Victoria Plains site

Event	Start Date	TKN (kg/ha)				NO_x-N (kg/ha)				Urea-N (kg/ha)			
		T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4
1	24/12/12	*0.36*	*0.09*	*0.12*	0.12	*0.26*	*0.10*	*0.02*	0.03	*0.02*	*0.02*	*0.01*	0.02
2	30/12/12	0.26	*0.10*	*0.07*	*0.10*	0.14	*0.09*	*0.01*	*0.01*	0.02	*0.03*	*0.01*	*0.01*
3	24/01/13	1.12	0.73	0.83	1.07	0.25	0.20	0.52	0.60	0.04	0.07	0.09	0.06
4	14/02/13	0.78	0.45	0.43	0.55	0.06	0.03	0.03	0.04	0.11	0.04	0.06	0.07
5	19/02/13	0.39	0.31	0.36	0.50	0.01	0.02	0.04	0.02	0.03	0.03	0.09	0.05
6	23/02/13	2.27	0.34	0.19	0.19	0.01	0.03	0.01	0.01	0.05	0.03	0.02	0.02
7	26/02/13	1.50	0.86	0.60	0.40	0.04	0.15	0.01	0.01	0.10	0.09	0.10	0.07
8	02/03/13	*3.90*	*1.44*	*1.15*	*1.48*	*0.07*	*0.09*	*0.01*	*0.02*	*0.14*	*0.13*	*0.15*	*0.20*
9	05/03/13	*0.40*	*0.22*	*0.21*	*0.27*	*0.01*	*0.01*	*0.00*	*0.00*	*0.01*	*0.02*	*0.03*	*0.04*
10	06/04/13	*0.10*	*0.10*	*0.11*	*0.08*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.01*	*0.02*	*0.01*
11	09/04/13	0.51	*0.44*	0.43	0.65	*0.00*	*0.01*	0.01	0.03	0.02	0.04	0.07	0.13
Total load (kg/ha)		**12**	**5.6**	**4.9**	**5.7**	**0.9**	**0.8**	**0.7**	**0.8**	**0.6**	**0.6**	**0.7**	**0.7**
Flow-weighted av. conc. (μg N/L)		**1457**	**830**	**706**	**984**	**103**	**112**	**96**	**135**	**68**	**83**	**100**	**125**

(Note – T1 = Treatment 1 (1.5 m row spacing, 197 kg N/ha applied); T2 = Treatment 2 (1.8 m row spacing, 135 kg N/ha applied); T3 = Treatment 3 (1.8 m row spacing, 197 kg N/ha applied); T4 = Treatment 4 (1.8 m row spacing, 135 kg N/ha applied). Figures in *italics* indicate loads estimated from regression curves (Table 7) where samples were not collected)

3.3.6.3 Phosphorus

Similar to nitrogen, sampling from the first two runoff events was very limited. As a result of the limited sampling in these initial events, there is **limited confidence** in the findings and loads calculated.

From the limited samples collected in the first two events (late December 2012), FRP concentrations were 112-164 µg P/L. Concentrations were generally the highest (160-316 µg P/L) in late January 2013, before declining to generally <50 µg P/L by the end of the season (Figure 10). Concentrations from Treatment 2 were consistently lower than other treatments. Seasonal concentrations of TKP were similar between treatments (173-191 µg P/L), except Treatment 2 (128 µg P/L) (Table 14). It is unknown why concentrations of FRP and TKP were lower in Treatment 2, as all treatments received the same amount of applied phosphorus (25 kg/ha; Table 3).

Similar to seasonal TKP and FRP concentrations, loads were lowest from Treatment 2 (0.9 kg/ha and 0.4 kg/ha, respectively) with other treatments being similar (Table 14). The total loss of FRP in runoff was ~2-3% of the applied phosphorus, slightly higher than the previous season (~2%).

Across all of the samples collected, FRP comprised the majority (81%) of the TFP signature and 56% of TP.

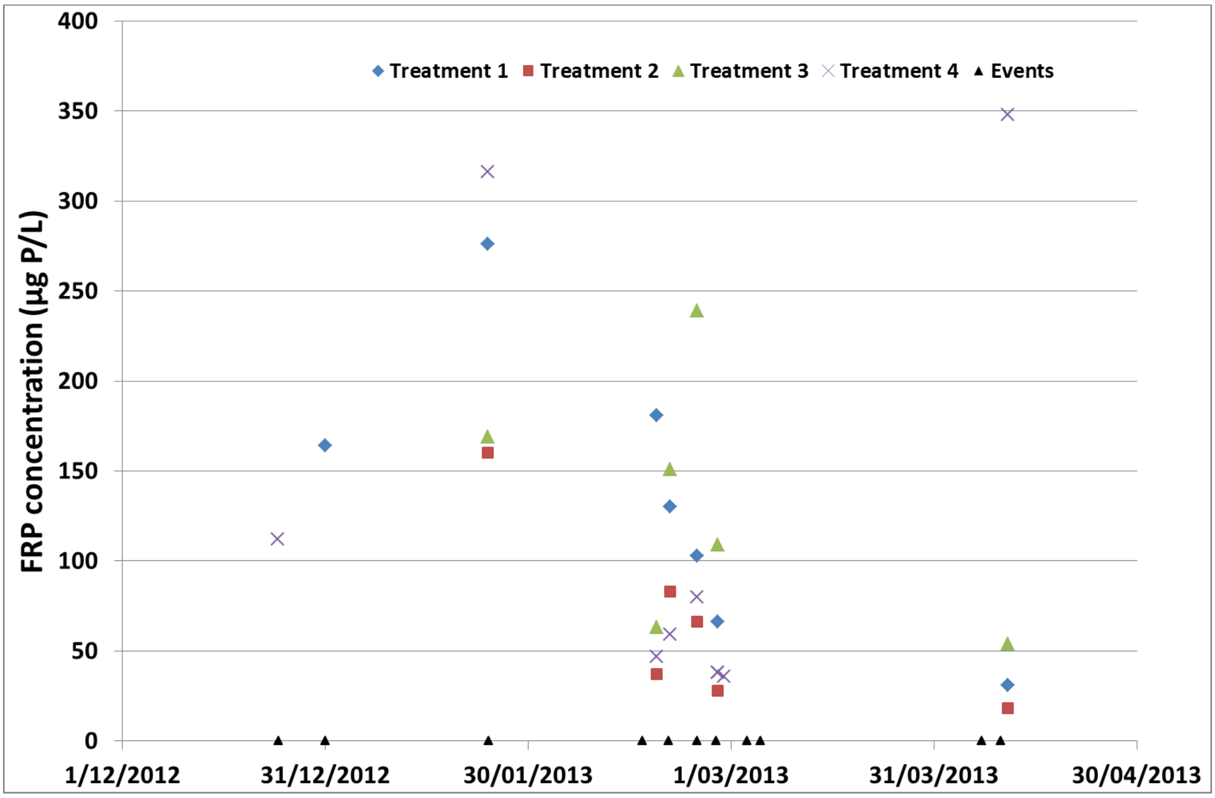

Figure 10 Filterable reactive phosphorus concentrations in rainfall induced runoff, Victoria Plains site

Table 14 Calculated event loads of phosphorus from rainfall induced runoff, Victoria Plains site

Event	Start Date	TKP (kg/ha)				FRP (kg/ha)			
		T1	T2	T3	T4	T1	T2	T3	T4
1	24/12/12	*0.06*	*0.02*	*0.03*	0.01	*0.05*	*0.02*	*0.03*	0.01
2	30/12/12	0.03	*0.03*	*0.02*	*0.02*	0.02	*0.02*	*0.02*	*0.01*
3	24/01/13	0.42	0.21	0.26	0.37	0.35	0.15	0.18	0.29
4	14/02/13	0.18	0.06	0.06	0.07	0.11	0.02	0.03	0.03
5	19/02/13	0.06	0.06	0.10	0.08	0.05	0.04	0.07	0.02
6	23/02/13	0.07	0.04	0.07	0.03	0.04	0.02	0.05	0.02
7	26/02/13	0.10	0.07	0.15	0.06	0.06	0.02	0.10	0.02
8	01/03/13	*0.55*	*0.27*	*0.38*	*0.26*	*0.28*	*0.10*	*0.23*	*0.10*
9	05/03/13	*0.05*	*0.03*	*0.05*	*0.04*	*0.02*	*0.01*	*0.03*	*0.01*
10	06/04/13	*0.01*	*0.01*	*0.03*	*0.01*	*0.00*	*0.00*	*0.01*	*0.00*
11	09/04/13	0.08	0.05	0.10	*0.06*	0.03	0.01	0.05	0.24
Total load (kg/ha)		**1.6**	**0.9**	**1.3**	**1.0**	**1.0**	**0.4**	**0.8**	**0.8**
Flow-weighted av. conc. (µg P/L)		**191**	**128**	**180**	**173**	**120**	**63**	**115**	**129**

3.3.6.4 Herbicides

Diuron and hexazinone were detected in the highest concentrations in the first rainfall runoff event of the season from all treatments where it was applied (Figure 11 and Figure 12). Concentrations were generally lower in Treatment 4 where the herbicides were applied on a ~33% band (compared to 100% blanket application in the other treatments). Due to the lower concentrations in the banded treatment, the total season diuron and hexazinone loads in runoff were lower (approximately half) than blanket application, and row spacing had little effect on loss (Table 15). Losses this season (even with the banded application) were higher than the previous season due to the timing of the first runoff event (and consequently, the initial concentration); 128 days in the previous season (~0.2-0.4% loss) and 63 days this season (0.7-1% for corresponding treatments). Although the losses from the banded application were lower than the blanket application, the proportion lost was higher due to only ~50% reduction from a 33% band.

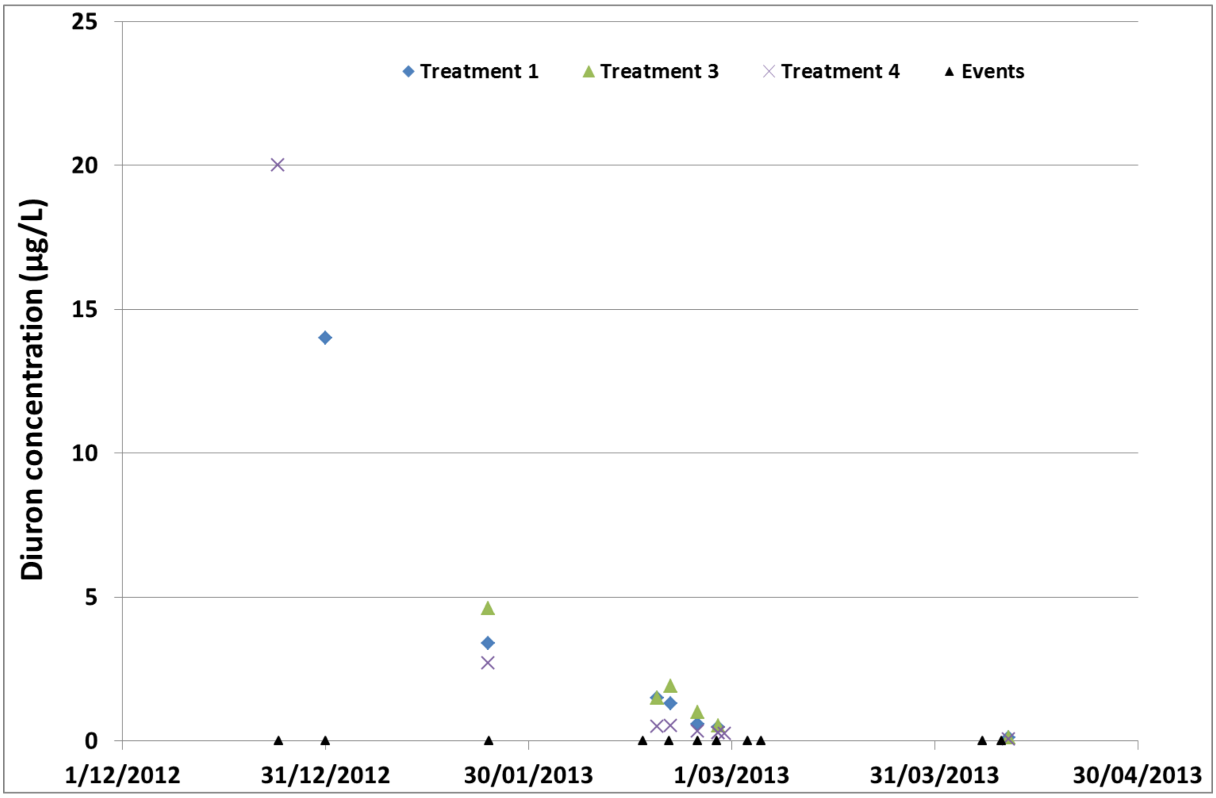

Figure 11 Diuron concentrations in rainfall induced runoff from Treatments 1, 3 and 4, Victoria Plains site

(Note – Herbicides applied on 22nd October 2012)

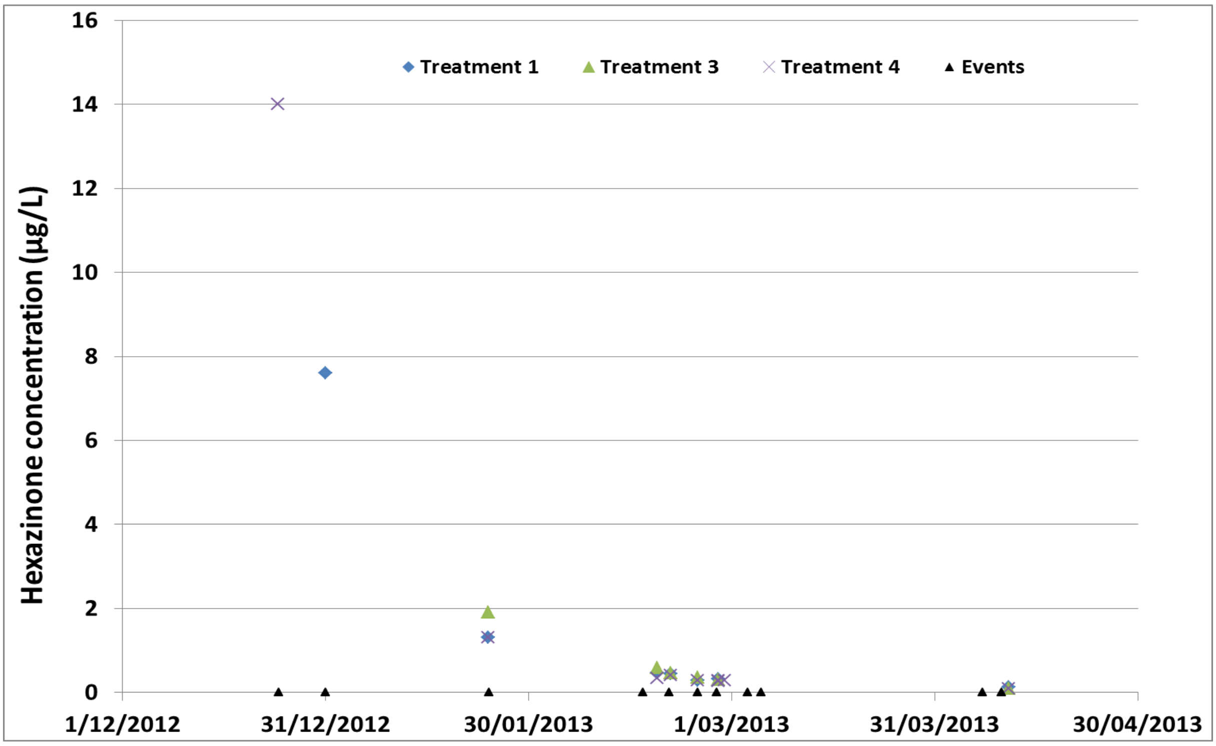

Figure 12 Hexazinone concentrations in rainfall induced runoff from Treatments 1, 3 and 4, Victoria Plains site

(Note – Herbicides applied on 22nd October 2012)

Table 15 Calculated loads of herbicides from rainfall induced runoff, Victoria Plain site

Event	Start date	Diuron (g/ha)			Hexazinone (g/ha)		
		T1	T3	T4	T1	T3	T4
1	24/12/12	*2.5*	*2.4*	1.2	*0.81*	*0.48*	0.84
2	30/12/12	1.6	*1.1*	*0.64*	0.87	*0.24*	*0.32*
3	24/01/13	4.3	5.0	2.5	1.7	2.1	1.2
4	14/02/13	0.89	0.81	0.29	0.27	0.32	0.20
5	19/02/13	0.46	0.91	0.19	0.16	0.23	0.15
6	23/02/13	0.23	0.21	0.07	0.12	0.08	0.06
7	26/02/13	0.42	0.49	0.16	0.29	0.28	0.16
8	01/03/13	*1.89*	*1.46*	*0.59*	*1.07*	*0.58*	*0.52*
9	05/03/13	*0.15*	*0.17*	*0.08*	*0.09*	*0.07*	*0.07*
10	06/04/13	*0.01*	*0.02*	*0.01*	*0.01*	*0.01*	*0.01*
11	09/04/13	0.10	0.09	0.04	0.11	0.08	0.07
Total (g/ha)		**13**	**13**	**5.7**	**5.4**	**4.4**	**3.6**
Flow weighted seasonal av. conc. (µg/L)		**1.49**	**1.51**	**0.68**	**0.65**	**0.53**	**0.43**
Product transported in runoff (% of applied)		**0.70**	**0.70**	**0.93**	**1.0**	**0.88**	**2.0**

(Note – figures in *italics* indicate loads estimated from regression curves (Table 7) where samples were not collected. Herbicides applied to Treatment 4 were on a 33% band)

Imazapic was only detected (1 µg/L) in two runoff events in mid-February 2013 (~120 days after application. As outlined in Section 3.3.4, it was detected in the irrigation event runoff (36 days after application) at 6 µg/L.

3.3.7 Agronomic

Yield and percent recoverable sugar (PRS) information collected during machine harvest (14th October 2013) and processing showed very similar cane yield (and PRS) from all treatments (Table 16), despite Treatments 2 and 4 receiving 62 kg N/ha less than Treatments 1 and 3. The pre-harvest measurements also showed very little difference in the nitrogen content of the stalk or leaf.

Table 16 Pre-harvest and machine harvest yield results of the third ratoon cane crop, Victoria Plains site

	Treatment 1	Treatment 2	Treatment 3	Treatment 4
N applied (kg/ha)	197	135	197	135
Stalk N content (% dm)	0.12	0.12	0.10	0.11
Leaf N content (% dm)	0.56	0.64	0.56	0.59
Cane (t/ha)	69	71	77	72
PRS	18.1	17.6	17.6	17.3
Sugar (t/ha)	12.5	12.5	13.6	12.5

3.4 Marian site

3.4.1 Soil nutrients

After harvest (19th September 2012), soil nitrate-N concentrations (KCl extraction) were ≤ 1 mg/L in all treatments (row and interspace) at all depths. Ammonium-N concentrations were ≤ 1 mg/kg, except for Treatment 3 row at 0.1-0.2 m depth (4 mg/kg).

Soil phosphorus concentrations (KCl extraction) were variable across the treatments and showed no treatment effects (phosphorus applied to Treatments 1 and 2 only). Average profile concentrations varied from 208 µg/kg (Treatment 3 interspace) to 468 µg/kg

(Treatment 5 interspace), with an overall range of 129-1010 µg/kg across all samples collected from all treatments.

3.4.2 Rainfall

A total of 1652 mm of rainfall was recorded at the Marian site between 1st October 2012 and 30th September 2013. This was slightly lower than the estimated long-term average of 1679 mm (Te Kowai Research Station, 1889/90-2009/10) for October-September. The highest daily rainfall total was 263 mm on 4th March, 2013.

3.4.3 Agronomic

Yield and percent recoverable sugar (PRS) information collected during machine harvest (7th October 2013) and processing showed that row spacing (Treatments 1 and 2) had little impact on cane yield (and PRS) and applying higher rates of nitrogen (than Six Easy Steps; Treatment 3) also had no impact on cane yield (Table 17). The lower rate of nitrogen applied to Treatment 4 (N replacement) reduced cane yield by 30%, and the skip row (Treatment 5) yielded 73% of the solid plant (Treatment 3), despite only 56% of the area planted to cane (10 cane rows and 8 “skip” rows).

Table 17 Machine harvest yield results of the third ratoon cane crop, Marian site

	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5
N applied (kg/ha)	197	197	159	70	165
Cane (t/ha)	111	118	113	79	82
PRS	15.4	15.9	16.2	16.1	15.6
Sugar (t/ha)	17.4	18.6	18.3	12.8	12.8

3.5 Multi-farm site

3.5.1 Rainfall and runoff

A total of 1677 mm of rainfall was recorded at the Multi-farm site between 1st October 2012 and 30th September 2013. This was similar to the estimated long-term average of 1679 mm (Te Kowai Research Station, 1889/90-2009/10) for October-September. The highest daily rainfall total was 263 mm on 4th March, 2013.

Total wet season runoff was 553 mm (Table 18), or 33% of rainfall. This season’s runoff was less than that measured in the previous three seasons (649-1364 mm, average 922 mm).

3.5.2 Runoff water quality

3.5.2.1 Total suspended solids, turbidity and electrical conductivity

All samples collected from the Multi-farm site had a low TSS concentration (Figure 13). The lowest concentration (2 mg/L) was detected in the second small irrigation event prior to the commencement of the wet season, while the highest concentration (38 mg/L) was from one of the largest peak discharge events of the season (Event 3; Table 18). The total estimated sediment load was 117 kg/ha, with a flow-weighted average concentration of 21 mg/L (Table 18). This load and average concentration was much lower than that measured in the previous three seasons (average 1128 kg/ha and 122 mg/L). Due to the low range of TSS concentrations, there was no significant relationship with turbidity.

Table 18 Event rainfall, runoff and TSS loads and concentrations during the 2012/13 wet season, Multi-farm site

Event	Start date	Rainfall		Runoff		TSS	
		Total (mm)	Max. I_{30} (mm/hr)	Total (mm)	Peak discharge (cumecs)	Load (kg/ha)	EMC (mg/L)
Irrig_1	16/12/12	Irrigation		<1	0.01	<0.1	17
Irrig_2	19/12/12	Irrigation		<1	0.01	<0.1	2.3
1	23/12/12	131	34	1.3	0.5	*0.2*	*19*
2	31/12/12	93	46	27	5.6	5.1	19
3	24/01/13	260	57	87	15	33	38
4	16/02/13	91	22	78	9.7	14	18
5	23/02/13	616	78	275	16	49	18
6	17/03/13	195	18	85	10	16	19
7	05/05/13	43	10	<1	0.0	*<0.1*	*19*
Total				**553**		**117**	
Flow weighted seasonal av. conc. (mg/L)							**21**

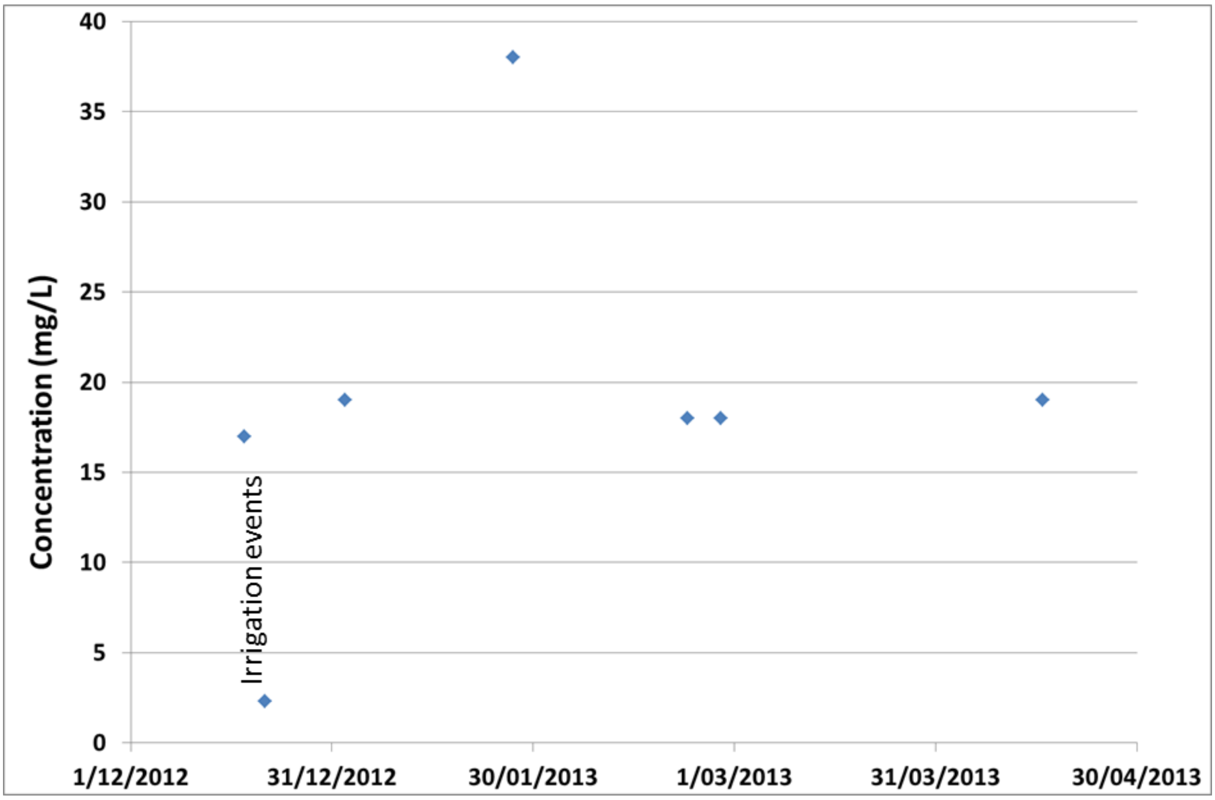

Figure 13 Concentrations of TSS in runoff during the 2012/13 wet season, Multi-farm site

The two sampled irrigation events at the beginning of the season (December 2012) produced the highest EC values (554-614 µS/cm) of the season, with 205 µS/cm recorded in the first rainfall runoff event (early January 2013). Values then decreased markedly to 42-87 µS/cm for the remainder of the season.

3.5.2.2 Nitrogen

The highest NO_x-N and TKN concentrations were detected in the small irrigation events in late December 2012. Concentrations of NO_x-N in rainfall runoff events were much lower (by at least one-third), with concentrations further decreasing as the wet season progressed. Concentrations of TKN followed a similar trend to NO_x-N (Figure 14). The total loss of NO_x-N in runoff was 1.6 kg/ha (20% less than the average of the previous three seasons) and 4.8 kg/ha for TKN (half the average of the previous three seasons). The flow-weighted seasonal mean concentration for NO_x-N and TKN was 217 µg N/L and 345 µg N/L, respectively (Table 19).

In the small irrigation events, NO_x-N comprised 70% of the TN (TKN+NO_x-N), whereas the proportion was much lower in the rainfall runoff events; ~40% in the initial two events, decreasing to be generally 12-13% for the remainder of the season.

Table 19 Calculated loads of nutrients and herbicides from runoff during the 2012/13 wet season, Multi-farm site

Event	Start date	TKN (kg/ha)	NO_x-N (kg/ha)	TKP (kg/ha)	FRP (kg/ha)	Ametryn (g/ha)	Atrazine (g/ha)	Diuron (g/ha)	Hexazinone (g/ha)
Irrig_1	16/12/12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrig_2	19/12/12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	23/12/12	*0.03*	*0.02*	*0.00*	*0.00*	*0.01*	*0.10*	*0.09*	*0.00*
2	31/12/12	0.60	0.46	0.09	0.06	0.13	2.2	2.0	0.06
3	24/01/13	1.2	0.78	0.52	0.39	0.08	5.1	5.6	0.50
4	16/02/13	0.78	0.11	0.27	0.17	0.02	0.63	1.6	0.12
5	23/02/13	1.6	0.11	0.81	0.48	0.04	0.90	2.3	0.17
6	17/03/13	0.68	0.10	0.22	0.10	0.00	0.14	0.62	0.03
7	05/05/13	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Total load		**4.8**	**1.6**	**1.9**	**1.2**	**0.3**	**9.1**	**12**	**0.9**
Flow weighted seasonal av. conc.		**875 µg N/L**	**286 µg N/L**	**345 µg P/L**	**217 µg P/L**	**0.05 µg/L**	**1.6 µg/L**	**2.2 µg/L**	**0.16 µg/L**

(Note – Load calculations in *italics* indicate those generated from estimated concentrations as described in section 2.3.2)

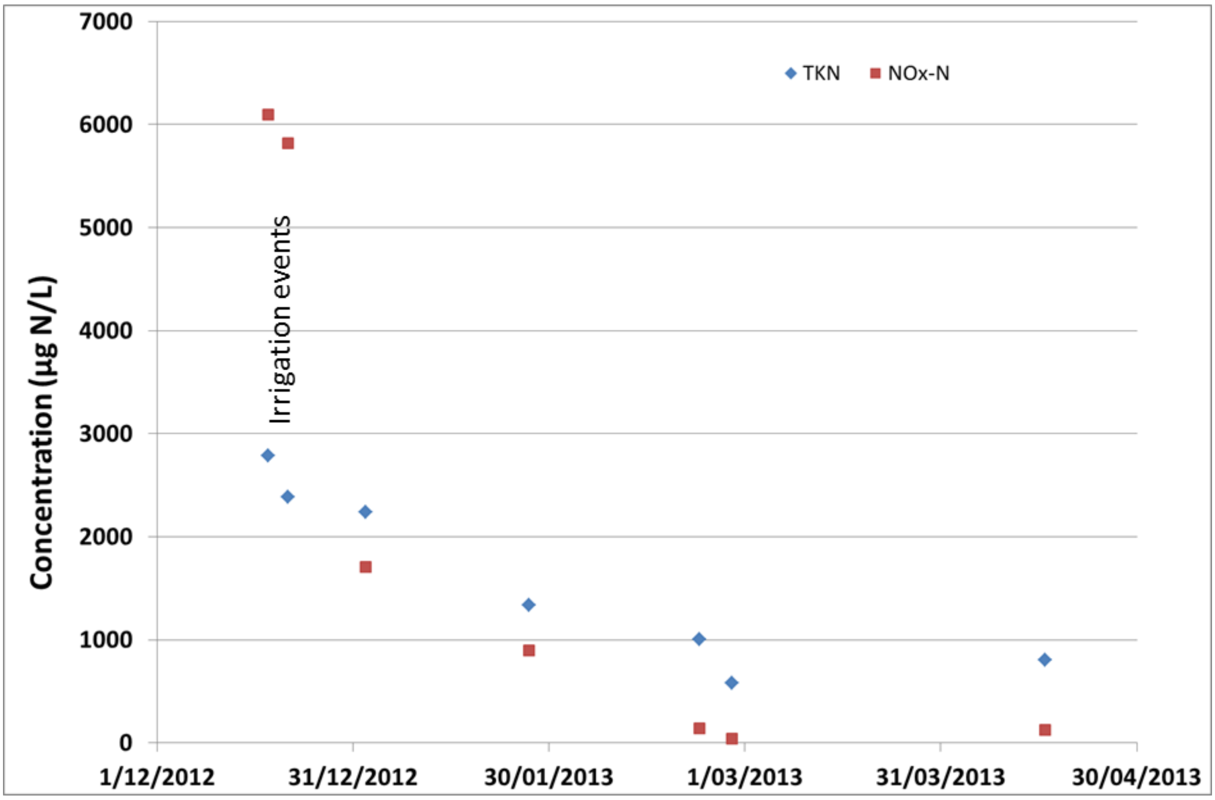

Figure 14 Concentrations of TKN and NO_x-N in runoff during the 2012/13 wet season, Multi-farm site

3.5.2.3 Phosphorus

Concentrations of phosphorus in runoff followed a different trend to nitrogen (Figure 15). The initial irrigation events generally produced the lowest FRP and TKP concentrations of the season (12-100 µg P/L and 64-179 µg P/L, respectively). Concentrations increased to their maximum in late January (445 µg P/L and 595 µg P/L for FRP and TKP, respectively) and then decreased as the wet season progressed. The total loss of FRP in runoff was 1.2 kg/ha (similar to the previous three seasons) and 1.9 kg/ha for TKP (half the average of the previous three seasons). The flow-weighted seasonal mean concentration for FRP and TKP was 286 µg N/L and 875 µg N/L, respectively (Table 19).

In contrast to nitrogen, the phosphorus species composition was similar between irrigation and rainfall runoff; FRP was 56% of the TP signature across all samples collected. This varied very little throughout the season, presumably due to the low and relatively consistent TSS concentrations (Figure 13).

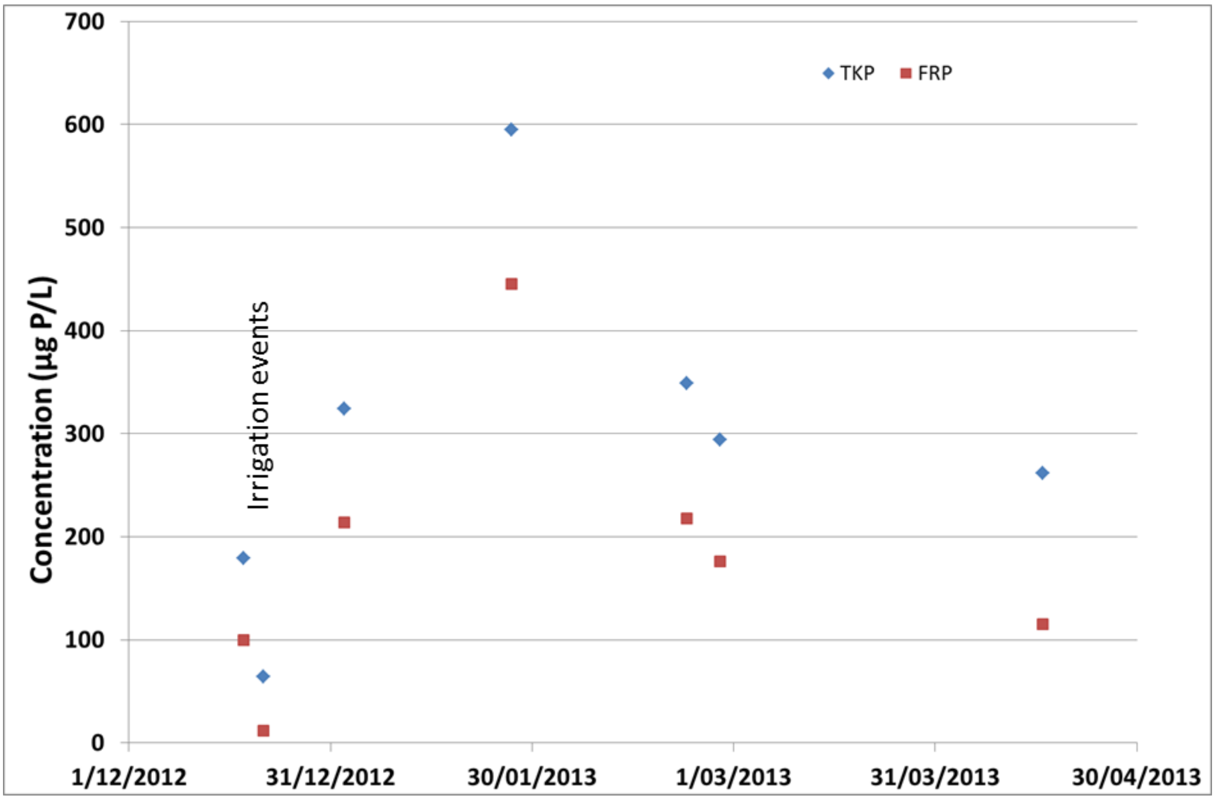

Figure 15 Concentrations of TKP and FRP runoff during the 2012/13 wet season, Multi-farm site

3.5.2.4 Ametryn

Ametryn was detected in low concentrations (0.02-0.03 µg/L) in the initial two small irrigation runoff events. Concentrations then increased to 0.49 µg/L in the initial rainfall runoff event, and then decreased to be not detected (<0.01 µg/L) in the final sampled runoff event (April 2013) (Figure 16). The total seasonal ametryn load was 0.3 g/ha (approximately 1/3 of the average of the previous three seasons), with a flow-weighted seasonal average concentration of 0.05 µg/L (Table 19). It is estimated that the first 50% of the seasonal ametryn load was delivered in the initial 5% of the seasonal runoff (Figure 17).

3.5.2.5 Atrazine

Atrazine concentrations followed a similar trend to ametryn, but were at least 10-times higher. Concentrations in the two small irrigation events were 0.29-0.78 µg/L, increasing to 8.1 µg/L in the first rainfall runoff event, and then decreased to 0.16 µg/L in the final sampled event (Figure 16). The total seasonal atrazine load was 9.1 g/ha (1.6 times the average of the previous three seasons), with a flow-weighted seasonal average concentration of 1.6 µg/L (Table 19). It is estimated that the first 50% of the seasonal atrazine load was delivered in the initial 11% of the seasonal runoff (Figure 17).

3.5.2.6 Diuron

Diuron concentrations in the initial irrigation events were relatively low (0.22-0.51 µg/L). Concentrations then increased to 7.3 µg/L in the first rainfall runoff event, and decreased throughout the season to be ~0.5 µg/L in the final three sampled events (Figure 16). The total seasonal diuron load was 12 g/ha (1.4 times higher than the average of the previous three seasons), with a flow-weighted seasonal average concentration of 2.2 µg/L (Table 19). It is estimated that the first 50% of the seasonal diuron load was delivered in the initial 15% of the seasonal runoff (Figure 17).

3.5.2.7 Hexazinone

In contrast to other herbicides, hexazinone concentrations increased throughout the season from 0.09 µg/L in the initial irrigation events to a maximum of 0.58 µg/L at the end of January. Concentrations then decreased to be 0.03 µg/L in the final two sampled events (Figure 16). The total seasonal hexazinone load was 0.9 g/ha (approximately 2/3 of the average of the previous three seasons), with a flow-weighted seasonal average concentration of 0.16 µg/L (Table 19). Approximately the first 50% of the seasonal hexazinone load was delivered in the initial 15% of the seasonal runoff (Figure 17).

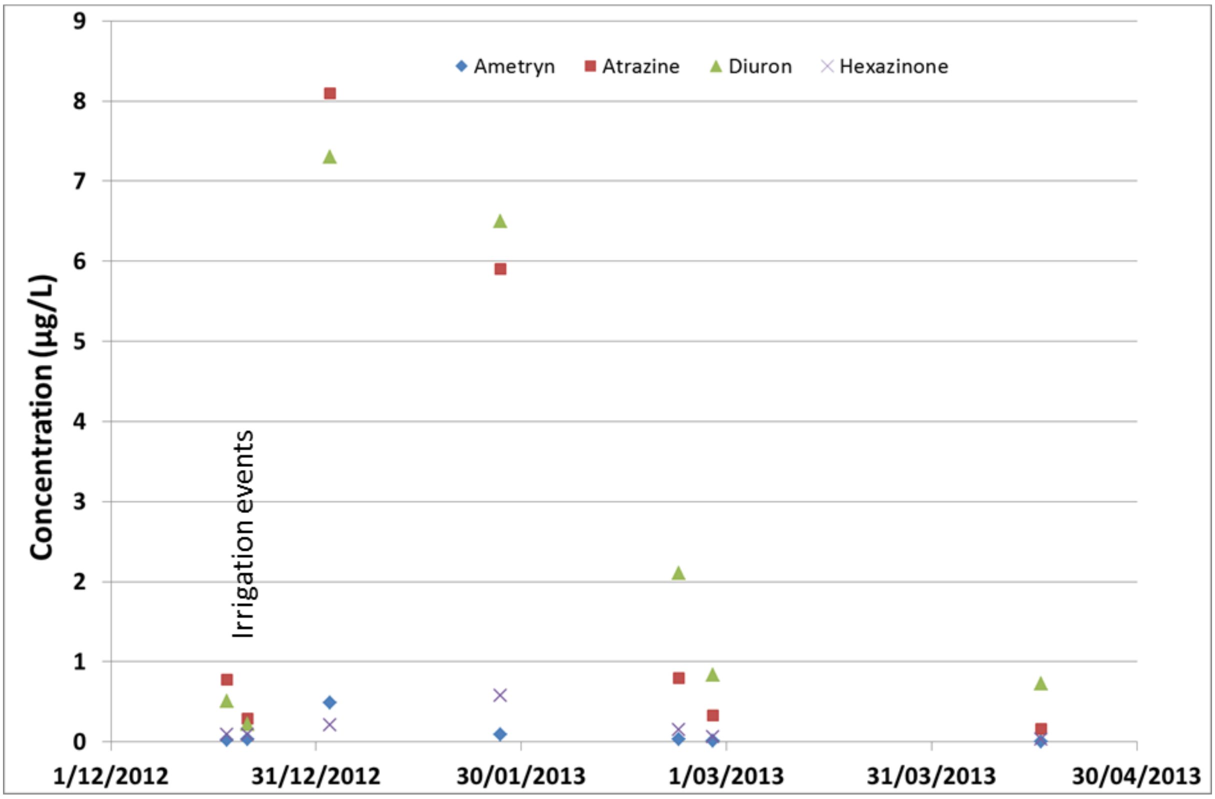

Figure 16 Concentrations of herbicides in runoff during the 2012/13 wet season, Multi-farm site

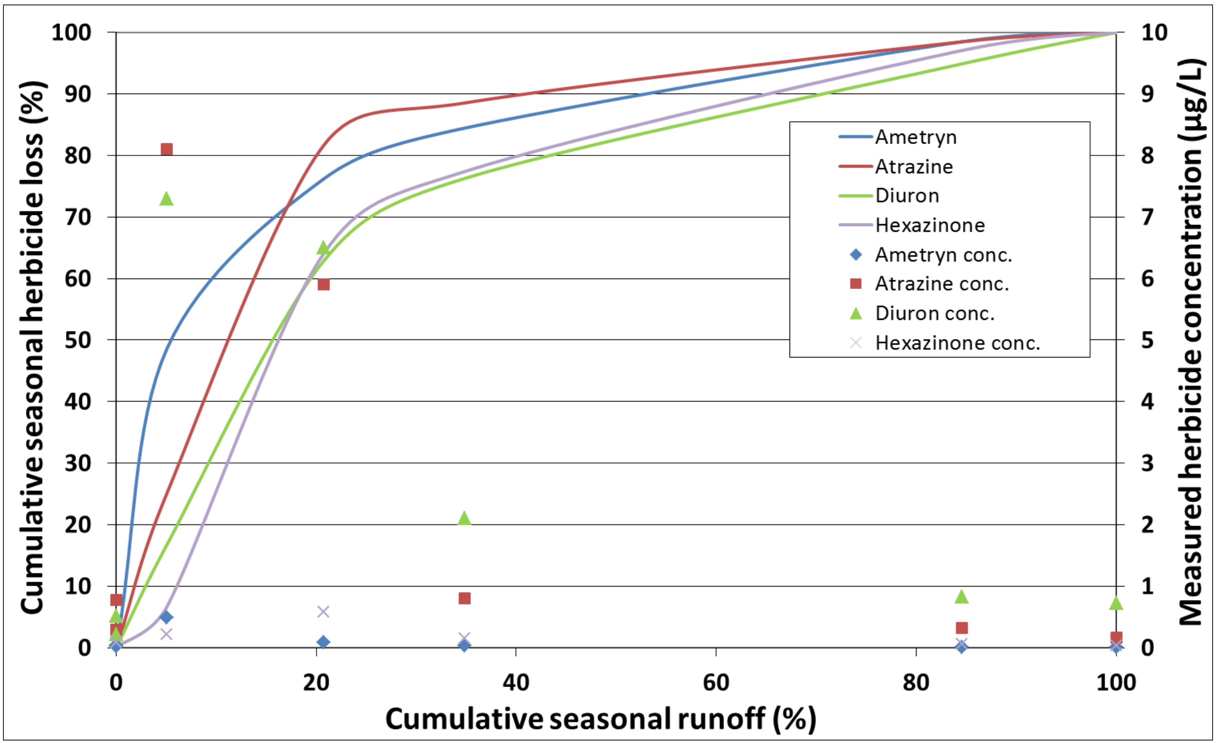

Figure 17 Cumulative seasonal runoff and herbicide loss, Multi-farm site

3.5.2.8 Other pesticides

Metolachlor was detected in all rainfall runoff events (0.02-0.32 µg/L), but was not detected in the two irrigation events (<0.01 µg/L). Isoxaflutole was detected at low concentrations in all samples (0.01-0.03 µg/L), except for the initial two rainfall runoff events (0.10-0.19 µg/L). 2,4-D followed a similar trend to hexazinone, where it was detected at the highest concentration (1.7 µg/L) in late January, decreasing to 0.18-0.23 µg/L from March onward. Imidacloprid was not detected (<0.01 µg/L) in the initial irrigation events, but was detected (0.05-0.38 µg/L) in all rainfall runoff events.

Simazine was only detected in two samples (0.02 µg/L) in January, with bromacil only detected (0.01 µg/L) in early January. Imazapic was not detected in any samples (<0.5 µg/L).

4 DISCUSSION

4.1 Effects of row spacing/wheel traffic on runoff

The results from the four treatments at the Victoria Plains site allowed a comparison of row spacing/wheel traffic effects on runoff. Treatment 2 (1.8 m row spacing, controlled traffic) had 20% less runoff than Treatment 1 (1.5 m row spacing) across the 2012/13 wet season. The additional two 1.8 m row spacing treatments (Treatments 3 and 4) also produced less runoff (17-31%) than Treatment 1. The runoff reduction from Treatment 2 is more than other seasons (14-18%; Rohde *et al.* 2013), possibly due to the slightly drier season. These results are comparable to other soil compaction and controlled traffic studies.

In a review of the environmental impacts of controlled traffic farming, water runoff was found to reduce by 27-42% when compared to runoff from random traffic farming (Gasso *et al.* 2013). Controlled traffic on a heavy clay soil in a broadacre grain production system reduced the mean annual runoff of all tillage treatments by 31% (61% for zero tillage treatments) (annual runoff ~200 mm) (Tullberg *et al.* 2001). In that study, treatment effects were greater on dry soil, but were also maintained during large and intense rainfall events on wet soil. Similarly, non-wheel traffic furrows yielded 36% less runoff than that of wheel-track furrows under conditions conducive to runoff (moist, crusted, bare soil) on a Vertosol (Silburn *et al.* 2011). Results from five years of field plot runoff monitoring on the Loess Plateau (sandy loam), China showed that no tillage with residue cover and no compaction reduced runoff by 40% when compared to the control (traditional mouldboard ploughing without residue cover) (average annual runoff 18 mm and 31 mm, respectively) (Wang *et al.* 2008). Results from a rainfall simulation study on a Marian soil in the Mackay region showed that runoff averaged 43% less from 2 m controlled traffic cane treatments compared to 1.5 m current practice treatments on dry soil, to 30% less on wetter soils (Masters *et al.* 2008, Masters *et al.* 2012). All of these studies support our findings of increased treatment differences on drier soils.

4.2 Factors affecting sediment (TSS) concentrations in runoff

The flow-weighted mean TSS concentrations measured at the Victoria Plains site this season (22-26 mg/L for Treatments 1 and 2) were similar to the mean TSS concentrations measured in the previous season (22-24 mg/L) (Rohde *et al.* 2012). Concentrations in Treatments 3 and 4 (33-36 mg/L) were higher than the original two treatments, but would still be considered low. Total soil erosion was ~0.2 t/ha (no clear treatment differences), slightly lower than the previous season due to the reduced runoff, and at least one-tenth of that measured in the 2009/10 and 2010/11 seasons (Rohde *et al.* 2013). This may be due to the green cane trash blanket for the past two seasons, compared with bare, cultivated soil in the plant cane (2009/10 season), and the reduced runoff volume (more than halved) compared to the 2010/11 season. The lack of treatment differences (and the reduction from bare, plant cane to trash blanketed ratoons) is not surprising, as the main factors found to affect soil erosion are tillage and ground cover (Prove *et al.* 1995, Connolly *et al.* 1997, Silburn and Glanville 2002).

The estimated soil erosion (~0.2 t/ha) measured from the Victoria Plains site was much lower than that historically recorded. Soil erosion rates of 42-227 t/ha/year have been recorded in the Mackay region under conventional tillage and burnt cane harvesting (Sallaway 1979). In that study, changes in the furrow profile cross-section were measured from sites with slopes of 2.5-9.2%. With the move to green cane harvesting, trash blanketing and minimum tillage, soil erosion rates have dropped to <5-15 t/ha/year (Prove *et al.* 1995). Although the soil erosion measured this season is considered low, it is still well above the rate of soil formation (0.3 m per million years; ~3-4 kg/ha) resulting from basaltic flows in semi-arid tropical Australia (Pillans 1997).

Sediment concentrations in runoff are driven by peak runoff rate, ground cover and roughness; while peak runoff is influenced by rainfall intensity, runoff depth and ground cover (Freebairn *et al.* 2009). Freebairn *et al*. (2009) report that peak discharge was the most important factor influencing sediment concentration (accounting for 41% of variation), as it best represents stream power, a measure of energy available for detachment and transport of soil in runoff. In our study at the Victoria Plains site, there was a general trend of increasing sediment concentration with increasing peak runoff rate. This trend was not evident at the Multi-farm site, possibly due to the consolidation of cultivation soil as the wet season progressed and/or the low TSS concentrations in all events (although the highest concentration was detected in one of the largest runoff events.

4.3 Factors affecting nutrients in runoff

Two main factors appeared to control nitrogen concentrations in runoff this season; the amount of product applied (fertiliser) and time between application and first runoff. Direct comparisons of nitrogen concentrations in runoff between the four monitored wet seasons are difficult due the period of time between application and runoff (influencing the nitrogen species in runoff) and the different products (formulations being used).

At the Victoria Plains site, nitrogen in the flood irrigation event (Treatment 2 only; 12 days after nutrient application) contained NO_x-N concentrations higher than any other sample collected for the season (first rainfall runoff 39 days after nutrient application). Concentrations tended to decline as the wet season progressed and as the supply of nitrogen decreased. The total wet season loss of NO_x-N and urea-N (mainly sourced from applied fertiliser) in the runoff was relatively consistent between treatments and represented 0.7-1.0% of the applied nitrogen to each treatment. This was similar to the previous season when runoff first occurred 75 days after application, but is an order of magnitude lower than the 2010/11 season when runoff occurred with 10 days of application. At the Multi-farm site, the seasonal NO_x-N concentrations were similar to previous seasons, but the load in runoff was lower (due to less runoff).

These relatively low concentrations of dissolved nitrogen are encouraging for riverine and marine water quality. Elevated concentrations of urea-N have been shown to be a preferred form of nitrogenous nutrients for many phytoplankton, including some dinoflagellates which form harmful algal blooms (Glibert *et al.* 2005).

Concentrations of FRP in runoff from the Victoria Plains site this season (flow-weighted mean 63-129 µg P/L) were higher than previous years (overall seasonal flow-weighted range 31-77 µg P/L). This is thought to be due to the period of time between application and runoff: 39 days this season, 75 days in 2011/12, but three days in 2010/11 (seasonal mean concentration may have been low due to the exhaustion of P from excessive runoff). As a result of the higher concentrations, FRP loads (0.4-1.0 kg/ha) were also generally higher than previous years, except for 2010/11 when high runoff resulted in higher loads (1.2-1.3 kg/ha).

At the Multi-farm site, the seasonal flow-weighted NO_x-N concentration (286 µg N/L) was similar to 2009/10 and 2011/12, but lower than 2010/11 (Rohde *et al.* 2013). As a result of the lower runoff, the load this season (1.6 kg/ha) was lower than previous seasons (1.8-2.2 kg/ha). The load of FRP (1.2 kg/ha) was similar to previous seasons, but the flow-weighted mean concentration was much higher (217 µg P/L, compared to 95-172 µg P/L for the previous three seasons).

4.3.1 Nutrient ratios (N:P)

One of the more significant references to ecological stoichiometry is the ratio of carbon to nitrogen to phosphorus, termed the Redfield Ratio (Redfield 1958). Redfield showed that the elemental ratio of C_{106}:N_{16}:P_1 for marine particulate and dissolved matter was consistent. This suggested a dynamic equilibrium between C, N and P in and out of the biota in a marine environment. A significant amount of literature supports this ecological ratio (Annika *et al.* 2007, Harris 2001, Trott and Alongi 1999) or presents slight modifications.

A number of riverine studies focus on the N and P ratio, with deviations from the classic N_{16}:P_1 determining whether N or P is limiting or in excess. In standing waters, these fluctuations can often discern a biological explanation. For example, where the ratio exceeds 16:1, green alga or chlorophytes may dominate. Conversely, where the ratio is much lower than 16:1, blue-green algae or cyanophytes may dominate (Lapointe *et al.* 2004). It must be stressed that many other factors lead to substantial deviations from the classic Redfield Ratio, so simplistic interpretation must be undertaken with caution, especially when not considering carbon in the assessment (as in this study).

When assessing the total seasonal runoff losses this season of N and P (whether total or dissolved), the N:P ratio at all sites was <10 indicating excess P (or limited N). Although not previously reported, this is similar to previous years except for the Victoria Plains site in 2009/10 when DIN:FRP was >20, indicating excessive DIN. This was due to the high soil nitrate concentrations due to the previous legume crop and additional nitrogen applied (Rohde and Bush 2011). As previously reported, the Marian site had high FRP concentrations in runoff due to the high background soil P concentrations (Rohde *et al.* 2013). Across all of the runoff samples collected from that site, the average DIN:FRP was 1.2 (maximum 19) indicating excessive P.

4.4 Factors affecting herbicides in runoff

Timing of rainfall after herbicide application (and the amount of product applied) in this study greatly influenced the concentrations of herbicides detected in runoff water. Concentrations for a range of chemicals were lower the longer the period between application and runoff. At the Victoria Plains site, the first rainfall runoff event occurred 63 days after herbicide application, compared to 128 days the previous season.

The total diuron loss for the season from blanket application (Treatments 1 and 3) was 13 g/ha, representing a seasonal loss of 0.7% of the applied diuron. These losses were higher than the previous season (<0.2%). Imazapic, applied at a much lower application rate than diuron, was generally not detected in runoff. These losses are still considered low, as single event runoff losses in the range of 1-2% are not uncommon, however losses greater than this are generally considered only to occur as a result of extreme environmental conditions (Wauchope 1978). Wauchope's (1978) study defined runoff events as "critical" if they occurred within a two week period of application and had a runoff volume which was 50% or more of the rainfall.

Runoff losses from the 33% banded treatment (Treatment 4; 5.7 g/ha) were lower than the treatments where it was blanket applied, but the proportion lost (1%) was higher. It is interesting to note that the runoff loss was halved, but the herbicide was only applied to approximately 1/3 of the plot (the row area). Other work has similarly shown that reduced rates of application results in reduced loss in runoff. In rainfall runoff from a hill-furrow layout on a cracking clay, banded spraying (~40% band) reduced rainfall runoff concentrations (cf. blanket) of diuron by 54% and losses by 50% (Silburn *et al.* 2011). In a rainfall simulation experiment on a duplex soil, banded spraying (50% band) reduced runoff concentrations (cf. blanket) one day after application by 54% and losses by 38% (Masters *et al.* 2012). In a flood irrigation study in the Burdekin basin, two moderately soluble herbicides (atrazine and diuron) were applied as a broadcast or banded application (to raised beds only; less than 60% of the total area) to a sugar cane system. The average total load of both herbicides moving off-site decreased by >90% when it was banded on the raised beds only (compared to the broadcast application) (Oliver *et al.* 2014). Therefore, while previous studies have shown the water quality benefits of banded spraying are proportional to the reduction in area sprayed, a smaller reduction was observed in the current study.

5 CONCLUSIONS

Farm management practices for reducing off-site environmental impacts of sugarcane farming were evaluated on a Vertosol in the Mackay Whitsunday region. Controlled traffic (matching machinery wheel spacing to crop row width) reduced runoff by 20% when compared to mis-matched spacings. Due to the high ground cover provided by the green cane trash blanket, soil erosion rates were low and consistent between treatments (~0.2 t/ha). These findings are consistent with previous seasons.

Nitrogen concentrations in runoff were driven by the application rate of fertiliser, and the period between application and first runoff. Dissolved concentrations in the initial runoff events were the highest, and then declined through the season as the nutrient supply was exhausted. Runoff losses this season (NO_x-N and urea-N; mainly sourced from applied fertiliser) were relatively consistent between treatments and represented 0.7-1.0% of the applied nitrogen to each treatment. This is similar to the previous season when runoff first occurred 75 days after application (39 days this season), but is an order of magnitude lower than the 2010/11 season when runoff occurred within 10 days of application.

Similar to nutrients, the loss of herbicides in runoff is also driven by the timing of rainfall after herbicide application and the amount of product applied. Where herbicides (e.g. diuron) were applied as a blanket application, losses were 0.7% of the applied product (first runoff 63 days after application). These losses are higher than the previous season (<0.2%) when runoff first occurred 128 days after application. Imazapic (applied at a much lower application rate than diuron) was generally not detected in runoff. Where herbicides were banded (33% band on the hill), runoff losses of diuron were half those of the blanket applied treatments (this season only). These results show that the most effective practice to reduce herbicide losses will be to allow time for the herbicides to dissipate before runoff occurs (through timing applications early in the season, or infiltrating rainfall), but additional benefits can be gained from banding.

At both sites, row spacing had little impact on cane yield, and applying higher rates of nitrogen (above Six Easy Steps) had no impact on cane yield. At the Marian site, the lower rate of nitrogen applied to the N replacement treatment (56% less than Six Easy Steps) reduced cane yield by 30%, and the skip row treatment yielded 73% of the solid plant, despite only 56% of the area planted to cane.

In summary, results from the 2012/13 season showed similar trends between treatments as those observed in previous seasons. Controlled traffic can reduce runoff, higher rates of nitrogen application lead to higher runoff losses, banded spraying will reduce herbicide losses in runoff, but maximizing the time between application of nutrients and herbicides and first runoff will further reduce runoff losses. All of these practices have shown little/no impact on crop productivity.

5.1 Future monitoring

Subject to funding for a further three years, it is proposed that monitoring be continued at the existing monitoring sites (Multi-farm and Victoria Plains). Continued monitoring of water quality at the Multi-farm site and management practice adoption within the catchment over the coming seasons would aim to identify improved water quality with increased adoption of improved management within the catchment. Monitoring over the coming three wet seasons at the Victoria Plains site will capture additional data from the site, specifically:

- 2013/14 season – continue the existing treatments (4th ratoon) to gain another year of data, particularly from the blanket vs. banded herbicide treatments
- 2014/15 season – fallow using various tillage and legume combinations to gain a broad range in ground cover, soil structure and soil nutrient status
- 2015/16 season – plant cane phase, with treatments consisting of row spacing, nutrients rates and herbicide rates/products.

These monitoring sites add value to other components of the P2R program, and well as other regional projects. The sites are within the Sandy Creek catchment, and an end of catchment loads monitoring site is located downstream. It is also envisaged that a marine monitoring site within the P2R Marine Monitoring Program will be located offshore from this catchment so that water quality will be measured at relevant scales in a fully nested approach. Other complimentary monitoring within the Sandy Creek catchment includes water quality monitoring of a wetland (within the Multi-farm catchment), and the existing paddock site is also used as part of an Action on the Ground Carbon Farming Initiative research project where nitrogen gas emissions are monitored.

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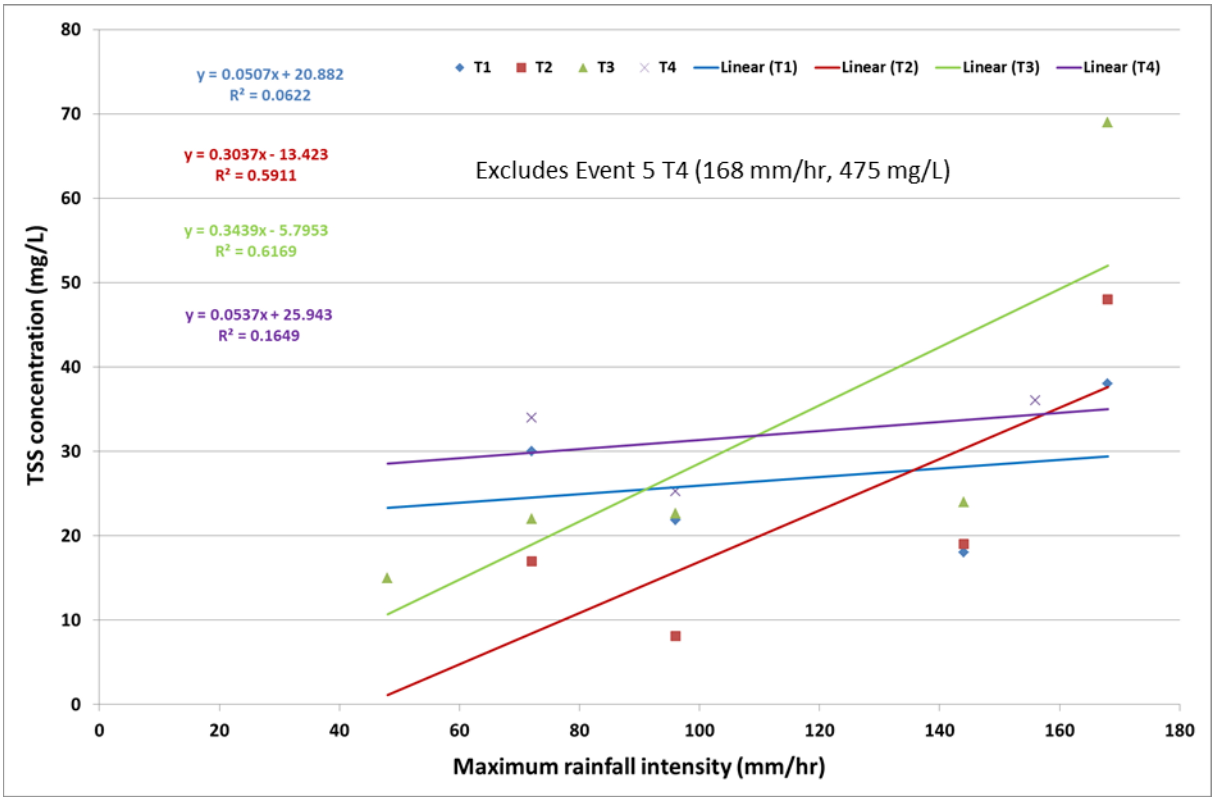
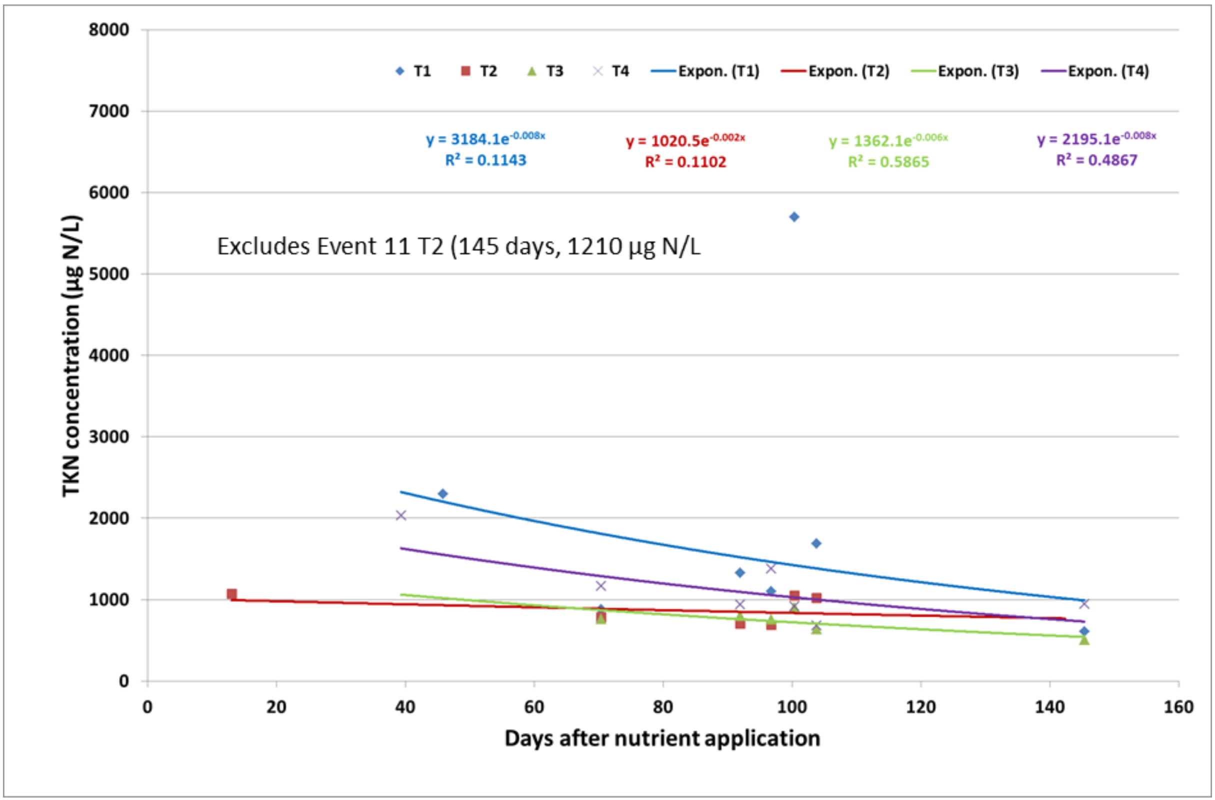
7 APPENDICES

7.1 Regression plots used to estimate concentrations for runoff load calculations, Victoria Plains site

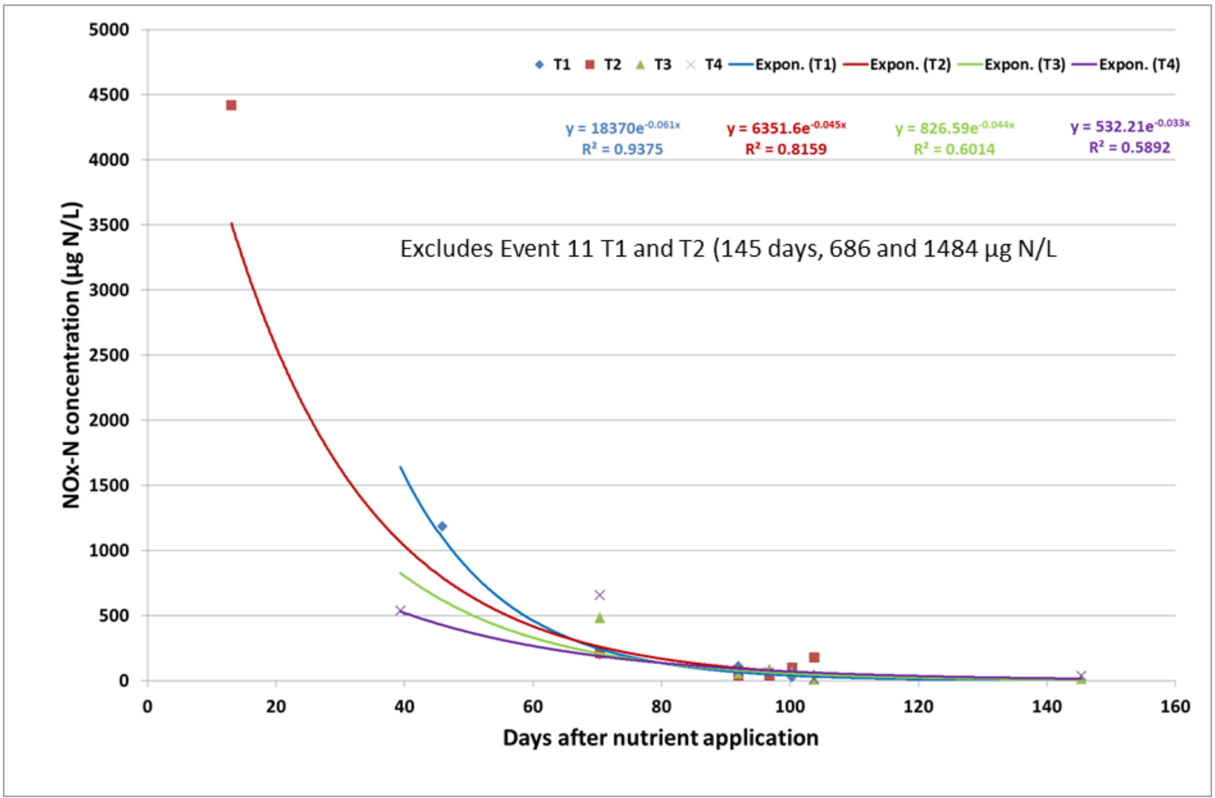
7.1.1 Total suspended solids



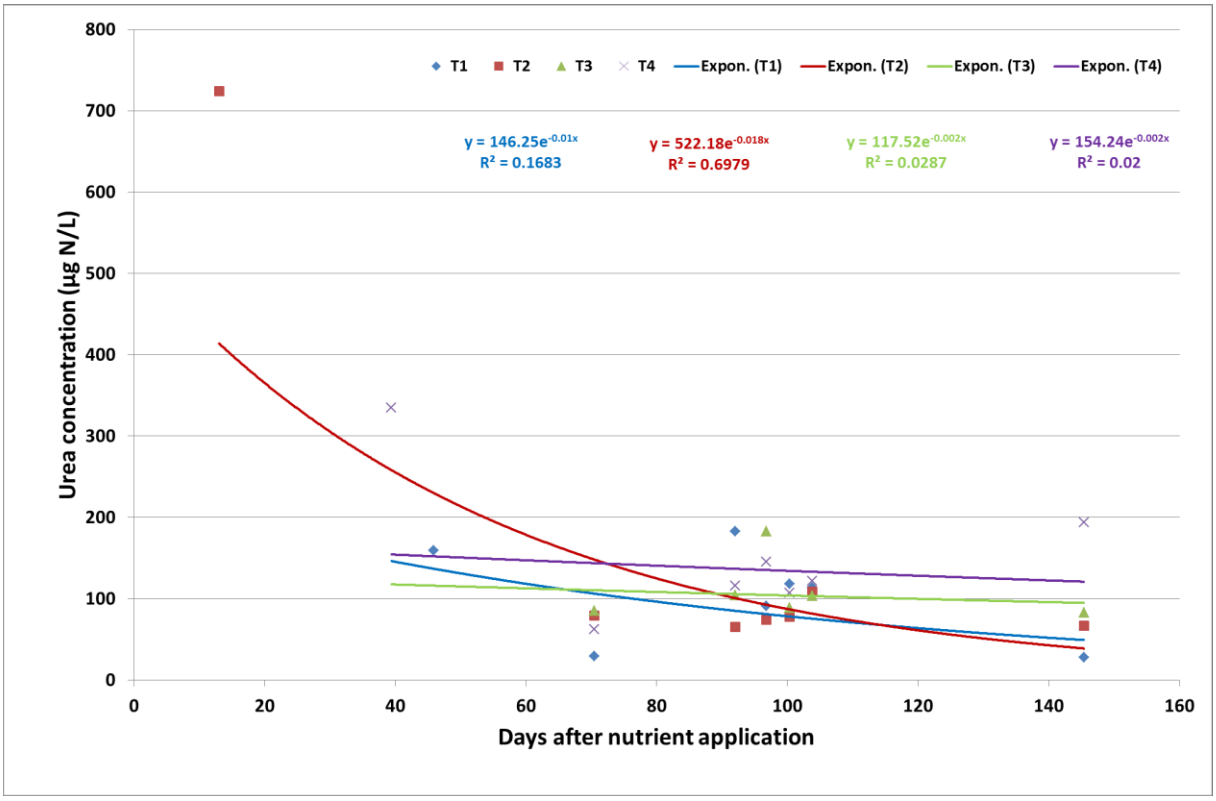
7.1.2 Total Kjeldahl nitrogen



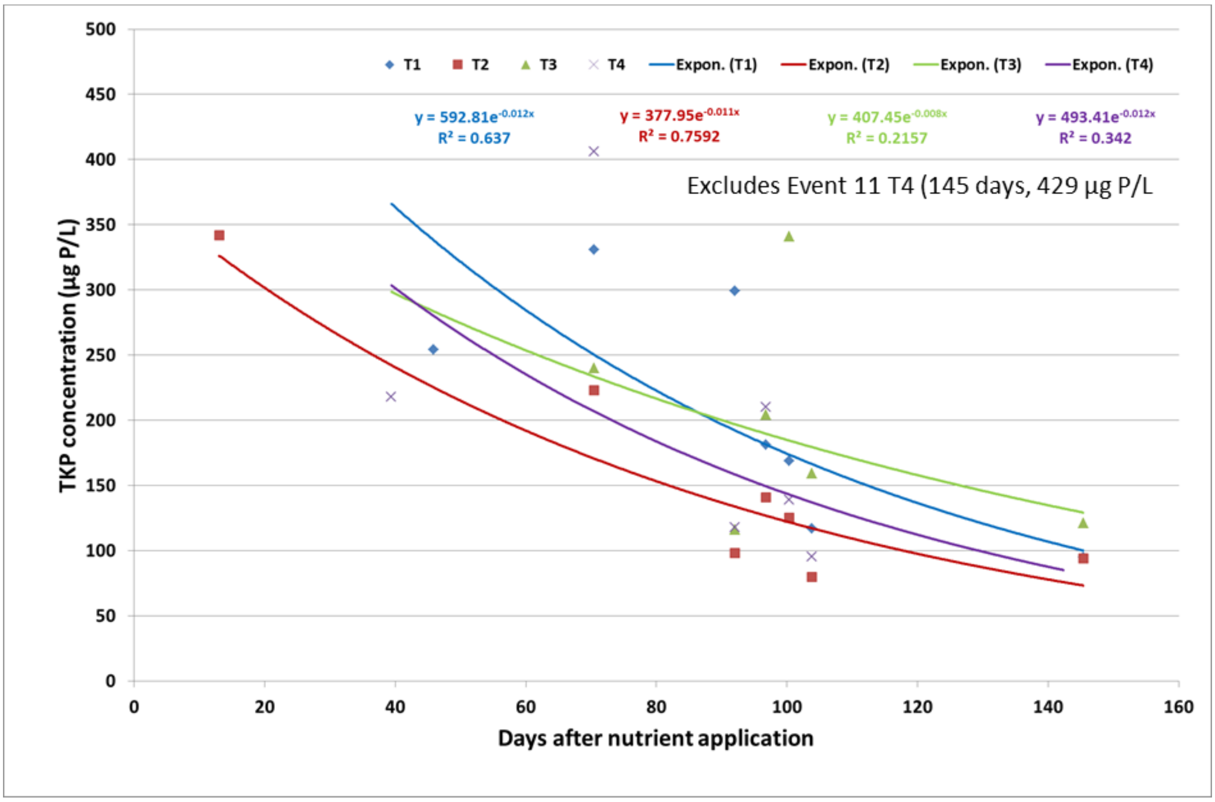
7.1.3 NO_x-N



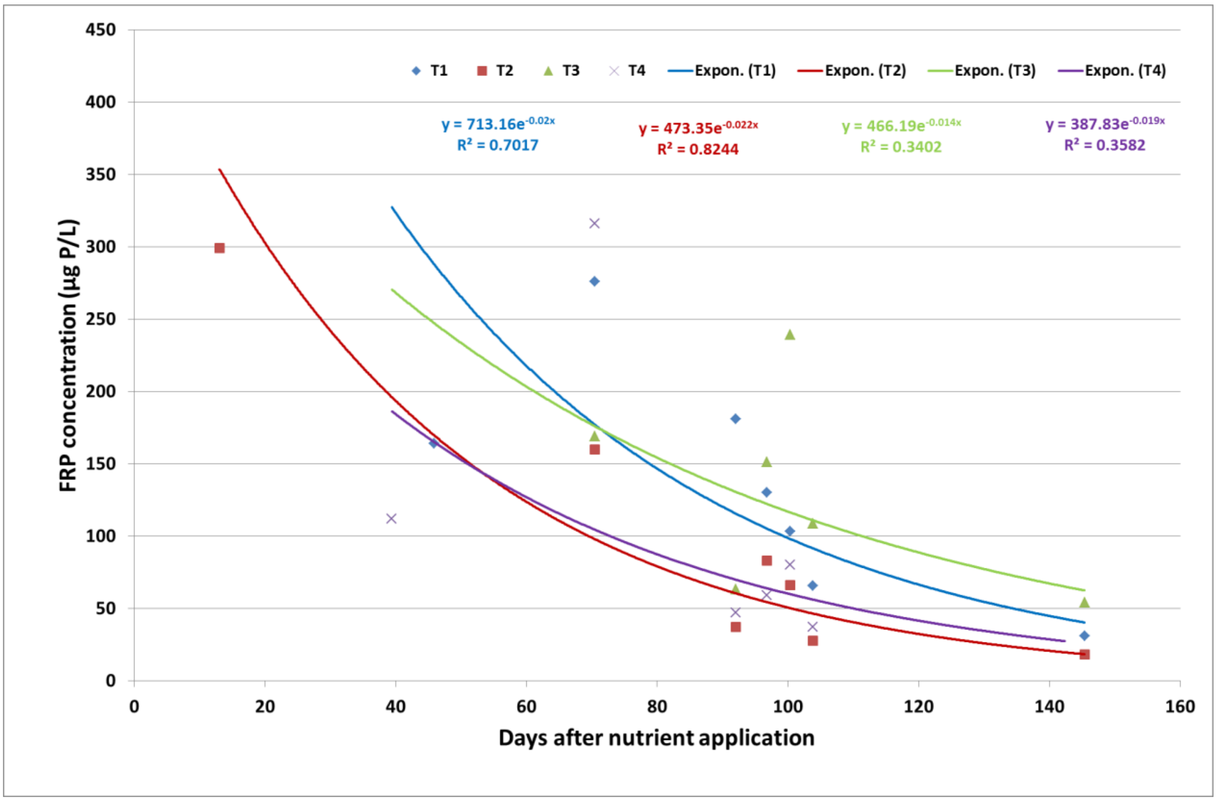
7.1.4 Urea-N



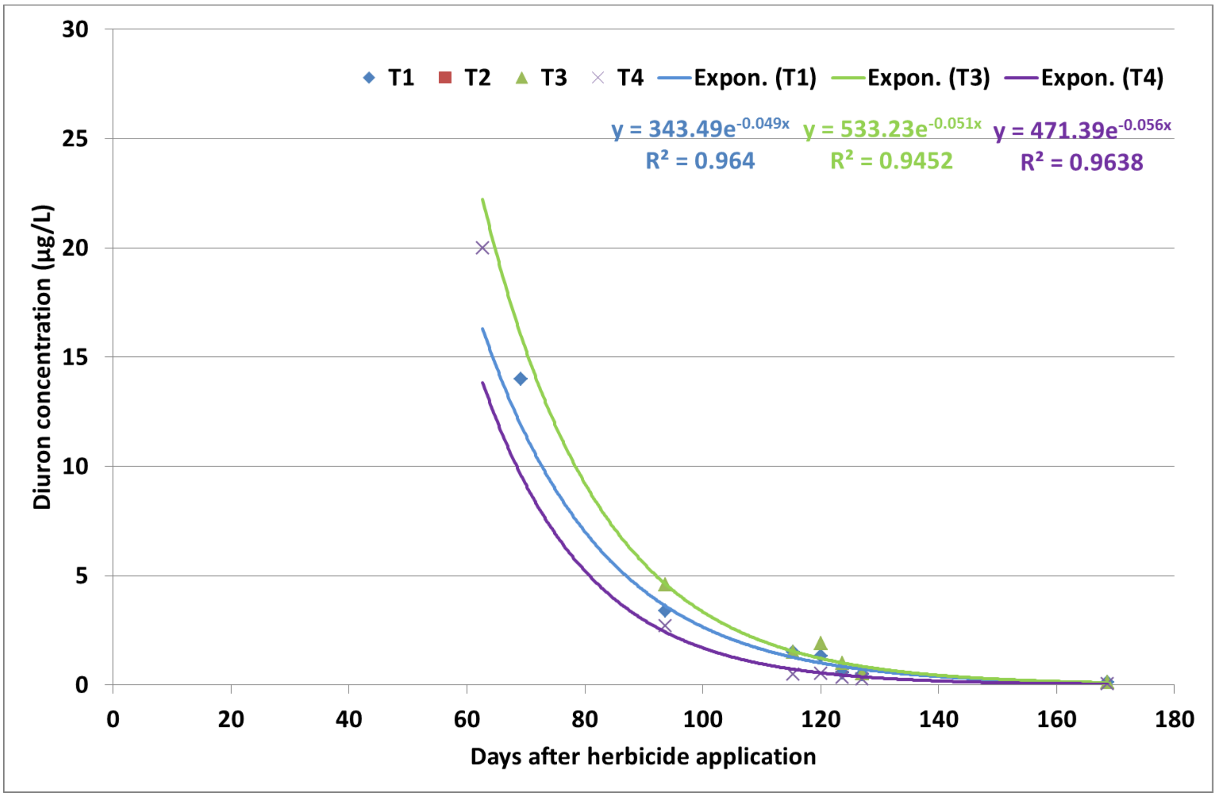
7.1.5 Total Kjeldahl phosphorus



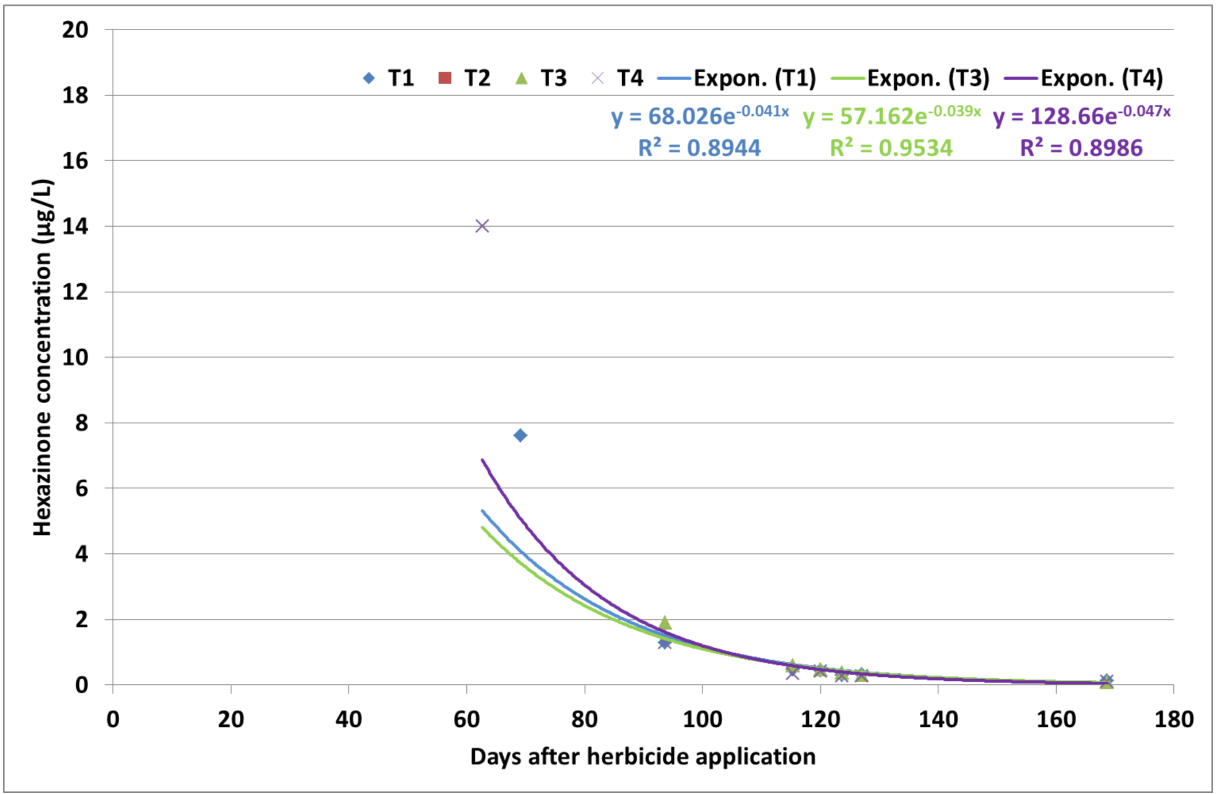
7.1.6 Filterable reactive phosphorus



7.1.7 Diuron



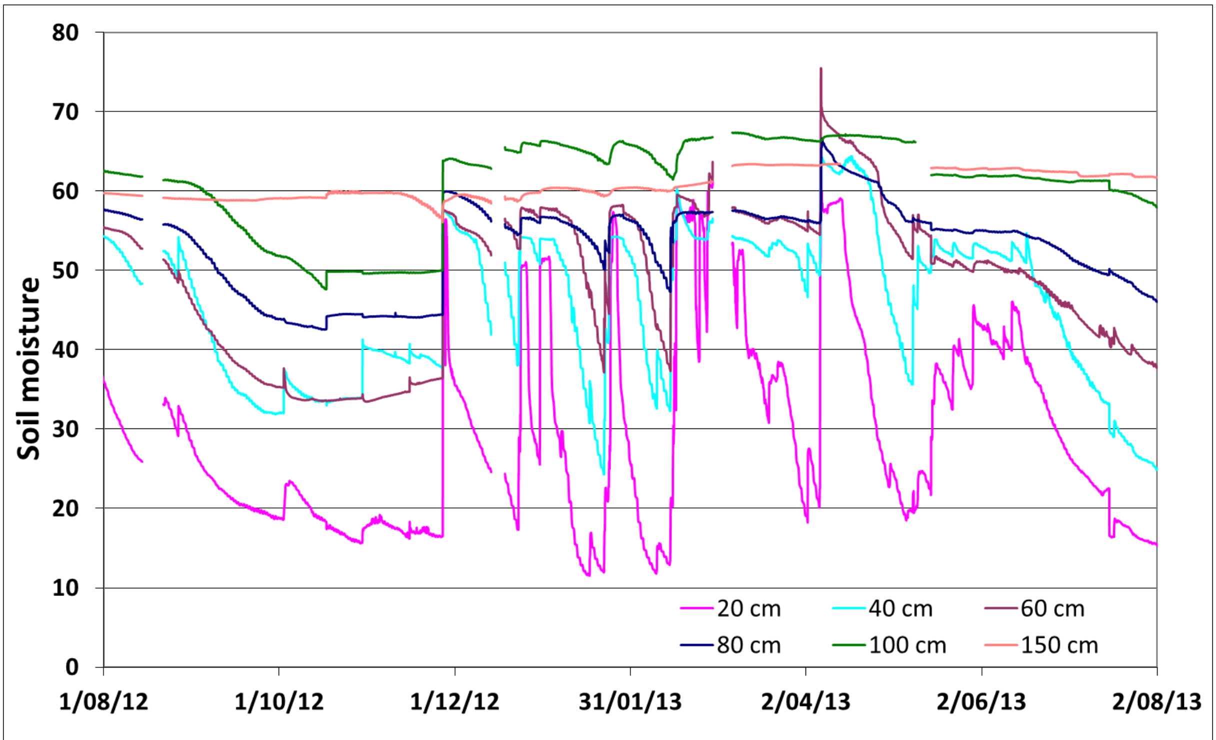
7.1.8 Hexazinone



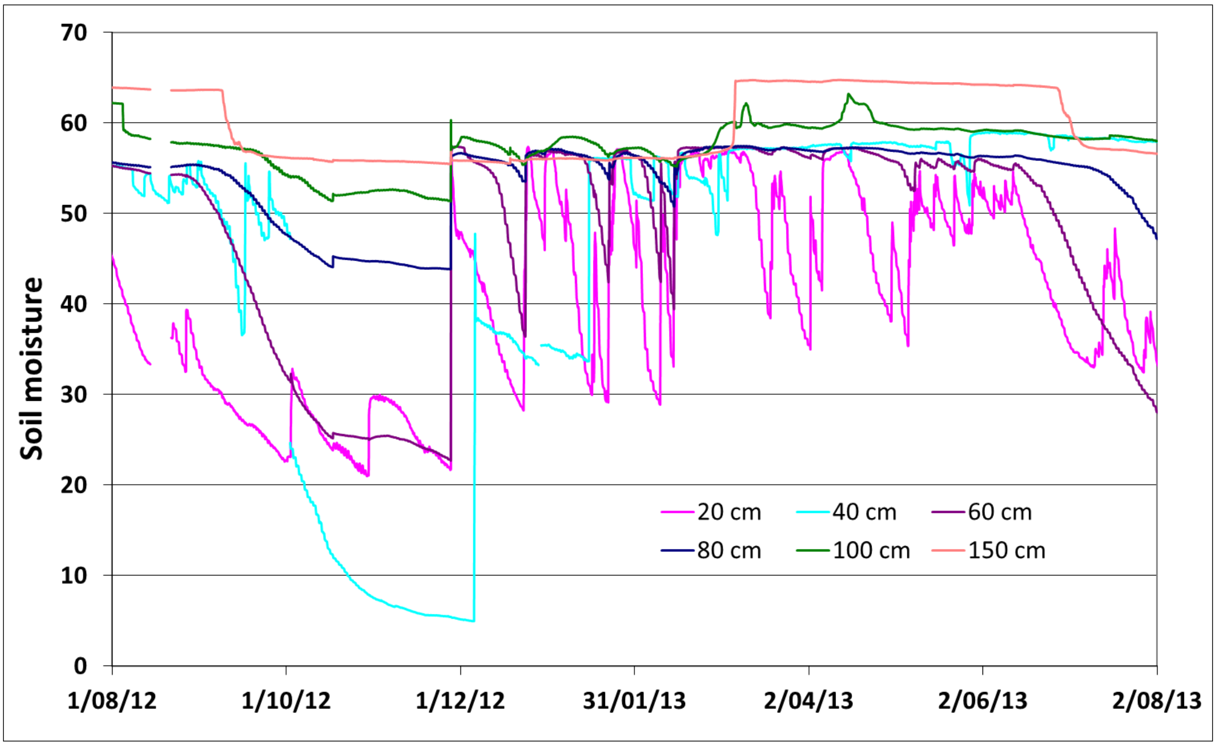
7.2 Soil moisture plots

Soil moisture shown in the plots below are an uncalibrated volumetric water content (no units)

7.2.1 Victoria Plains Treatment 1



7.2.2 Victoria Plains Treatment 2



7.3 Rainfall intensity-frequency-duration graph

Extracted from http://www.bom.gov.au/water/designRainfalls/ifd/index.shtml in May 2013.