

Reef Rescue Research & Development

Technical Report

Minimising off-farm movement of nitrogen in the north Queensland banana industry *RRRD049*



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Minimising off-farm movement of nitrogen in the north Queensland banana industry (Project RRRD049)

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Acronyms and abbreviations

ABGC	Australian Banana Growers' Council Inc.
ANOVA	Analysis of variance
BMP	Best Management Practice
BoM	Bureau of Meteorology
CR	Controlled release (fertiliser)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAFF	Queensland Department of Agriculture, Fisheries and Forestry
DNRM	Queensland Department of Natural Resources and Mines
DSITIA	Queensland Department of Science, Information Technology, Innovation & the Arts
DW	Dry weight
ESP	EcoSciences Precinct (41 Boggo Road, Annerley, Qld.)
FW	Fresh weight
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
NATA	National Association of Testing Authorities
P2R	Paddock to Reef Integrated Monitoring, Modelling and Reporting Program
RRRC	Reef and Rainforest Research Centre Limited
RRRD	Reef Rescue Research & Development
SJ	South Johnstone
SJRS	South Johnstone Research Station

Nutrients in soils

NH₄-N	Ammonium-nitrogen or ammonium-N
NO₃-N	Nitrate-nitrogen or nitrate-N

Nutrients in waters

NH₄-N	Ammonium-nitrogen or ammonium-N
NO_x-N	Oxidised nitrogen, includes nitrate-N and nitrite-N
Urea-N	Urea-nitrogen
FRP	Filterable reactive phosphate (measures mainly phosphate)
DON	Dissolved organic nitrogen
DOP	Dissolved organic phosphorus
PN	Particulate nitrogen
PO₄-P	Phosphate
PP	Particulate phosphorus
TN	Total nitrogen
TP	Total phosphorus

Units

g/mL	grams per millilitre
g a.i./ha	grams of active ingredient per hectare
kg/ha	kilograms per hectare
kg N/ha	kilograms of nitrogen per hectare
kg P/ha	kilograms of phosphorus per hectare
L/ha	litres per hectare
mg/L	milligrams per litre
mm	millimetres
m³	cubic metres
µg/L	micrograms per litre

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Executive Summary

Background

Loss of nitrogen (N) fertiliser off-farm is considered to be a serious threat to reef water quality. In addition to surface water runoff, deep drainage or leaching of N through the soil profile is an important loss pathway.

Approximately 90 per cent of the Australian banana industry is located on Queensland's wet tropical coast bordering the Great Barrier Reef. The average industry N application rates have decreased since the mid-1990s by as much as 40 per cent and as a result a substantial reduction in N loss in deep drainage has been measured. Controlled release (CR) fertilisers have been considered the next step in improving nutrient management as the release of N may be better aligned with plant demand. However, there is an increasing range of CR products available with different methods of controlling the rate of release of N, and the impact on N in plant uptake and deep drainage has not been previously qualified.

The objective of this trial was to determine the effect of controlled release fertiliser products on N loss rates in deep drainage and plant performance in the north Queensland banana industry. The study commenced in 2011 at the South Johnstone Research Station (SJRS), and evaluated the fertilisers: 1) urea (an industry standard), 2) porous bags containing a commercial blend of NPK fertiliser and 0.4 percent humic acid, 3) Novatec liquid (nitrification inhibitor, BASF), 4) Multicote (polymer coated urea, Haifa) and 5) CoRoN (polymethylene urea, Barmac).

The project monitored loss of N in deep drainage, soil fertility and crop performance in a plant crop and first ratoon.

Key findings

Deep drainage

There were high concentrations of nitrate-N in deep drainage during the first few months of monitoring. This is consistent with high concentrations of mineral N in the soil at planting (refer to Soil nitrogen below). By February 2012 when bunches were emerging, concentrations had decreased to generally low concentrations, where they remained until the harvest of the plant crop. Loads of N in deep drainage were 23-48 kg N/ha for the plant crop with little difference evident between the different forms of fertiliser and rates of N applied. Loads of N in deep drainage were much lower in the ratoon crop. This is consistent with lower soil nitrate concentrations at the start of the ratoon crop cycle and a mature root system capable of taking up more N. N losses were ~1 kg N/ha.

Soil nitrogen

There were high concentrations of nitrate-N and ammonium-N in the soil profile at planting as a result of soil disturbance during cultivation. The load of soil mineral N in the surface 0.6 m was 165 kg N/ha. Similar high mineral N loads at planting have been reported previously. At harvest of the plant crop 9 months later, concentrations were low in the urea treatment, reflecting loss from the soil in plant uptake, deep drainage and possibly denitrification. The high load at planting has masked differences in rates of N loss in deep drainage from the N fertiliser treatments during the plant crop.

Plant performance

In both the plant and the first ratoon crops, there were no significant differences in the plant parameters measured, notably bunch yield and height of the following sucker. This lack of difference was partly by design as we sought to investigate differences in losses of N in deep drainage from the treatments when plant growth was not limited by nutrient supply.

Leaf nitrogen

There were no differences among treatments in leaf N concentrations following intensive monitoring of the plant and ratoon crops. All leaf N concentrations were within the optimal range. Thus all the N fertiliser treatments have provided an adequate supply of N to the plant.

Benefits and application

- Low rates of N loss in deep drainage are encouraging, demonstrating that moderate N fertiliser targets (150 kg N/ha for plant crop and 250 kg N/ha for ratoons) are an important component of efficient N management.
- Although there is no evidence of a benefit from controlled release fertilisers in reducing loss of N in deep drainage, these fertilisers may have other benefits. These would include the ability to ensure the crop is receiving adequate nutrients during the extended wet season when standard forms/methods of fertilising such as fertigated urea treatment or broadcast fertiliser can be very difficult to apply on most plantations. In contrast, controlled release fertilisers can be conveniently applied prior to the commencement of the wet season.
- There is a need to consider the high loads of readily available mineral N from ground preparation before planting to manage N losses. Incitec Pivot Ltd. have indicated a desire to incorporate this result into routine N fertiliser recommendations.
- The release of mineral N by cultivation for planting may provide more N than can be used by the crop. The use of permanent bed systems, with only a fraction of the paddock cultivated, should reduce the loss of N to the environment. Currently permanent bed systems account for less than 10 per cent of the overall area under bananas in north Queensland.

Future directions

- Monitoring of deep drainage in another ratoon crop is desirable before making any conclusive recommendations about current fertilising strategies. In the plant crop, differences in the performance of the fertilisers were masked by the large amount of available nitrogen in the soil at planting. Rain during the first ratoon was comparatively low (approximately 67 per cent of the average).
- On-farm use of controlled release N fertilisers requires development. It is desirable to determine how they fit in with normal fertiliser practices, including paired comparisons with a grower's standard practices for demonstration purposes.
- There are opportunities for development and extension of previous work on strategies (N target/integrated nutrition management) as well as demonstration of previous phosphorus studies which can be adopted by industry.
- Supplementary to this development and extension is the further development and release of Bananaman[®] decision support software to help banana growers improve the management of crop nutrition.

- The total N pool in the soil was very large, with more than 11 tonnes of N in the top 0.6 m measured at the commencement of this trial. A better understanding of what factors affect its release may improve management of soil N and minimise losses to the environment.
- Controlled release N fertilisers also have the potential to reduce losses of nitrous oxide, which is a major greenhouse gas. This requires quantification from the perspective of both greenhouse gas emissions and efficient N management.

Introduction

Bananas are the second most important intensive crop, after sugarcane, grown in the Wet Tropics with a crop area of 11,000 ha and a total value of production of \$347 million (ABGC pers. comm.). This is approximately 90 percent of the Australian banana industry and is located on Queensland's wet tropical coast bordering the Great Barrier Reef. Off-farm loss of nitrogen (N) fertiliser is considered to be a serious threat to reef water quality. In addition to surface water runoff, leaching of N through the soil profile has been considered an important loss pathway (Rasiah *et al.* 2012).

Average industry N application rates have decreased by as much as 40%, from 520 kg N/ha/year in 1995 to 315 kg N/ha/year in 2010. High rates of N loss in deep drainage have been measured when high rates of N fertiliser (400-600 kg N/ha/crop) are applied (Armour *et al.*, 2012). However, by matching N fertiliser application rates to plant crop demand N loss in deep drainage has been substantially reduced (Armour *et al.*, 2013). Despite this improvement there is still further need to reduce losses whilst maintaining crop performance in the industry. Controlled released (CR) fertilisers have been considered the next step in improving nutrient management if the release of N can be further aligned with plant demand.

Controlled release N sources have been available commercially for some time now, but their cost has always been prohibitive. However, this could change if sufficient quantity was used with associated economies of scale, or if severe restrictions on use of soluble nutrients were imposed to protect aquatic ecosystems. In addition, there is an increasing range of CR products available with different methods of controlling the rate of release of N. They have the potential to reduce leaching of N, if the rate of release is better aligned with plant demand.

Project objectives

The objective of this trial was to determine the effect of controlled release fertiliser products on nitrogen loss rates in deep drainage and plant performance in the north Queensland banana industry. The study commenced in 2011 at the South Johnstone Research Station (SJRS), and evaluated the fertilisers: 1) urea (an industry standard); 2) porous bags; 3) Novatec liquid (nitrification inhibitor, BASF); 4) Multicote (polymer coated urea, Haifa); and 5) CoRoN (polymethylene urea, Barmac).

We monitored loss of N in deep drainage, soil fertility and crop performance in a plant crop and first ratoon.

Methods

Study area

The site is located at South Johnstone approximately 14 km south of Innisfail (Figure 1). The site is located at coordinates 17.607° S, 145.997° E. The soil is a Haplic, Dystrophic Brown, Dermosol (Australian Soil Classification, Isbell, 1996) and locally described as an Innisfail series (Murtha et al., 1996). This soil is representative of 18% of the banana land use area in the Johnstone catchment. Average annual rainfall is 3303 mm/year (BoM weather station No. 032037 is located at South Johnstone Research Station).

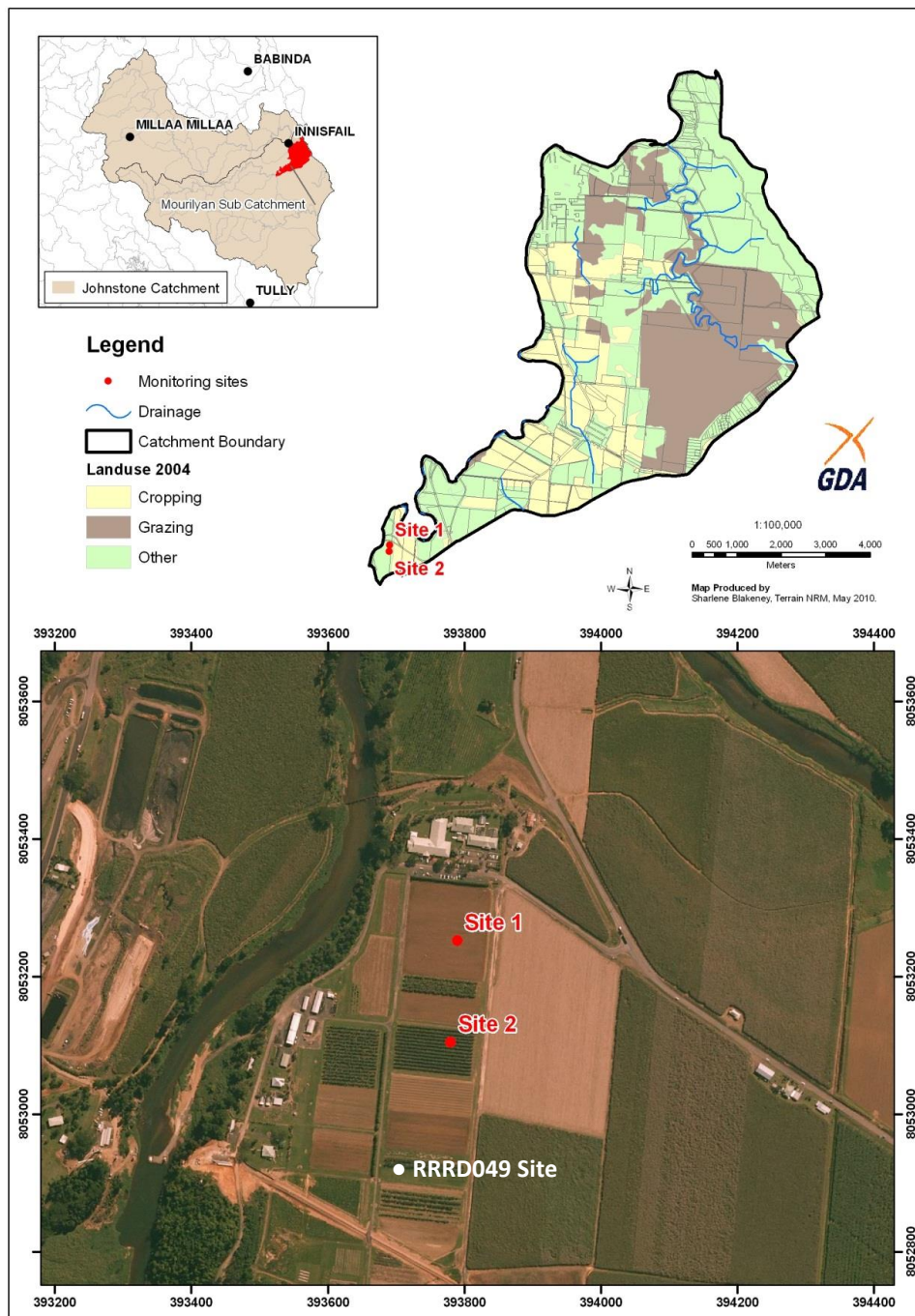


Figure 1. Location of RRRD049 monitoring site in the Johnstone catchment

Note: red sites indicate P2R paddock monitoring plots.

The SJRS block on which the site is located had previously been cropped to tea and more recently an unfertilised grass pasture that was regularly slashed. The block was prepared for planting by discing, deep ripping, lime broadcasting, discing, rotary hoeing and finally mounding by opening two furrows. 'Williams Cavendish' bananas were bagged on 30/05/2011 in an Innisfail series soil from the Research Station and grown in greenhouse/glasshouse until ready for field planting. Fifteen lysimeters were installed on 23/08/2011, the week before the suckers were hand-planted (29-30/08/2011). Bagged suckers were planted in a double row formation at a spacing of 6.5 m x 1.5 m x 1.8 m to give approximately 1709 plants/ha. The site was irrigated by under-plant mini-sprinklers (at 3 m spacing) and irrigation inflows are estimated from farm management records. During the three weeks following planting, suckers were irrigated for 2 hours every second day, as required. Once established, approximately one 5 hour irrigation application per week was required in the cooler months, and 2-3 applications per week in the warmer months. Two EnviroSCAN[®] tubes were installed in two adjacent rows in order to monitor soil moisture content over time. The inter-row was slashed and mounds were spot-sprayed with glufosinate (Basta), as required, to keep grass and other competition species low. Other pesticide treatments were applied as required to ensure adequate pest control was maintained. Farm pest-management practices included mancozeb and oil at 14 day intervals for leaf spot control and bunch covering with inclusion of SuSCon ribbons (a.i. chlorpyrifos) for control of rust thrips.

Nutrient treatments

This experimental design was a randomised complete block with eight treatments and three replications (24 plots). Treatments are four slow release nitrogen fertiliser products (possible 'A Class' practice) of varying rates, compared with current best management practice of urea fertigated fortnightly ('B' practice; Table 1). The lower rates for the slow release treatments (Treatments 3, 5 and 7) were chosen in conjunction with advice from the suppliers to ensure that production would not be limited. A complete summary of total nutrient application rates for each treatment and crop cycle are detailed in Table 2.

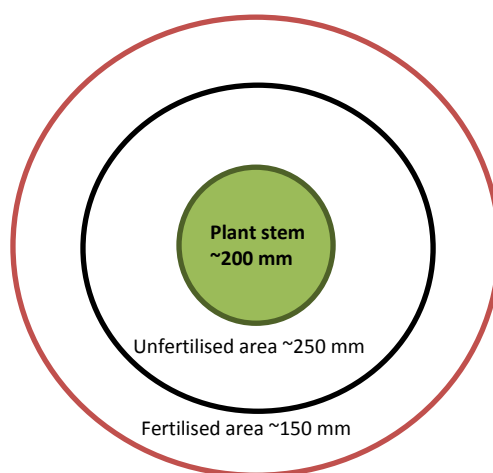
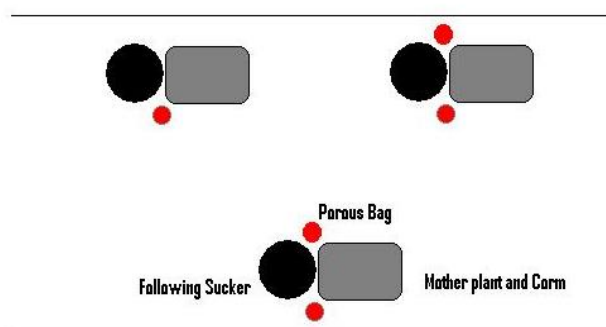
Nitrogen application

Application of the products and their distribution over the mound was different for the plant crop and first ratoon. In the plant crop all fertilisers were applied close to the base of the plants because the porous bag treatment was localized and we wished not to bias our leaching results by placing the other fertilisers over broader areas as would normally be the case commercially. However, for the first ratoon crop, N fertilisers were applied through the irrigation sprinklers for Treatments 1, 3, 4, 7 and 8 (Table 1). Treatments 5 and 6 (Multicote urea) were surface broadcast on the mound (excluding the outer edges of mound) (Figure 2). Treatment 2 was applied by hand with 1 bag placed 20-30 cm from the base of the following sucker (Figure 3). In the first ratoon crop, three months after the first bag was applied, another two bags were applied 20-30 cm from the base of the following sucker. In addition to the porous bag this treatment received an application of gypsum over the entire mound at a rate of 100 kg/ha, as an additional source of sulphur. Dates and amount of N applied are detailed in 'N application summary' in Appendix 1.

Table 1. Summary of nitrogen treatments

<i>Treatment</i>	<i>Description</i>
T1*	Control, 150/250 kg N/ha/ratoon as urea, dissolved and applied fortnightly
T2*	Porous bag fertiliser (NPK), one bag/plant applied 3 times/yr, 140/224 kg N/ha]
T3*	Entec nitrification inhibitor (Novatec liquid), 120/200 kg N/ha
T4	Entec nitrification inhibitor (Novatec liquid), 150/250 kg N/ha
T5*	Polymer coated urea, 105/175 kg N/ha
T6	Polymer coated urea, 150/250 kg N]
T7*	Polymethylene urea (CoRoN/Barmac), 113/187 kg N/ha
T8	Polymethylene urea (CoRoN/Barmac), 150/250 kg N/ha

* indicates treatments monitored with lysimeter; lower/higher rates refer to the plant and first ratoon crops, respectively.


Figure 2. Fertiliser application band around banana plant

Figure 3. Porous bag placement around banana plant

Phosphorus application

Initial soil sampling showed a trend to lower available P concentrations from replicate 1 to replicate 3. As a result, P was applied to replicates 2 and 3 before planting to increase available soil P concentrations to those of replicate 1. Additional P of 20 kg/ha was applied to all treatments, except Treatment 2 (porous bag), at the start of the fertiliser program for the ratoon crop to correct marginal P concentrations noted in the plant crop post-harvest sampling. Treatment 2 received 43 kg P/ha from the fertiliser blend in the porous bag.

Potassium application

Potassium was applied to all treatments (excluding Treatment 2) on a monthly basis. Potassium chloride (muriate of potash) and potassium sulphate (sulphate of potash) were rotated on a 2:1 ratio, and applied by hand over the mounds. The total application for ratoon crop cycle was 620 kg K/ha.

There was a routine application of lime (80% Ca and 20% Mg) at 5 t/ha on 25/05/2011. As a result of low soil concentrations, B (0.8 kg/ha as Solubor) and Zn (2 kg/ha as zinc sulphate) were applied by fertigation on 09/12/2011.

Table 2. Nutrient application rates for each treatment and crop cycle

<i>Plant crop 09/09/2011-04/07/2012</i>				
Treatment	N kg/ha	P kg/ha	K kg/ha	No. of N applications
T1	150	26	400	20
T2	140	26	372	4 (3 bags)
T3	120	26	400	20
T4	150	26	400	20
T5	106	26	400	4 (2 Multicote)
T6	152	26	400	4 (2 Multicote)
T7	113	26	400	20 (19 CoRon)
T8	150	26	405	20 (19 CoRon)
<i>Ratoon crop 30/07/2012-22/04/2013</i>				
Treatment	N kg/ha	P kg/ha	K kg/ha	No. of N applications
T1	250	20	620	20
T2	224	43	620	3
T3	200	20	620	20
T4	250	20	620	20
T5	175	20	620	2
T6	250	20	620	2
T7	187	20	620	20
T8	250	20	620	20

Note: Urea application at planting (09/09/2011) makes up the difference in brackets

Deep drainage

Field equipment

Fifteen barrel lysimeters (devices used to sample soil water moving through the profile) were installed under five of the eight N treatments (Table 1). These were Treatments 1, 2, 3, 5 and 7 (Treatments 3, 5 and 7 are the lower rates of the controlled release fertiliser and were selected as the most likely to demonstrate reduced N loss in drainage). Three lysimeters were installed under one rep of each treatment on 23/08/2011, totaling 15 lysimeters at the site (Figure 4). Each lysimeter was installed at the bottom of a 1 m hole, made by an auger fitted to a small excavator, before backfilling by hand to return the soil in the original horizons and to the original bulk density. The depth of installation was selected on the basis that 85% of root biomass was in the surface 0.6 m (Carr 2009) and so nutrients sampled below this depth at 1 m are assumed to be lost to the environment.

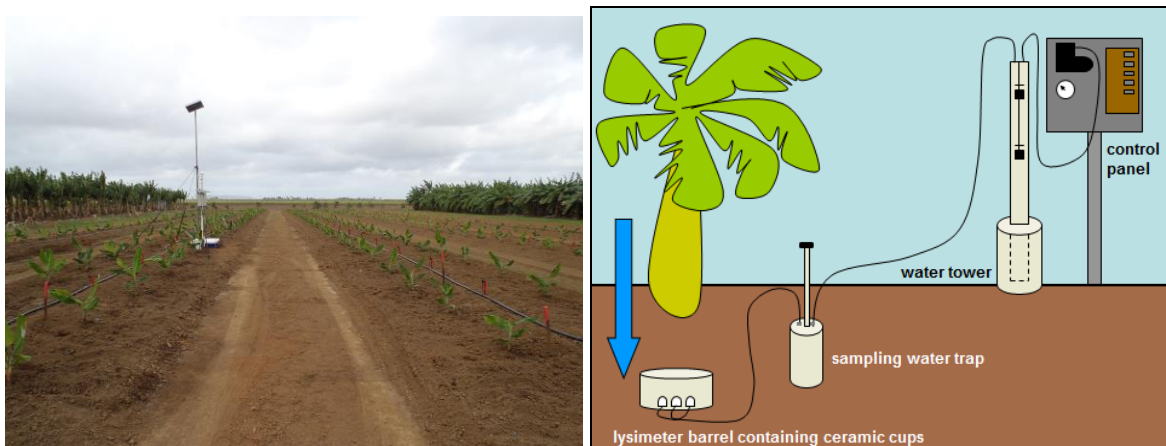


Figure 4. Site establishment, each pink post marks a lysimeter barrel 1 m below (left); Simplified lysimeter system schematic (right)

The lysimeters were made from PVC cylinders, 308 mm in diameter. Three ceramic cups (Cooinda Ceramics, Melbourne, Australia) were installed in the base, covered with a layer of fine silica to ensure good contact with the soil. Ceramic cups have been used for sampling soil water for nitrogen movement studies (Vandenbruwane *et al.*, 2008). The ceramic cups were connected in parallel to a vacuum line that carried drainage water (leachate) to a water trap that was installed at the edge of the mound to avoid interference in normal farm operations. The vacuum was controlled by a falling column of water in a tower located at the end of the plot. A 12 V pump provided the vacuum in the water tower and was powered by a battery which was charged by a solar panel. The system was designed to provide a low and constant vacuum to the ceramic cups of approximately 16-18 kPa and hence simulate natural drainage. The volume of drainage water was converted to a depth by dividing the volume by the surface area of the lysimeter. This system has previously been used to capture deep drainage in the Wet Tropics (Armour *et al.*, 2012). A simplified lysimeter system schematic is illustrated in Figure 4.

Installation of the above-ground components of the lysimeter system was completed on 08/09/2011, with the first samples collected on 25/10/2011. Individual samples were analysed for N (ammonium-N and oxidised-N) and P (filtered reactive phosphorus, FRP) content.

Drainage sampling

Deep drainage was collected from the lysimeter water traps on approximately a fortnightly basis, depending on rainfall. Volumes of drainage were recorded and sub-samples collected for laboratory analysis. Samples were collected over the period 25/10/2011-14/06/2013, although repairs and maintenance resulted in a system shutdown from 22/11/2012-21/01/2013. During this period approximately 325 mm of rainfall was recorded on-site and deep drainage rates would have been very low. Approximately 500 lysimeter samples were collected over 36 occasions during the monitored period.

Soil sampling

Samples were collected before the treatments were imposed and from all plots at the end of each cropping cycle (Table 3).

Table 3. Soil sampling program

<i>Date</i>	<i>Sampling</i>	<i>Analysis</i>	<i>Details</i>
04/08/2011	Preliminary	Mineral N	6 samples collected 0-0.2, 0.2-0.4 m; 3 reps x 3 cores bulked
01/09/2011	Pre-treatment	Full analytical suite	18 samples collected Row: 3 reps x 3 cores bulked; 0-0.9 m Inter-row: 3 cores bulked; 0-0.3 m
13/06/2012	Plant crop bunch harvest	Full analytical suite	150 samples collected Treatments: 1 core/plot taken in the area of fertiliser application; 0-0.9 m Row: taken from centre of intra-row, maximum distance from area of fertiliser application; 0-0.9 m Inter-row: 0-0.9 m
04/04/2013	First ratoon bunch harvest	Full analytical suite	135 samples collected Treatments: 1 core/plot taken in the area of fertiliser application; 0-0.9 m Inter-row: 0-0.9 m

Samples were placed in eskies chilled with freezer bricks in the field, then sent promptly to the laboratory for analysis. Mineral nitrogen (ammonium-N and nitrate-N) were extracted from the field-wet samples shortly after arrival at the laboratory and the results were adjusted to air dry values. All other analyses were completed on air dried, ground (<2 mm) samples with analytical methods described by Rayment and Lyons (2011).

Leaf sampling

An intensive program of leaf sampling and analysis was undertaken on a fortnightly basis until bunch emergence for the plant (7 times) and ratoon (6 times) crops. Leaf samples were collected from three plants and composited to produce one representative sample from each plot (24 leaf samples) and oven dried at 65°C. Dry samples were analysed at the DSITIA Chemistry Centre, Brisbane for N, P, K, Ca, Mg, S and micro-nutrients. Statistical analysis of leaf nutrient results was able to quantify variance between treatments.

Biomass sampling

The destructive harvest of three entire plants from a guard row was completed at the end of each crop cycle to monitor gross nutrient uptake (05/06/2012 for plant crop, 12/03/2013 for first ratoon crop). The guard area had a fertiliser program equivalent to Treatment 1 (urea). Three entire plants, minus some roots, were removed by lifting from the paddock with forks on the front of a tractor. Soil was washed off the corm, roots were trimmed and discarded and the remainder of the plant was weighed and sub-sampled for laboratory analysis (Table 4).

Table 4. Description of plant parts measured during destructive harvest sampling

<i>Plant part</i>	<i>Description</i>
Stem - mother	Main stem
Corm	Entire corm for main plant, followers and suckers
Leaf - mother	Leaf of main stem including petiole
Bunches	Bunches separated from bunch stem
Bench stem	Stem that holds the bunches
Stem - follower	Follower is the largest sucker and the basis for the following crop
Leaf - follower	Leaf of follower sucker
Suckers	Other small suckers, entire

Agronomic sampling

Farm operations (including tillage, nutrient applications, etc.) were recorded in a comprehensive field diary. Plant performance parameters measured included pseudostem height and girth, at bunching, number of fingers/bunch, date of bunching, harvest and bunch weight and grades of fruit.

Laboratory analyses

Water

Deep drainage samples collected for nutrient analysis were analysed by the Department of Science, Information Technology, Innovation and the Arts' (DSITIA) Chemistry Centre Ecosciences Precinct (ESP) laboratory in Brisbane. They were analysed for dissolved nutrients, ammonium-N, NO_x-N (oxides of N, mainly nitrate), filterable reactive phosphorus and K by methods accredited by NATA.

Soil

Soil samples were also analysed by the DSITIA Chemistry Centre ESP laboratory in Brisbane for pH (1:5 water), electrical conductivity, organic carbon, Colwell extractable P, PBI, extractable cations Na, K, Ca, Mg and Al, effective cation exchange capacity, DTPA extractable Cu, Zn, Mn and Fe, particle size analyses, nitrate-N and ammonium-N. The methods were NATA-accredited and described by Rayment and Lyons (2011). Nitrate-N loads (kg/ha) in the profile (to 1.2 m) were calculated from the nitrate-N content and an assumed soil bulk density down the profile of 1.2 g/mL.

Plant and leaf analysis

All plant samples were analysed at the DSITIA Chemistry Centre ESP laboratory in Brisbane. Leaf samples were analysed for N, P, K, Ca, Mg, S, Cu, Zn, Mn, Fe and B by NATA-accredited methods. Plant parts from the destructive harvest were analysed for N, P, K, Ca, Mg and S.

Data analysis

Drainage losses

Nutrient loads were calculated from the volume of drainage measured and the concentration of nutrient in the drainage. The nutrient loads calculated for most treatments were multiplied by a factor of 0.6 to account for fertiliser application only to the row, which is 60% of the paddock (the inter-row is the remaining 40%). However, for Treatment 2 (porous bag treatment) the factor was 0.14 to account for the small area that received fertiliser. Earlier work at nearby sites showed that nitrate-N concentrations from the unfertilised row area were consistently low in ratoon crops (~1 mg/L, Armour *et al.* 2012).

Statistical analysis

Statistical analysis of plant nutrient data was performed by Dr Carole Wright, Senior Biometrician (DAFF). Analysis of variance (ANOVA) was used to compare yield and other plant performance measurements for the treatments. A repeated measures ANOVA was used to compare leaf nutrients over time with the use of smoothing splines.

Results

Rainfall and irrigation

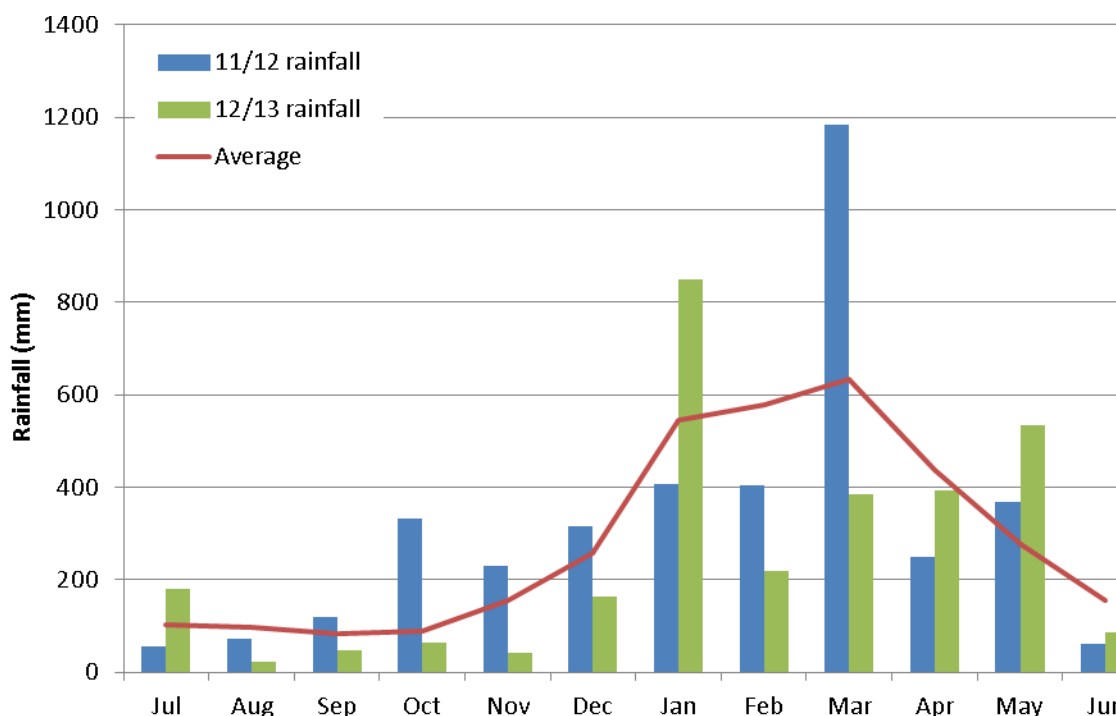


Figure 5. Total monthly rainfall for 2011/12 and 2012/13 seasons compared to the long-term average for the site

A total of 3797 mm of rain was recorded during 2011/12 (01/07/2011-30/06/2012) with a monthly average of 316 mm. This is slightly greater than the long term average for South Johnstone of 3413 mm. Approximately 50% of the total rainfall for the season occurred from January to March 2012. More than 1000 mm of rainfall was received during March 2012, which was significantly greater than the long term averaged of 634 mm. The first irrigation was applied on 16/09/2011 and on another 21 occasions over the remainder of the 2010/11 season for a total of 420 mm.

In contrast, 2012/13 was a drier year with the site receiving 2988 mm (01/07/2012-30/06/2013). Monthly rainfall was well below the long-term average for the majority of the wet season, with the exception of January (>600 mm of rain). Major daily rainfalls of >100 mm/day occurred on three occasions at both sites during the 2012/13 wet season, with >200 mm daily totals occurring at both sites on the 22nd and 23rd of January 2013. During the drier 2012/13 year, a total of 960 mm irrigation was applied on 48 occasions.

Deep drainage

During the monitoring period (25/10/2011-14/06/2013), deep drainage accounted for a mean of 36% (range 23-42%) of rainfall and irrigation (Table 5). Concentrations of NO_x-N in deep drainage below the root zone were high from October 2011 to January 2012 leading up to bunch emergence in the plant crop (Figure 6). The high concentrations were consistent with the high levels of available N in the soil following cultivation in preparation for planting (refer to Soils section below). However, by the time of bunch harvest in the plant crop, soil N

concentrations were much lower due to plant uptake, deep drainage and likely gaseous loss (denitrification).

Table 5. Rates of deep drainage for treatments for 25/10/2011-14/06/2013

<i>Treatment</i>	<i>Drainage (mm)</i>	<i>Drainage (% of rain + irrigation)</i>
T1	2219 (420)	31
T2	2934 (180)	41
T3	2983 (167)	42
T5	2452 (596)	35
T7	1640 (250)	23

Note: standard error in parentheses; % drainage calculated for a total of 7070 mm of rain + irrigation received during this period; Lysimeter system was temporarily shut down 22/11/2012-21/01/2013 when there was 325 mm of rainfall.

NO_x-N concentrations since then have generally remained low for most treatments, except Treatment 2 (porous bag). Because the porous bag delivers N to a concentrated zone it may be creating hot spots of N in deep drainage that cannot be recovered by plant roots.

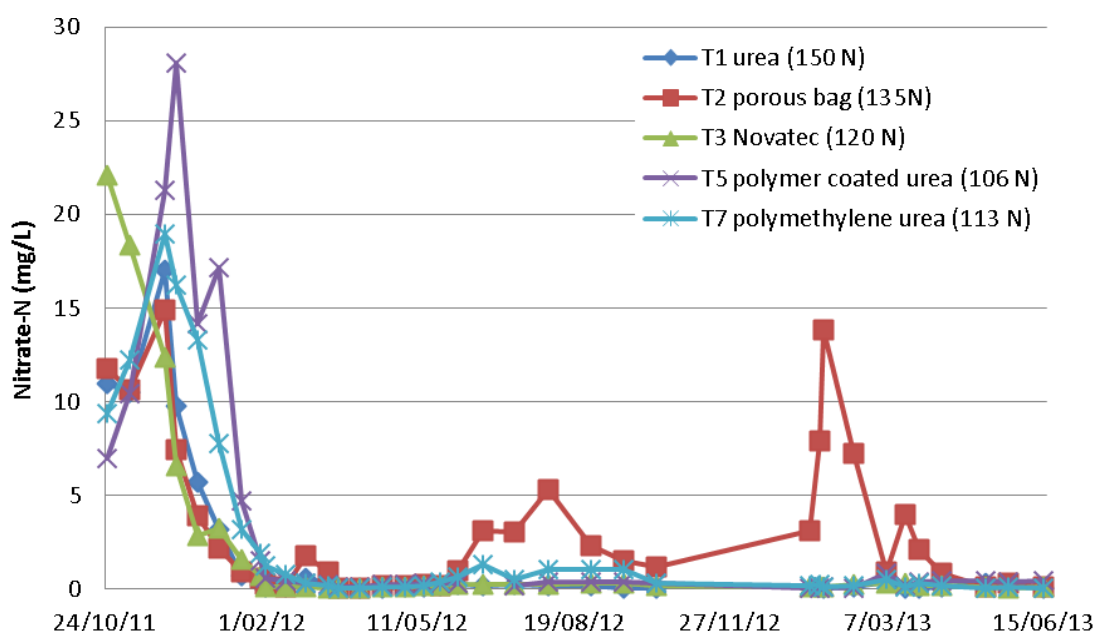


Figure 6. Nitrate-N concentrations in deep drainage under different controlled release products

NO₃-N loads in deep drainage ranged from 23 (T1) – 46 (T5) kg/ha in the plant crop and 0.9 (T1) – 5 (T2) kg/ha in the first ratoon crop (Table 6). The lowest loads were from Treatment 1 followed closely by Treatment 7 (with 23 and 1 kg/ha for each respective crop cycle).

Mean ammonium-N concentrations were 0.2 mg/L for the first three sample dates and then were very low (mean 0.01 mg/L) for all treatments over the next 18 months. Consequently NH₄-N loads in deep drainage were low, ranging from 0.1–0.6 kg/ha in the plant crop and 0.02–0.05 kg/ha in the first ratoon crop (Table 6).

K concentrations tended to decrease over time from planting to generally low concentrations in the ratoon crop, similarly to NO₃-N (Figure 7). K loads in deep drainage

ranged from 6–16 kg/ha in the plant crop and 3–7 kg/ha in the first ratoon crop (Table 6). The mean K concentration in deep drainage in the ratoon crop was 0.7 mg/L.

Table 6. Sum of loads (kg/ha) in deep drainage in plant and first ratoon crops

<i>Plant crop</i>	T1	T2	T3	T5	T7
NO ₃ -N load (kg/ha)	23 (2.5)	33 (6.6)	29 (10.1)	46 (13.6)	23 (10.0)
NH ₄ -N load (kg/ha)	0.6 (0.1)	0.2 (0.07)	0.4 (0.23)	0.1 (0.03)	0.2 (0.03)
K load (kg/ha)	6 (1.0)	14 (9.4)	16 (4.9)	7 (1.7)	7 (3.0)
<i>First ratoon crop</i>	T1	T2	T3	T5	T7
NO ₃ -N load (kg/ha)	0.9 (0.2)	5 (3.2)	1 (0.2)	2 (0.9)	1 (0.3)
NH ₄ -N load (kg/ha)	0.02 (0.00)	0.02 (0.01)	0.05 (0.01)	0.03 (0.00)	0.04 (0.01)
K load (kg/ha)	3 (0.5)	3 (0.4)	7 (2.1)	4 (0.9)	4 (0.8)

Note: Standard error in parentheses

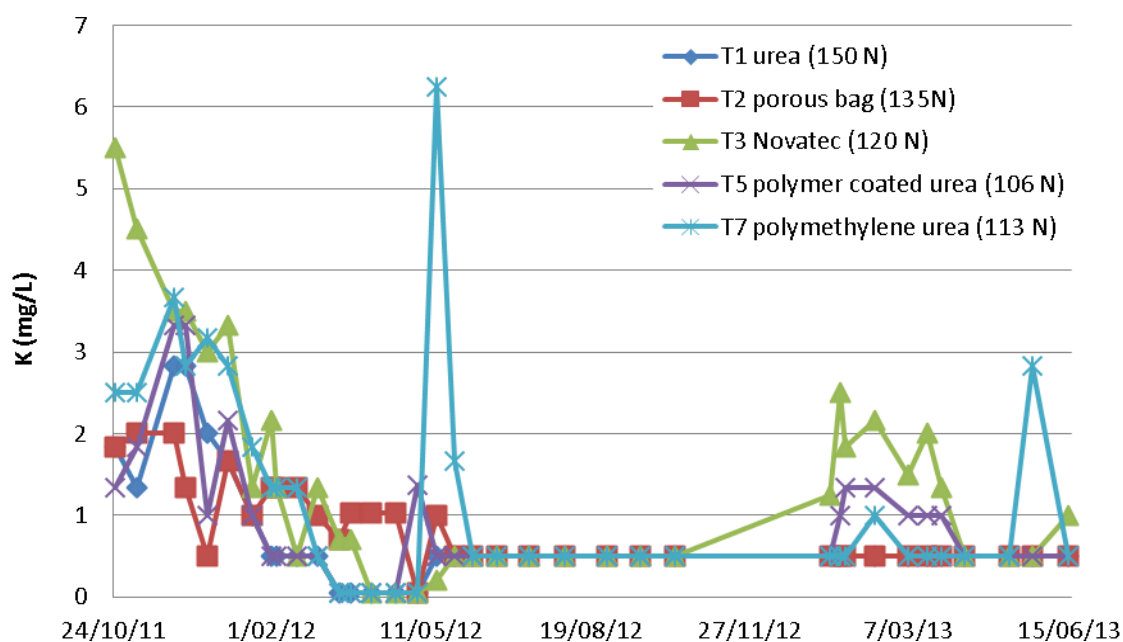


Figure 7. Potassium concentrations in deep drainage under different controlled release products

Soils

There was unfertilised grass pasture on the site for approximately two years before the paddock was prepared for planting. At planting, after normal ground preparation, there were high concentrations of nitrate-N (mean 19 mg/kg) and moderate concentrations of ammonium-N (mean 6 mg/kg) in the soil to a depth of 0.6 m (Figure 8). The load of mineral N (ammonium- and nitrate-N) in the surface 0.6 m was 165 kg N/ha, of which 75% was nitrate-N. By harvest of the plant crop in June 2012, mineral-N concentrations in both the unfertilised inter-row area and unfertilised row area had decreased to low levels (Table 7). However, concentrations of nitrate- and ammonium-N in the fertilised areas were highly variable and reflected placement of the N fertiliser and the soil sampling location. For example, in Treatment 2 (porous bag), the samples were collected directly under the bag which resulted in high concentrations throughout the profile.

At the harvest of the ratoon crop, mean concentrations of ammonium- and nitrate-N in the profile were low and similar for all treatments apart from Treatment 2 (porous bag), which remained high.

Concentrations were much lower than at the harvest of the plant crop for Treatments 5 and 6, clearly reflecting the broadcast application method (rather than concentrated around the plant) during this crop cycle.

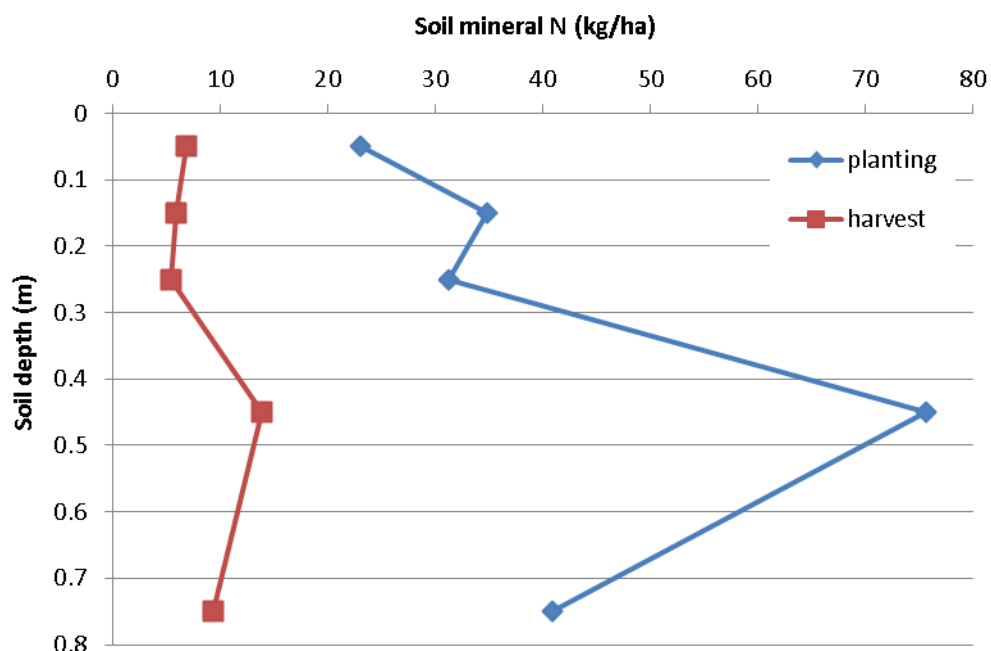


Figure 8. Loads of soil mineral N (ammonium + nitrate) in the row at planting and harvest of the plant crop for Treatment 1

Table 7. Mean concentrations of nitrate- and ammonium-N for 0-0.6 m at harvest of the plant and ratoon crops

Treatment	Plant crop harvest (June 2012)		Ratoon crop harvest (April 2013)	
	Nitrate-N (mg/kg)	Ammonium-N (mg/kg)	Nitrate-N (mg/kg)	Ammonium-N (mg/kg)
T1	4	2	6	6
T2	194	125	66	53
T3	4	1	4	5
T4	4	2	6	7
T5	19	64	2	3
T6	27	77	4	4
T7	4	2	4	3
T8	4	1	8	4
Non-fert. row	4	1		
Inter-row	5	1	3	3

Total N concentrations in the soil profile at planting decreased from 0.21% in the surface to 0.05% at 0.9 m. The load of total N in the profile was 13 t/ha, calculated from a soil bulk density of 1 g/mL in the soil surface and 1.2 g/mL for the remaining depths.

Leaf analysis

Nutrients

Plant nutrient concentrations were intensively monitored during the plant and ratoon crop cycles. Leaf samples were collected from 11/11/2011-03/02/2012 (plant crop) and from 22/08-06/12/2012 (first ratoon crop), which were the vegetative growth periods before bunch emergence (Table 8, Figure 9, Figure 10). Leaf concentrations of N and K were high in the plant crop for all treatments but lower in the first ratoon crop. There were no significant differences in the concentrations of N, P or K among the treatments in the plant crop.

Leaf N for Treatment 5 was significantly lower ($p=0.003$) over time than all other treatments except Treatment 7. There were no significant interactions between time and treatment ($p>0.05$) in the first ratoon crop for all nutrients using the repeated measures ANOVA. This suggests that the response over time is similar for all treatments.

Leaf B concentrations were marginal in the first 3 sample dates of the plant crop (~11 mg/kg). They increased to 14 mg/kg during December-January 2011 after B application in irrigation water. Concentrations were much higher in the ratoon crop even though no additional B was applied.

Table 8. Mean nutrient data from plant and ratoon crop leaf analysis

<i>Plant crop leaf analysis 11/11/2011-03/02/2012</i>							
Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	B (mg/kg)
T1	3.75	0.22	4.27	0.60	0.33	0.29	12.3
T2	3.80	0.22	4.22	0.59	0.32	0.28	11.5
T3	3.81	0.22	4.18	0.58	0.35	0.29	11.8
T4	3.83	0.22	4.27	0.59	0.34	0.29	11.6
T5	3.85	0.22	4.06	0.61	0.37	0.28	11.8
T6	3.84	0.22	4.09	0.64	0.34	0.28	11.5
T7	3.79	0.22	4.09	0.56	0.35	0.28	11.6
T8	3.80	0.22	4.18	0.60	0.33	0.28	11.7
<i>First ratoon crop leaf analysis 22/08-06/12/2012</i>							
Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	B (mg/kg)
T1	3.24	0.22	3.59	0.65	0.34	0.26	24.6
T2	3.24	0.22	3.61	0.56	0.31	0.26	20.4
T3	3.16	0.22	3.61	0.58	0.32	0.27	20.4
T4	3.18	0.22	3.56	0.58	0.33	0.26	21.1
T5	3.01	0.22	3.62	0.55	0.32	0.26	21.0
T6	3.16	0.22	3.70	0.61	0.32	0.26	20.3
T7	3.09	0.22	3.54	0.61	0.34	0.25	23.4
T8	3.22	0.22	3.59	0.66	0.32	0.26	20.7

Note: concentrations are treatment mean for each sampling period

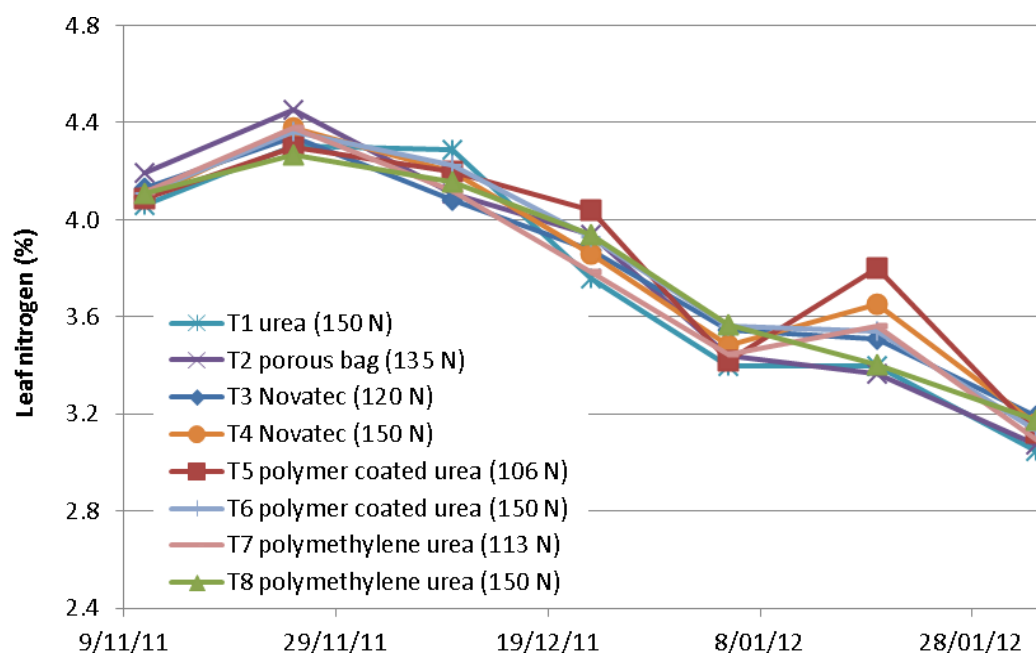


Figure 9. Leaf nitrogen (%) in plant crop

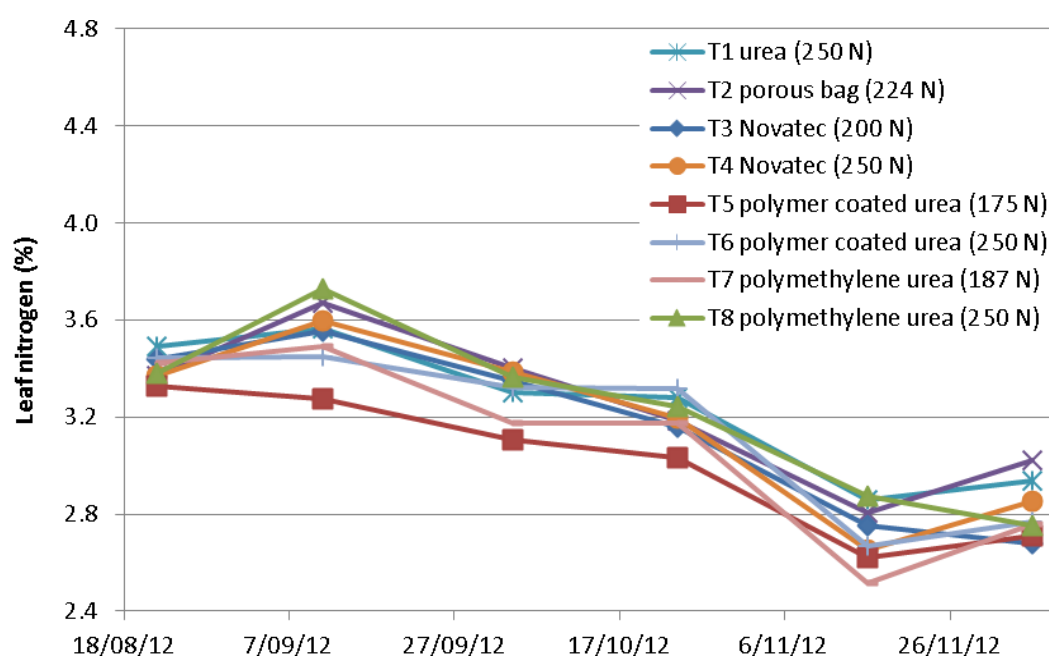


Figure 10. Leaf nitrogen (%) in first ratoon crop

Biomass sampling

Biomass sampling of the plant crop was completed on 05/06/2012 (Table 9) and on 12/03/2013 (Table 10) for the ratoon crop. Plant dry weight increased by 32% from 30 t/ha in the plant crop to 40 t/ha in the ratoon crop. In contrast, N uptake increased by only 8% but the other macro-nutrients increased by an amount (36-54%) similar to the increase in dry weight, except Mg which increased by 202%.

Table 9. Plant weight and nutrient uptake calculated from plant crop biomass sampling, 05/06/2012

	<i>Plant 1</i>	<i>Plant 2</i>	<i>Plant 3</i>	<i>mean</i>
Fresh weight (kg/ha)	210,891	210,207	174,831	198,643 (11,922)
Dry weight (kg/ha)	33,258	31,569	26,413	30,413 (2,061)
N (kg/ha)	335	281	250	289 (25)
P (kg/ha)	35	36	33	35 (1)
K (kg/ha)	1,279	1,314	1,150	1,248 (50)
Ca (kg/ha)	176	169	133	159 (13)
Mg (kg/ha)	53	47	39	46 (4)
Average of plant N %	1.28	1.08	1.18	1.18

Note: Standard error in parentheses.

Table 10. Plant weight and nutrient uptake calculated from first ratoon biomass sampling, 13/02/2013

	<i>Plant 1</i>	<i>Plant 2</i>	<i>Plant 3</i>	<i>mean</i>
Fresh weight (kg/ha)	346,927	328,128	361,966	345,674 (9,800)
Dry weight (kg/ha)	41,595	38,650	40,525	40,257 (862)
N (kg/ha)	327	288	325	313 (13)
P (kg/ha)	56	53	52	54 (1)
K (kg/ha)	1,868	1,784	1,832	1,828 (24)
Ca (kg/ha)	235	228	188	217 (15)
Mg (kg/ha)	110	74	95	93 (10)
Average of plant N %	1.04	1.07	1.15	1.08

Note: Standard error in parentheses.

Water and nitrogen balance

Water balances were calculated for the plant crop (Table 11) and first ratoon crop (Table 12) from measured components from Treatment 1 (standard urea treatment) and evapotranspiration (ET_c) was calculated by difference. Runoff volumes and rates of N loss via surface runoff were populated with data collected at a nearby P2R paddock monitoring site (Site 2) at SJRS. ET_c calculated from data collected throughout the plant crop was 2080 mm and 1882 mm for the first ratoon. These values are both similar to the value of 1790 mm, calculated simply from pan evaporation multiplied by a crop factor of 1.1 (Carr 2009).

The net N balance for the plant crop was -291 kg/ha, indicating that more N was removed from the paddock than was added. In contrast, the net N balance for the first ratoon crop was 182 kg/ha indicating that there was an excess of N calculated from the measured additions and losses.

Table 11. Water and nitrogen balance for banana plant crop (09/09/2011-04/07/2012)

Water balance (mm)		Nitrogen balance (kg/ha)	
Rain	3550	Fertiliser	150
Irrigation	440	Runoff ^B	-18
Rain + irrigation	3990	Deep drainage	-23
Runoff ^B	-590	Crop uptake ^A	-289
Deep drainage	-1320	Soil mineral N (0-1 m)	-111
ET_c	-2080	Net balance	-291

^A Banana N uptake calculated from biomass sampling 05/06/2012; ^BRunoff rates and N loads taken from nearby P2R paddock monitoring site; ET_c – crop evapotranspiration is calculated by difference.

Table 12. Water and nitrogen balance for banana first ratoon crop (30/07/2012-22/04/2013)

Water balance (mm)		Nitrogen balance (kg/ha)	
Rain	2131	Fertiliser	250
Irrigation	840	Runoff ^B	-3
Rain + irrigation	2971	Deep drainage	-1
Runoff ^B	-190	Crop uptake ^A	-24
Deep drainage	-899	Bunch harvest	-73
ET _c	-1882	Soil mineral N (0-1 m)	33
Net balance		182	

^A Banana N uptake calculated from biomass sampling 13/02/2013; ^BRunoff rates and N loads taken from nearby P2R paddock monitoring site; ET_c – crop evapotranspiration is calculated by difference.

Agronomic data

In the plant crop, there were no significant differences in the plant parameters measured (Table 13).

Table 13. Mean agronomic data for each treatment in the plant crop

Treatment	Planting to bunch harvest (d)	Bunch emergence to harvest (d)	Bunch weight (kg)	Fruit 20-26 cm in length (%)	Finger number/bunch	Pseudostem height (m)
T1	268	96.0	23.6	82.5	137	2.66
T2	268	97.2	22.6	83.4	133	2.58
T3	273	99.2	22.9	82.7	135	2.67
T4	266	95.7	22.6	80.8	133	2.62
T5	263	93.2	23.1	84.4	130	2.60
T6	266	95.8	22.5	82.9	133	2.58
T7	262	96.4	22.6	84.3	133	2.63
T8	268	102.6	23.5	79.4	138	2.66

As for the plant crop, there were no significant differences among the treatments for any of the variables analysed during the first ratoon crop (Table 14). This lack of differences was partly by design as we sought to compare all products at an application rate that was suitable for optimum yield. The emphasis of the trial was to investigate differences in loss by deep drainage among the products.

Table 14. Mean agronomic data for each treatment in the first ratoon crop

Treatment	Planting to 1st ratoon harvest (d)	Bunch emergence to harvest (d)	Bunch weight (kg)	Fruit 20-26 cm in length (%)	Finger number /bunch	Pseudostem height (m)	Following sucker height (m)
T1	556.2	86.5	40.8	72	213	3.25	2.26
T2	558.2	87.7	40.1	73	206	3.18	2.28
T3	569.6	86.9	41.0	70	204	3.26	2.18
T4	560.6	86.7	41.4	75	217	3.27	2.29
T5	562.8	86.7	40.6	72	201	3.21	2.10
T6	560.3	86.8	39.9	70	214	3.19	2.12
T7	560.0	86.3	41.6	75	207	3.29	2.22
T8	559.3	85.1	39.7	73	209	3.24	2.23

Discussion

Bunch yield and all other plant parameters were similar for urea, the industry standard N source, and the controlled release products evaluated. They were also similar for the two rates of applied N investigated for Entec, polymer coated urea and polymethylene urea. Yield, in comparison to the district, was considered average for the plant crop and well above average for the ratoon crop. This indicates that N, other nutrient management and general crop management was adequate for average to high yields during years with average and below average wet seasons.

The absence of treatment effects in the plant crop from the fertiliser form and rate of application are consistent with the large amount of mineral N in the soil profile at planting. This was as high as 165 kg N/ha in the surface 0.6 m, which is more than the target N application for the plant crop. However, at the start of the ratoon crop, soil mineral N was low in the unfertilised area of the row and the inter-row. From this low base, treatment differences would have been expected if there was a high loss of N from the soil, or release of N from the CR products was inadequate for good plant growth.

Loss of N from the root zone in deep drainage was the focus of the environmental assessment of the experiment, based on earlier work which identified that this was the major loss pathway in water (Armour *et al.* 2012). Concentrations of NO_x-N and consequently loads of N in deep drainage were generally much lower than those previously measured with a higher rate of N application at a nearby site. Mean NO_x-N concentrations in this experiment were <1 mg/L for all treatments in the ratoon crop for rates of N of 175-250 kg N/ha. In comparison, the mean concentration was 38 mg/L when 400 kg N/ha/crop cycle was applied (Armour *et al.* 2012). The load of NO_x-N in deep drainage from the ratoon crop was 0.9-5 kg/ha, which is low in comparison to the fertiliser N applied. This implies either efficient uptake of N in this experiment and/or high rates of gaseous loss. However, high bunch yield and observations of very healthy plants support the conclusion that the plants had an adequate supply of N from the modest N rates used.

Potassium concentrations and loads in deep drainage were also low in comparison to earlier work (Armour *et al.* 2012), despite an application rate that was 24% higher in this experiment. In the ratoon crop, the mean K concentration was 0.7 mg/L (2.8 mg/L earlier), with a mean K load of 4 kg/ha (16 kg/ha earlier).

The water balance that was calculated from site measurements and other local experiments indicated that the lysimeter system was adequately sampling deep drainage. Deep drainage was approximately 34% of rainfall and irrigation which was similar to the value of 37% reported by Armour *et al.* (2012).

The soil N balance that was calculated from N inputs and losses from the system had a deficit in the plant crop of 291 kg N/ha, which means that more N was removed from the soil than could be accounted for by the nutrient sinks measured. In contrast, there was a surplus of 182 kg/ha in the ratoon crop. The magnitude of both the deficit and surplus was small in comparison to 13 t/ha of total N in the soil to a depth of 0.9 m.

Low leaf N concentrations in the ratoon crop for Treatment 5 (lower rate of polymer coated urea) and a trend for lower N concentrations in Treatment 7 (lower rate of polymethylene urea) suggest that the N supply to the plants from the fertiliser was limited. However, this was not reflected in yield or follower height. A reduction in the height of the follower has been previously shown to reflect an inadequate supply of N (Armour *et al.* 2012). Results for the second ratoon crop will be important in determining if these lower concentrations result in lower yield.

The N uptake in the first ratoon crop was only 24 kg/ha (8%) larger than for the plant crop, whereas dry matter increased by 32%. This could be explained by a N deficiency, but as previously discussed, there is no evidence of this.

Benefits and application

- Low rates of N in deep drainage are encouraging, suggesting that setting N targets for a crop at low levels (150 kg N for plant crop and 250 kg N for ratoon crops) will reduce losses of N in deep drainage.
- Although we do not yet have much evidence of benefits of controlled release fertilisers in reducing leaching losses further, it is likely that such fertilisers would have other benefits. These would include the ability to ensure the crop is receiving adequate nutrients during the extended wet season when standard forms of fertiliser can be very difficult to apply. In contrast, controlled release fertilisers can be conveniently applied prior to the commencement of the wet season.
- There is a need for greater attention to freely available mineral N loads at planting to manage N losses (i.e. our plant crop results masked by the high N levels) by incorporating this in fertiliser application recommendations.
- Cultivation prior to planting leads to significant release of N from the large soil N pool and may release more N than can be used by the crop. Therefore, any strategies such as permanent bed systems, which cultivate only a fraction of the paddock area, should lead to less losses of N to the environment. Currently permanent bed systems account for <10% of the area under bananas in north Queensland.

Conclusions

The experiment has demonstrated efficient use of N fertiliser and low rates of loss in deep drainage. There were no differences in bunch yield or other plant parameters, apart from lower leaf N in Treatments 5 (polymer coated urea) and 7 (polymethylene urea).

Future directions

- Leachate data from another ratoon crop would be desirable before making any conclusive recommendations to current fertilising strategies. In the plant crop, differences in the performance of the fertilisers were masked by the large amount of available nitrogen in the soil at planting. The data from the first ratoon crop has been for a relatively dry wet season (~67% of average).
- On-farm use of controlled release N fertilisers requires development. It is desirable to determine how they fit in with normal fertiliser practices including paired comparisons with a grower's standard practices for demonstration purposes.
- There remain opportunities for development/extension of previous work on strategies (N target/integrated nutrition management) as well as extension/demonstration of previous P studies which can be adopted by industry.
- Supplementary to this D&E is the further development and release of Bananaman[®] decision support software to help banana growers better manage their crop nutrition.

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Appendix 1

Field layout schematic

<i>guard row</i>	Rep A		Rep B		Rep C		<i>guard row</i>
← North	A8			B3	C6		
	A1			B4	C2		
	A5			B6	C8		
	A6			B7	C1		
	A4			B2	C3		
	A7	9		B8	C4		
		8					
		7					
	A2	6	15	B5	C7		
		5	14				
		4	13				
		e sky					
	A3	3	12	B1	C5		
		2	11				
		1	10				

Note: numbers represent lysimeter locations

Summary of total N applied to treatments

<i>Total kg N/ha applied</i>	T1	T2	T3	T4	T5	T6	T7	T8
Plant crop	150	140	120	150	105	150	113	150
First ratoon crop	250	224	200	250	175	250	187	250

N application summary

<i>Plant crop – kg N/ha applied</i>								
Date	T1	T2	T3	T4	T5	T6	T7	T8
09/09/2011	5	5	5	5	5	5	5	5
27/09/2011	3	45	2	3	53	75	2	3
12/10/2011	3		3	3			3	3
26/10/2011	3		3	3			3	3
09/11/2011	3		3	3			3	3
23/11/2011	4		3	4			3	4
07/12/2011	8		7	8			6	8
21/12/2011	8		6	8			6	8
05/01/2012	8		6	8			6	8
18/01/2012	8	45	6	8			6	8
01/02/2012	8		6	8			6	8
10/02/2012					48	70		
16/02/2012	8		6	8			6	8
01/03/2012	8		6	8			6	8
16/03/2012	8		6	8			6	8
28/03/2012	8		6	8			6	8
11/04/2012	8	45	6	8			6	8
25/04/2012	12		10	12			9	12
09/05/2012	12		10	12			9	12
23/05/2012	12		10	12			9	12
06/06/2012	12		10	12			9	12
Sum	150	140	120	150	106	152	113	150
<i>First ratoon crop – kg N/ha applied</i>								
Date	T1	T2	T3	T4	T5	T6	T7	T8
30/07/2012	13	45	10	13			9	12
31/07/2012					88	125		
13/08/2012	13		10	13			9	12
27/08/2012	13		10	13			9	12
14/09/2012	13		10	13			9	12
24/09/2012	13		10	13			9	12
08/10/2012	13		10	13			9	12
22/10/2012	13	90	10	13			9	12
05/11/2012	13		10	13			9	12
19/11/2012	13		10	13			9	12
02/12/2012					88	125		
3/12/2012	13		10	13			9	12
17/12/2012	13		10	13			9	12
31/12/2012	13		10	13			9	12
14/01/2013	13	90	10	13			9	12
28/01/2013	13		10	13			9	12
11/02/2013	13		10	13			9	12
25/02/2013	13		10	13			9	12
11/03/2013	13		10	13			9	12
25/03/2013	13		10	13			9	12
08/04/2013	13		10	13			9	12
22/04/2013	13		10	13			9	12
Sum	250	224	200	250	175	250	187	250

Linkages

Links to other projects in RRRD

RRRD054: Strong linkages to provide Tony Webster (CSIRO) with banana growth information from the South Johnstone trial site for crop modelling purposes. This collaboration will assist in the extrapolation of results from our study site (RRRD049).

P2R program

Project output made available to better measure and report on progress resulting from banana adoption of ABCD management practices. Results used to validate Source Catchments modelling and load estimation.

Reef Rescue WQ grants

Direct use in the Reef Rescue grants program in the Wet Tropics region, including improved ABCD list.

Communication

A field walk at the South Johnstone trial site was held on 29 November 2012 for a group of approximately 20 banana growers (some of whom were Australian Banana Grower Council delegates) and 10 fertiliser company representatives to communicate knowledge of the scope of the work in progress

An article describing the project was published in the mid-year 2012 edition of Australian Bananas magazine.

Controlled release product suppliers have visited the trial site on five occasions. Two groups of international visitors have also toured the trial site and were presented with informal talks on the trial objectives.

Film crew from DAFF (Canberra) interviewed some of the project team and filmed sampling of deep drainage on 8 August 2012.