

Reef Rescue Research & Development

Technical Report

Advanced drip and optimised furrow irrigation to minimise sediment, nutrient and pesticide losses to the environment through deep drainage and run-off from sugarcane and banana industries in northern Queensland
RRRD004



Surya P Bhattarai and David J Midmore



Australian Government
Department of the Environment



Advanced drip and optimised furrow irrigation to minimise sediment, nutrient and pesticide losses to the environment through deep drainage and run-off from sugarcane and banana industries in northern Queensland (RRRD004)

Surya P Bhattarai¹, David J Midmore¹

¹ School of Medical and Applied Science, CQUniversity, Rockhampton, QLD 4702, Australia



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Cover photographs: Top left: Micro-sprinkler irrigation and arrangement for bypassing run-off contamination on trial plot from adjoining block in the field for banana trial in Bundaberg; Top right: Interrow pit traps designed for capture of run-off and sampling for drip and furrow irrigated sugarcane in Ayr, QLD; Bottom left: Banana plant showing rooting depth of 50-70 cm suggest maintenance of soil moisture and fertilizer within this depths to minimise deep drainage; Bottom right: Instrumentation for monitoring of rainfall, irrigation, samplings stations for water quality monitoring for drip and furrow irrigated sugarcane in Ayr, QLD. Photos provided by Surya P Bhattarai, CQU with permission from participants.

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Acronyms

BBIFMAC	Bowen and Burdekin Integrated Flood Management Advisory Committee
BFVGA	Bundaberg Fruits and Vegetable Growers' Association
CPWS	Center for Plant and Water Science
CQU	Central Queensland University
CSIRO	Commonwealth Scientific and Industrial Research Organization
DSEWPac	Department of Sustainability, Environment, Water, Population and Community
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
NRM	Natural Resource Management
QDAFF	Queensland Department of Agriculture, Fisheries and Forestry
RRRC	Reef and Rainforest Research Centre Limited
RRRD	Reef Rescue Research & Development
SMAS	School of Medical and Applied Science
TropWATER	Centre for Tropical Water and Aquatic Ecosystem Research

Abbreviations

DD	Deep Drainage
DI	Drip irrigation
GBR	Great Barrier Reef
MS	Micro-sprinkler
NUE	Nutrient use efficiency
RO	Run-off
SDI	Sub-surface drip irrigation
WUE	Water use efficiency

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We are greatly thankful to collaborating growers ('Grower 1' and 'Grower 2' - sugarcane growers from Burdekin and 'Grower 3' – banana grower from Bundaberg) for their active participation and support on conducting the field trials, and assistance in various stages for installation of equipment, managing irrigation and harvest of the crops.

The project team comprised a multidisciplinary group from a wide range of organizations. CQUniversity managed the overall project, with the support of staff from the Bowen and Burdekin Integrated Flood Management Advisory Committee (BBIFMAC) particularly for installation and operation of bed load traps, lysimeters, water sampling, and preparation of water samples for quality analysis and assistance in socio-economic analysis in sugarcane research sites in Burdekin. Netafim contribution in irrigation engineering and hardware, CSIRO inputs for on-farm transport modeling, JCU support on hydrological aspects and sample analysis, DAFF and DERM support on policy inputs and communication with growers and industry were pivotal for the success of field trials. We gratefully acknowledge their very active participation and support throughout the project period.

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Executive Summary

Many areas of the sugarcane in Queensland are irrigated by furrow or flood irrigation. Previous research with small plot trials for sugarcane and other crops has demonstrated the benefits of drip and subsurface drip irrigation for yield and also the opportunity to save irrigation water. As part of the Reef Rescue Research and Development Program, this project (RRRD004) compared the efficiency of furrow and subsurface drip irrigation at the paddock level for sugarcane (Ayr) and bananas (Bundaberg) in the Great Barrier Reef (GBR) catchments. Comparative assessments were carried out to evaluate crop performance and soil water movement, and water quality leaving the farm.

Farmers' participatory on-farm trials were conducted in 2011-2014, evaluating irrigation options for sugarcane and bananas that are consistent with enhancement of on-farm water use efficiency (WUE), nitrogen use efficiency (NUE), and that limit the dispersal of herbicides from the paddock in two soil types (vertisol and ferrosol). These aims are also consistent with developing resilience in the farming systems in the face of climate change. The project provided a tool to measure the extent of nutrients, suspended solids, and herbicides removed from the paddock, evaluated the response of crops to different irrigation methods for yield, quality, WUE, NUE and contributed data for modeling impacts of irrigation on hydrological aspects at the paddock and farm scales. It also allowed for socio-economic benchmarking, and probed policy implications of these interventions at the catchment scale by the way of systematic survey of all relevant stakeholders in the sugarcane industry.

Sugar cane trials

The project trialled furrow and subsurface drip irrigation methods for sugarcane at Ayr in the Burdekin region. For sugarcane on a clay loam soil, the deep drainage load was significantly larger for the furrow irrigation compared to the drip irrigation; in the first year it was up to 16%, while in the second year it was as high as 23% of the total irrigation water inputs. Deep drainage under drip irrigation was as much as 15% of the total irrigation during the first season. While in the third year after optimisation of drip irrigation, the deep drainage was reduced to 10%.

Sugarcane surface run-off accounted for 15% and 2.5% of the total irrigation water inputs in the first year for furrow and drip irrigation respectively. While in the third year, 11% and 2.1% of the total irrigation water inputs was lost as run-off for the furrow and drip irrigation, respectively. A lower soil infiltration rate was recorded under the furrow irrigation (12.56 mm/hr) on sugarcane compared to drip irrigated treatment (25.19 mm/hr) when the crop was in full canopy cover at 165 days of crop age. Greater infiltration in the drip irrigation plot compared to the furrow irrigation plot allowed for more rainfall water storage in the root zone, hence, for the given rainfall amount, the run-off from the drip irrigated plot was smaller.

The first year of drip irrigation trial was on a five year old planting hence a ratoon crop, in the following year it was a plant cane, and in the third year a first ratoon crop. Likewise, for the furrow irrigation block a ratoon cane was harvested in the 2011-12 season, a plant cane harvested in the 2012-13 season, and a first ratoon crop was harvested for the third year. In the first year (2011-2012 season) both irrigation treatments produced yield over 100 t/ha (101 vs 121 ton/ha for drip and furrow, respectively). In the second year (2012-2013 season), the harvested cane yield for the drip and furrow irrigation was 82 t/ha and 112 t/ha respectively. Consistently, in the third year (2013-2014 season) also the yield of cane in the drip irrigation block was lower compared to that for the furrow irrigation (72 vs 114 t/ha), indicating continuously declining yield of drip irrigation (caused by root intrusion, mice damage, and emitters blockage). Therefore, immediate major maintenance of the drip irrigation infrastructures has been recommended for this site. Drip irrigation maintenance through hydrogen peroxide treatment has commenced on this site following the completion of the Reef Rescue R&D research activities in this site. The drip irrigation installation in sugarcane has been able to demonstrate positive water quality outcomes leaving the farm, however, in the current site,

drip irrigation is poorly competing with furrow for harvestable yield of sugarcane. Drip irrigated sugarcane yield needs to be improved above that of the furrow in order to attract growers' interest for further adoption of environmentally benign and water saving irrigation methods, such as subsurface drip irrigation for sugarcane.

Traces of herbicides were detected in the deep drainage samples in both irrigation methods. Traces of 2,4-D, MCPA (2-methyl-4-chlorophenoxyacetic acid), Glyphosate and Diuron were noted in the deep drainage samples under both irrigation management systems, however, to a greater quantity in deep drainage of furrow compared to subsurface drip irrigated crops particularly for 2,4-D. Substantial quantities of 2, 4-D and Glyphosate and small amounts of MCPA and traces of Diuron were also noted in the run-off samples under both irrigation management. Volume of run-off and loads of herbicides were greater for furrow irrigation compared to the subsurface drip irrigated sugarcane crop in Home Hill.

Nitrogen (N) distribution in the soil, soil water, and plant was assessed throughout the trial period. There were no great differences among treatments for leaf N concentrations across different growth periods in either crop. Tissue N concentrations were within the optimal range. Hence N fertiliser deficiency was not a cause of poor crop growth. Higher concentrations of nitrate-N loads were recorded in deep drainage and run-off samples collected during the early stage of both sugarcane crops in the field. N applied in sugarcane ranged from 77 to 120 kg/ha per crop; the crop did not have luxuriant growth across this range.

The amount of $\text{NH}_4\text{-N}$, urea N, and Filterable reactive phosphorus (FRP) loads were greater in deep drainage of furrow irrigation compared to the deep drainage samples of the drip irrigation. Estimates of NUE of sugarcane ranged from 0.6-1.32 ton/kg of N, with higher NUE recorded for drip irrigation compared to furrow in the first year (1.32 Vs 0.72 ton/kg), but the difference between the two treatments was reversed in year 3 of the trial (0.60 vs 0.69 ton/kg) due to poor cane yield in subsurface drip irrigation.

Water use efficiency (WUE), expressed as harvestable yield (t/ML) ranged from 12.89 to 22.04 t/ML, with greater WUE recorded for drip compared to the furrow in the first year (22.04 vs 14.17). However, the gain in WUE for drip was not prominent during third year due to poor sugarcane performance in the drip irrigation block.

Banana trials

The project trialled drip and micro sprinkler (MS) irrigation for bananas in the Bundaberg region. For bananas grown on the ferrosol (red loam soil), the deep drainage under drip irrigation was only 2.6% of the total irrigation water inputs during the crop period. The deep drainage load was slightly larger for the micro sprinkler compared to the drip irrigation system, i.e. 3.1% of the total irrigation water inputs to the crop. Similarly, the run-off load was 9 and 12.7% of the total irrigation for the drip and micro-sprinkler treatment, respectively.

In the banana site, a set of piezometers (supplied by Hydroterra Australia) was installed for ground water monitoring, drainage lysimeters (Decagon USA) for deep drainage, Parshall flumes with water height sensor (Odyssey data flow) for run-off measurement and ISCO 3700 samplers for run-off sampling. Low soil infiltration rate (2.60 mm/hr), accompanied with greater run-off (5.99 ML/ha) was noted for the micro sprinkler block compared to drip irrigated bananas (infiltration 2.34 mm/hour and run-off 3.88 ML/ha) in the red loam (ferrosol) soil. Traces of herbicides including Atrazine and Metolachlor were recorded in the irrigation water source; Imidacloprid was recorded in the ground water under the drip irrigation plot, whereas Diuron, Imidacloprid and Metolachlor were recorded in the ground water samples under the micro-sprinkler irrigation plot.

For bananas, the experimental crop was at two different maturity stages, the drip irrigated block was a mature stand, whereas the MS plot was a new plantation. Yearly average yield of bananas was

calculated as 33.67 t/ha for drip and 15.85 t/ha/year for micro-sprinkler. The micro-sprinkler crop was still not at full bearing stage at the end of this trial period, hence the reported yield for MS in this trial does not represent the potential yield of micro-sprinkler for banana. Yield of banana was presented as the total weight of fruit bunches. The current industry practice in Bundaberg selectively harvest mature bunches and incorporate the biomass (pseudo stem, part of the fruit stem) of the harvested plants back into the soil in the same paddock.

N applied to banana was largely as a basal dose, and small amount side dressed twice a year (total 584 kg N/ha). Based on the N input applied to the soil and using data on the crop performance, the NUE has been calculated (yield ton/kg N input) as 0.173 and 0.0271 ton fruit/kg N for drip and micro-sprinkler irrigation, respectively. Therefore, the NUE was significantly higher (0.173 ton/ML) for drip irrigation compared to poor performance of micro-sprinkler irrigation (0.026 ton/kg). Likewise, the WUE was significantly greater for drip irrigation compared to that of the micro-sprinkler (2.34 t/ML vs 0.0336 t/ML).

Conclusions

In these experiments, a sizable reduction in deep drainage and surface run-off volumes, and therefore a reduction in the loss of N, were evident for subsurface and drip irrigation compared to either furrow or microsprinkler irrigation in sugarcane and bananas respectively. Reduced deep drainage also led to reduced contamination of ground water by applied agrochemicals. The optimised subsurface dripper irrigation kept the soil surface drier, hence allowed for a greater interception of rainfall that potentially lower the run-off from subsurface dripper irrigation compared to furrow irrigation.

A multidisciplinary team of collaborating organisations provided significant contributions to the project outputs, through their active involvement in their components of research activities and their respective roles in the team activities of the project. This collaboration provided a unique forum of expertise ensuring the translation of research output into practical adoption of irrigation innovation by the growers and industry. The project has made a positive change in perception about run-off and deep drainage impacts on water quality of sugarcane and banana farming areas in the catchments of the GBR.

The 4 year project period enabled presentation of results from a single full crop season of banana. The results for the second season banana crop and the combined results from the three years of sugarcane trials are being presented for separate publication as journal manuscripts. These results show occurrence of rainfall and irrigated induced run-off and deep drainage for furrow irrigation while for subsurface drip irrigation, run-off are only noted with repeated and heavier rainfall events, in excess of 50 mm and more. Although drip irrigation resulted in reduced deep drainage compared to furrow, opportunities exist for further reduction of deep drainage in subsurface drip irrigated sugarcane crops. Optimisation of the subsurface drip irrigation to match soil, crop, growth stage and weather conditions will lead to further improvements in the irrigation efficiency. Current levels of deep drainage noted in subsurface drip irrigation can be reduced through soil and crop specific pulsing and matching in season water balance more specifically by accurate timing the irrigation with crop water demand. In spite of higher cane yields in the furrow compared to the subsurface drip irrigation in all three harvest seasons, water use efficiency and nitrogen use efficiency were consistently greater for subsurface drip irrigation compared to furrow. However, in the banana crop, these early observations need to be confirmed and substantiated by at least two seasons' data from the comparable irrigation treatments, crops and irrigation water quality. Hence, multi-season data collection from these trial sites is suggested as is the continuation of optimisation of subsurface drip irrigation for water and nutrient management of sugarcane and bananas so that the effects of different irrigation methods on soil water movements and hydrological processes for wet and dry years can also be evaluated.

1. Introduction

Paddock-scale monitoring and investigations have enhanced our understanding of the relative contributions of different land use activities to the overall nutrient and sediment export to the coast (Faithful and Finlayson, 2005). Some of the recent studies established that the presence of pesticides and nutrient residues in sugarcane and banana cropping farm run-off in the northern wet tropics are causing potential threat to the sustainability of Great Barrier Reef (GBR). However, to date limited studies have been undertaken to investigate practical interventions that can mitigate off-farm movement of sediments and pollutants from these industries, which consuming more than 15 ML/ha/yr of irrigation. Our project area spans from the Burdekin in the north for sugarcane to the Burnet region of the south of Queensland in Bundaberg for banana. These industries were targets for irrigation management interventions and dissemination aimed at minimizing off-farm movement of pollutants.

This project implemented on-farm action research comprising an irrigation intervention (furrow irrigation and drip irrigation systems) for two target industries (sugarcane and bananas), that is consistent with enhancement of on-farm water use efficiency (WUE) and nutrient use efficiency (NUE), to limit the dispersal of nutrients and pesticides from the paddock in two major soil types. The activities on water management are consistent with developing resilience in the farming systems in the face of climate change. The proposal provides a tool to measure the extent of nutrients, suspended solids, and herbicides that will be removed from the paddock. The project evaluated the response of crops to these irrigation methods in terms of yield, quality, WUE, and also contributed data for modeling to generate scenarios of off-farm movement of water, nutrients and herbicide in response to irrigation interventions to the paddock level, which could potentially contribute towards up-scaling to farm and the micro-catchment scale hydrology. It also facilitated socio-economic benchmarking, with the purpose of probing policy implications of these interventions at the catchment scale.

This project brings multidisciplinary expertise and innovative irrigation approaches for on-farm soil and water management that minimise nutrients, herbicides and sediment loss and improve water quality in run-off and deep drainage. CQuniversity Centre for Plant and Water Sciences (CPWS) collaborated with irrigation business leader-Netafim Australia, a community based organization-Burdekin Bowen Integrated Floodplain Management Advisory Committee (BBIFMAC) in the Ayr with a strong grower base, and CSIRO, JCU, DERM, and DAFF in evaluation of the effects of irrigation interventions. A broad range of assessment was carried out on aspects of crop agronomy, physiology, hydrology, transport of pollutant and modeling for the prediction under different scenarios of rainfall and irrigation events. This assemblage provides a unique forum of expertise ensuring the translation of research output into practical adoption by the growers to make a positive change in managing run-off and deep drainage that impact water quality outcomes.

We aim to provide information to industries on irrigation approaches to reduce on-farm pollutants in run-off and deep drainage, as well as soil and water management tools that are economically viable and compatible with cane and banana industry practices. Any improved irrigation practices that brings gain in yield, quality of the produce, water use efficiency and nutrient use efficiency, by way of optimization, becomes an attractive option for adoption. The resulting outcomes should lead to the optimization of furrow and drip irrigation and which should contribute to increased adoption of subsurface drip irrigation (SDI) by the sugarcane industry and adoption of the surface drip irrigation technology by the banana industry in the GBR zone in Queensland, Australia.

Five major questions were addressed as part of this project:

1. Under what conditions will there be a measurable reduction in the sediment loss in run-off and movement of nutrients and pesticides in run-off and deep drainage from different Irrigation methods (sugarcane and banana)?
2. Why should there be a measurable difference in the quality of run-off and how does that relate to the changes in the Irrigation management system (comparison of furrow with drip irrigation in the first year, followed by optimizations in next two years)?
3. How innovative Irrigation practices (e.g. minimization of soil surface run-off, deep drainage) offer long term positive impacts on soil stability through their effect on soil physical, chemical and biological properties that reduce run-off.
4. How water wise irrigation innovations and soil management practices, tested and proven to be better than current practice at the plot and paddock level, can be translated to farm and catchment levels with appropriate extrapolation and modeling techniques.
5. What are the key factors for adoption of Best Management Practices (BMP), including the design of a decision support system, an analysis of socio-economic drivers and resistance for adoption, and a test of fit under a triple bottom line matrix for different methods that substantially reduce sediments and run-off loads?

We aim to provide information to industries on irrigation approaches to reduce on-farm pollutants in run-off and drainage and on indicative cost-benefit analyses for subsurface drip irrigation, as well as to suggest optimization options based on soil and water management tools that are economically viable and compatible with cane and banana industry practices.

Project Objectives

The objectives of this project were to:

1. Measure the losses of pesticides and nutrients from cane and banana fields, and their distribution in run-off and deep drainage. Linking with Reef Rescue projects led by Tony Webster, John Reghenzani, and Peter Thornburg.
2. Determine why differences in water quality arise from different management protocols. (Comparison of furrow with drip irrigation in the first year, followed by optimizations in the next years)
3. Quantify long term impacts on soil stability and structure through effects on soil physical, chemical and biological properties that reduce run-off
4. Undertake modelling to quantify scaled up projected beneficial water wise irrigation innovations and soil management practices, to farm and catchment levels. Linking with Reef Rescue projects led by David Freebairn and Stuart Whitten.
5. Determine the key factors for adoption of Best Management Practices, including the design of a decision support system, an analysis of socio-economic drivers and resistance for adoption, and a test of fit under a triple bottom line matrix for different methods that substantially reduce sediments and run-off loads? Linking with Reef Rescue projects led David M. Freebairn and Stuart Whitten.

2. Study sites

2.1 Study area (Burdekin): Sugarcane Site 1

Trial: Comparison of subsurface drip and flood irrigation

Collaborating grower and location: Grower 1, Home Hill, Burdekin. Trial set up presented as Figures 1-4.

Field	Description
Name	Grower 1, Home Hill, Burdekin region, QLD. Sugarcane research site.
Measurements	Two distinct irrigation treatments, i.e. subsurface drip irrigation (SDI) and furrow irrigation were tested. Measurements and data collection involve water inputs both as irrigation (furrow) and rainfall (mm/day); nutrients and pesticides applications; crop growth and yield; leaf area index; canopy cover; soil moisture; deep drainage; water advance measurements and modeling, suspended sediments (mg/L); nutrient and herbicide movement in the soil profile and in the run-off. Installation of pit traps in the furrows (three on each of the furrow and drip irrigation blocks) also allowed for measurement of surface flow and potential run-off and sampling of surface flow water quality parameters in the two different blocks.
Description	Ratoon crop (planted in 2009 and 2010) in medium to heavy texture soils. This site has moderate rows length (310m), in 1.83 m wide dual row bed configurations. Monitoring of run-off and transport of sediments, nutrients, herbicides was carried out in both blocks of furrow and drip irrigated crops.
Category	Two blocks in Grower 1's farm were included in the study. The site and both blocks are part of current P2R monitoring program. The instrumentation for the measurement of deep drainage (lysimeters) and soil moisture (Sentek Enviroscan) was previously installed on the site. Additional lysimeters in the drip block, and pit traps for the measurement of overland flow and run-off were added in this site. An onsite rain gauge (Campbell Scientific), with remote data download facilities was likewise installed in this site.
Image	Figure 1: Installation of pit trap for monitoring of surface flow and sample collections from sugarcane paddock Figure 2: Comparison of furrow (left) with subsurface drip irrigation (right) for the control of run-off, deep drainage and measurement of sugarcane crop performance. Figure 3: Instrumentation for the collection, measurements and sampling of run-off from the furrow and subsurface drip irrigation block in the sugarcane trial at Home Hill Burdekin. Figure 4: Aerial view of the experimental site (Grower 1) for sugarcane research comparing subsurface drip irrigation and furrow irrigation (green pointer) in Home Hill, Burdekin, on a medium to heavy textured soil.



Figure 1. Installation of pit trap for monitoring of surface flow and sample collections from sugarcane paddock.



Figure 2. Comparison of furrow (left) with subsurface drip irrigation (right) for the control of run-off, deep drainage and measurement of sugarcane crop performance.



Figure 3. Instrumentation for rainfall and irrigation water input monitoring, measurements and sampling of run-off (over land flow), and deep drainage from the furrow and SDI block in the sugarcane trial at Home Hill, Burdekin.



Figure 4. Aerial view of the experimental site at Home Hill (Grower 1) in Burdekin for sugarcane research comparing subsurface drip irrigation and furrow irrigation (green pointer), on a medium to heavy textured soil [Google images].

2.2 Study area (Burdekin): Sugarcane Site 2

Trial: Monitoring N & herbicides mass balance in furrow irrigation

Collaborating grower and location: Grower 2, Clare, Burdekin. Trial set up presented in Figures 5-8.

Field	Description
Name	Grower 2, Michod Road, Clare, Burdekin region QLD. Sugarcane research site.
Measurements	Water inputs both as irrigation (furrow) and rainfall (mm/day); nutrients and pesticides inputs; crop growth and yield; leaf area index; canopy cover; soil moisture; deep drainage; water advance measurements and modeling, suspended sediments (mg/L); nutrient and herbicide movement in the soil profile and in the run-off.
Description	Initially a first ratoon crop of sugarcane in a vertisol. This site had long rows (1100 m), 30 crop rows in 1.8 m wide dual row bed configurations. Monitoring of run-off and transport of sediments, nutrients, herbicides was carried out in a block with 30 rows of furrow irrigated sugarcane crop.
Category	One block in the farm was included in the study. The site is part of a current P2R monitoring site. The instrumentation for the measurements of run-off and soil moisture was previously installed. Two sets of lysimeters each consisting one group of 3 lysimeters (one each in row, shoulder and interrow) were installed in this site in the 2011 season towards the top and bottom of the furrow.
Image	Figure 5: Preparation for installation of lysimeters in the ground with specialized coring equipment that collects the intact cores, on which the lysimeter base and ring is placed before the placing the lysimeter and core back into the ground. Figure 6: Lysimeter installed for monitoring of deep drainage and collection of water samples for analysis of nutrients and pesticides. Deep drainage is checked and collected after each irrigation and rainfall event at the site. Figure 7: Instrumentation for the collection, measurement and sampling of run-off from the end of the furrow irrigation block in the sugarcane trial block on a heavy clay soil, Clare, Burdekin. Figure 8: Experimental site (Grower 2) for sugarcane research using furrow irrigation (green pointer) in Clare, Burdekin on a heavy clay soil (on a long row configuration system). [Google Images]



Figure 5. Preparation for installation of lysimeters in the ground with specialized coring equipment that collects the intact cores, on which the lysimeter base and ring is placed before the placing the lysimeter and core back into the ground.



Figure 6. Lysimeter installed for monitoring of deep drainage and collection of water samples for analysis of nutrients and pesticides. Deep drainage is checked and collected after each irrigation and rainfall event at the site.



Figure 7. Instrumentation for the collection, measurement and sampling of run-off from the end of the furrow irrigation block in the sugarcane trial block on a heavy clay soil, Clare, Burdekin.

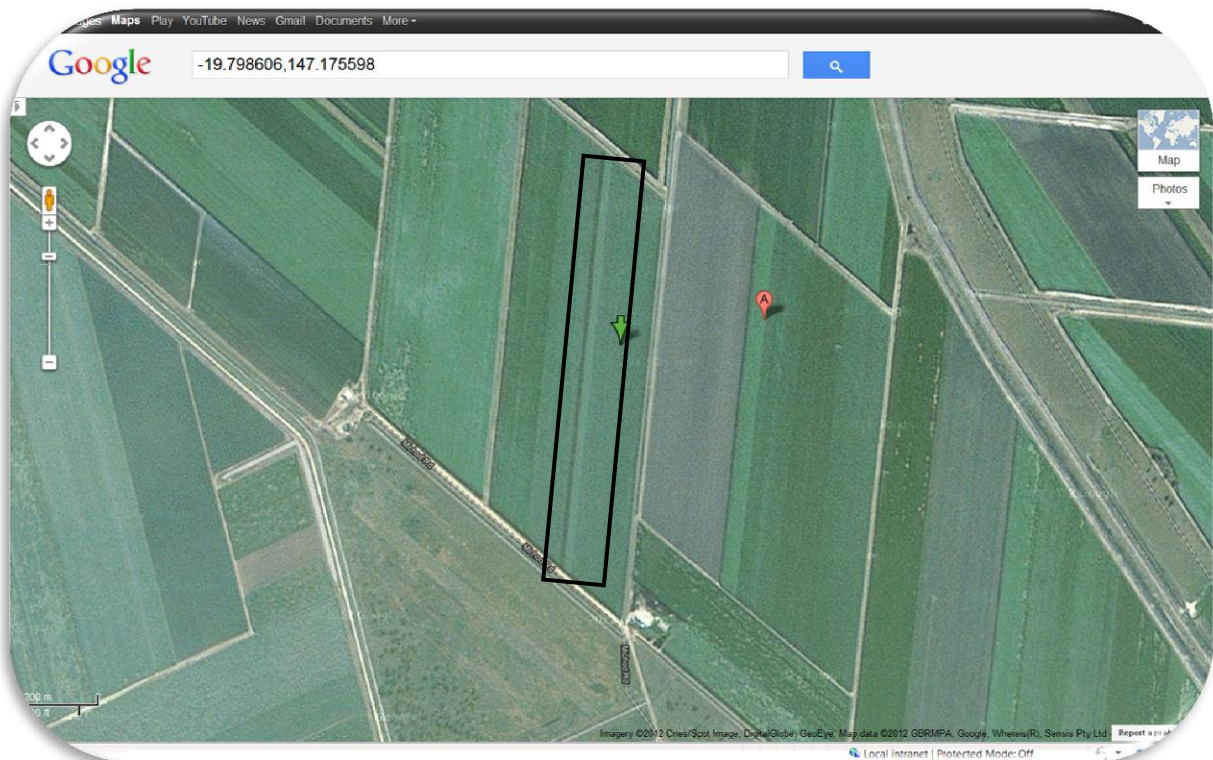


Figure 8. Experimental site (Grower 2) for sugarcane research using furrow irrigation (green pointer) in Clare, Burdekin on a heavy clay soil (on a long row configuration system).

2.3 Study area (Bundaberg): Banana Site 1

Trial: Monitoring of N & herbicides mass balances for drip and micro-sprinkler irrigation

Grower 3, Bundaberg. Trial set up presented in Figures 9 to 12.

Field	Description
Name	Grower 3, Heidkee Rd, Windermere, Bundaberg, QLD. Banana research site.
Measurements	Water inputs both as irrigation and rainfall (mm/day); nutrient and pesticide inputs; crop growth and yield; leaf area index; canopy cover; soil moisture; deep drainage; change in water table; suspended sediments (mg/L); nutrients and herbicides movement in the soil profile and in the run-off.
Description	1-3 years old banana crop in a ferrosol. Comparison of drip and micro-sprinkler irrigation systems for on off-farm movements of water, nutrients and pesticides as well of the crop performance under different irrigation management systems.
Category	Two blocks in the farm were included in the study. New blocks with micro-isprinkler irrigation system were on a younger plantation (6 months) whereas the old block accommodated a 3 year old banana crop. Both blocks have the same variety, soil type and irrigation water source but are at different maturity stages (crop age). The trial consisted of a comparison of drip and micro-sprinkler irrigation systems on off-farm movement of water, nutrients, pesticides, and an evaluation of crop growth under different irrigation management.
Image	Figure 9: Grower engaged in research, clearing the banana block for control of run-off in the drip irrigated banana paddock at Bundaberg. Figure 10: Lysimeter installed for monitoring of deep drainage and collection of water samples for quantification of leached nutrients and pesticides Figure 11: MEA Magpie sensors for continuous monitoring of change in soil moisture, soil temperature and electrical conductivity up to 120 cm depths in the micro-sprinkler irrigation. Figure 12: Experimental site for banana research using compared to the micro-sprinkler (on the right hand side). Aerial view of the experimental plot for sub-surface drip irrigation (green pointer) and micro-sprinkler irrigation system (to the east of the green pointer) captured through Google images.



Figure 9. Grower engaged in research, clearing the banana block for control of run-off in the drip irrigated banana paddock at Bundaberg.



Figure 10. Lysimeter installed in the micro-sprinkler block for monitoring of deep drainage and collection of water samples for quantification of leached nutrients and pesticides.



Figure 11. MEA Magpie sensors for continuous monitoring of change in soil moisture, temperature and electrical conductivity to 120 cm depths in the micro-sprinkler irrigation block.

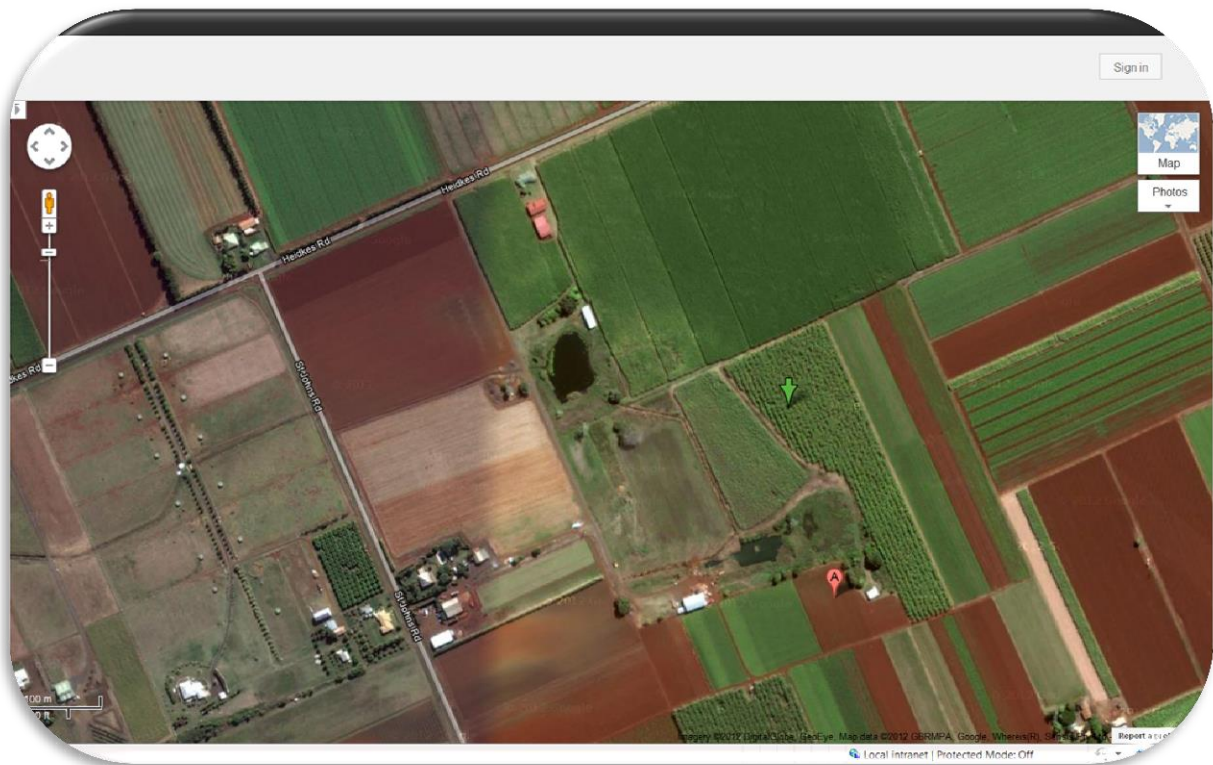


Figure 12. Experimental site for banana comparing drip irrigation to the micro-sprinkler (on the right hand side). Aerial view of the experimental plot for drip irrigation (green pointer) and micro-sprinkler irrigation system (to the east of the green pointer).

3. Methodology

The project team finalized project sites and collaborating growers for sugarcane and banana in Burdekin and Bundaberg, respectively in March 2011. Some revisions on project activities (particularly regarding the location of banana trials in Bundaberg), strengthening focus of the research and also the milestone and targets of the project, given the shorter duration of the project period and the need of integration of project methodology and activities were incorporated. We also conducted stakeholder workshops in Bundaberg and Burdekin for program orientation and discussion and detailing of the field activities. In-depth assessment of the project activities, and assignment of specific responsibilities for each collaborator for specific tasks including data collection from the trials sites, training needs, data management and data sharing between the research collaborators were discussed and finalized in those early meetings.

This project aimed at greater investigation of nutrient and herbicide movement in sugarcane and banana crops through run-off and deep drainage as affected by different irrigation management practices for better water quality outcomes. It also assessed changes in the water table depth and associated water quality over the seasons in the Bundaberg site. The first year activities were centered around benchmarking of run-off, deep drainage and movement of nutrients, herbicides and sediment loads from different land use practices (sugarcane and banana) and by irrigation methods (furrow irrigation vs. advanced drip irrigation-system in sugarcane and drip vs. micro-sprinkler in banana).

Benchmarking activities were largely focused on comparison; however, the second year activities were devoted towards the optimization of irrigation, and evaluating effects of these interventions on run-off, deep drainage and off-farm movement of nutrients, pollutants and herbicides from different irrigation treatments. User-friendly and affordable monitoring and measurement tools were supplied, and training of the growers, industry partners, and local natural resource management groups was conducted. The field trials consisted of comparing two different irrigation methods (furrow vs. drip) on two different soil types in sugarcane and one soil type for banana industry.

Monitoring of run-off samples were undertaken with automated sampling devices (we had access to four ISCO 3700 units available from DERM, and an upgraded refrigerated sampler from BBIFMAC) installed at each monitoring site. After each run-off (every occurrence of run-off or deep drainage) during this period (subject to equipment operation), water samples were collected for determination of N and herbicides, for mass balances calculations. Water volumes were monitored continuously (we had access to two units), with approximately 12-24 water samples collected per event grouped for analysis. Three to four water samples were composited per irrigation event at each site particularly around the period of a few weeks post-application of fertilizer and herbicides. Ground water samples from banana trials sites were analyzed by Forensic and Scientific Services, QLD, whereas most of the water samples from sugarcane from Burdekin were analysed by the Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) at JCU.

Run-off timing and volume in Bundaberg was measured with Parshall flumes, whereas in the Burdekin the run-off volume at the Grower 1 site was monitored by in-row pit traps designed to suit to the land type. The Grower 2 furrow plots were isolated and fitted with 0.3m and 0.25m diameter PVC discharge pipes, to quantify the contribution of cropping and irrigation management to water quality and runoff from the sugarcane crop. In Grower 2 site, runoff from each irrigation plot flowed through a bed load trap prior to entering the bay discharge pipe. Water height during irrigation bay discharge (runoff) was measured using stilling wells housing 'Dataflow' capacitance height recorders attached to the discharge pipes.

Deep drainage volumes and timings were measured in Decagon lysimeters in the banana crop at Bundaberg, but were measured in lysimeters assembled on site by BIFFMAC and deep drainage water where samples collected were analyzed by portable water quality monitoring units assembled at CQUniversity. The water content of soil was measured to 1.2 meter depth with EnviroSCAN in the Burdekin, and with Enviro-pro and Micro-Gopher probes in Bundaberg. Changes in the water table depth and salinity over the project period were monitored in the banana site with Hydroterra Piezometers using manual and water height capacitance sensors of Dataflow loggers comparing performance of the two different irrigation methods.

The resultant observed data from the first season were used to parameterize APSIM for sugarcane, and analyses were attempted in conjugation with How Leaky for banana cropping systems. We also shared our data with other project operating 'How Leaky' software for use by DERM, and APSIM by CSIRO. The models were then used to explore the impacts of possible management strategies to reduce long-term nitrogen, and herbicides losses from field sites.

Detailed socio-economic data was collected from the stakeholder survey to evaluate the triple bottom line success for the innovations. Data collected from the paddock were incorporated in to the APSIM model to validate models and to establish practical links between paddock, field, catchments and the mouth of GBR through collaboration, coordination and linkage with other service providers.

For promotion of wider-scale adoption of the innovation, project based support was provided through field days, fact sheets, contribution to a BMP manual, generating data for cost-benefit analysis, and contributing to development of decision support systems (DSS) and dissemination of findings carried out through the publication of research findings in the industry magazine and journal article by incorporating full yield data from banana and sugarcane. We participated in the number of field days for wider scale sharing of Reef Rescue activity results to enhance adoption of innovation, and communication was channeled through effective engagement of community organizations by their active involvement in planning, implementation and dissemination phases. The conduct of the research was highly participatory and attracted inputs from representatives of the following five sectors that are beneficiaries and/or end-users of our research: growers, consultants/extensionists, irrigation and ground water industry, researchers, and public sector policy makers. We focused much more strongly on the collection of field based data so that these can be input into modeling for the current trials and future analysis, and lesser on the socio-economic aspects, given project RRRD039 addressing the latter. However, the socio-economic survey carried out by the team on the barriers and drivers for the adoption of drip irrigation was crucial in understanding farmers' perspectives for adoption of drip irrigation for sugarcane and banana.

4. Results

4.1 *Sugarcane trials*

In the sugarcane crop, subsurface drip irrigation was compared with furrow irrigation in the Burdekin over three cropping seasons. The first two years largely focused on comparative performance of drip and furrow irrigation for yield performance and transport of water and nutrients in the soil profile, and the third season focused on optimizing the drip irrigation by improved scheduling to minimize the run-off and deep drainage from the plot.

Active participation and communication with irrigation businesses and industry, crop consultants, grower and growers group, local community and industry groups (BBIFMAC, BFVGA), and the water authorities (Burdekin Water Board) was maintained during the research period.

Optimization of drip irrigation performed for reducing the degree of deep drainage and run-off that contribute toward the adoption of BMPs. Various outputs of the research, e.g. findings of the research were shared with industry-wide stakeholders and growers. We incorporated farmers' feedback for improvements of drip adoption and operation, and we have been actively engaging irrigation businesses, crop consultants, farmers' groups, NRM bodies and extension agencies in research for continuous improvements of drip use by sugarcane and banana industry in the project areas.

Timely implementation of the activities outlined in the project and achievement of the project outputs has delivered project outcomes including methods on instrumentation for monitoring of deep drainage (DD) and run-off. These have been instrumental for quantification of loads and modelling based on collected data, and ultimately optimization of drip irrigation and fertigation, development of crop and soil specific scheduling to reduce run-off, deep drainage, and ground water contamination that all have direct impact on the on farm water quality, crop performance, which ultimately have influence on farmers' decision on adoption of irrigation method.

Project milestones, outputs and activities spelt out in the funding deeds and research reporting requirements have been completed. This report must be read in conjunction with the project milestone reports and final report. Some field instrument remains in the project sites where growers have shown interest to continue monitoring of soil moisture, deep drainage and water table depth. The project was conducted over the period of three years, with five key objectives as set out in the project proposal. All key activities, immediate and intermediate outcomes specified in the project document and listed in program logic have been completed during the project period.

The project outcomes by each objective are highlighted below.

- 1) *To measure the losses of pesticides and nutrients from cane and banana fields, and their distribution in run-off and deep drainage.*

Herbicides were detected in the deep drainage samples. Traces of 2,4-D, MCPA, Glyphosate and Diuron were noted in the deep drainage samples under both irrigation management, some to a greater quantity in deep drainage of furrow compared to SDI crops particularly for 2,4-D (Table 1).

Table 1. Loads of different herbicides in deep drainage water under the furrow and sub-surface drip irrigation in sugarcane at Home Hill, Burdekin, QLD over the period of 2011/12 crop season.

Irrigation methods	Glyphosate (g/ha)	Diuron (g/ha)	MCPA (g/ha)	2,4-D (g/ha)	Metribuzin (g/ha)
Furrow	0.044	0.002	0.091	0.222	0.761
Subsurface drip	0.044	0.002	0.096	0.111	0.064

Similarly difference in traces of herbicide loads were detected in furrow compared to subsurface drip irrigation water (presence of traces of herbicides in the furrow irrigation water source). Substantial quantities of 2, 4-D and Glyphosate and small amounts of MCPA and traces of Diuron were noted in the run-off samples under both irrigation management systems (Table 2). Volume of run-off and loads of herbicides were greater for furrow irrigation compared to the SDI crops and this trend remained similar for both sugarcane seasons in Home Hill.

Table 2. Loads (g/ha) of four key herbicides in surface run-off water under the furrow and sub-surface drip irrigation in sugarcane at Home hill, Burdekin, QLD over the period of 2011/12 crop season.

Irrigation methods	Glyphosate run-off load (g/Ha)	Diuron run-off load (g/Ha)	MCPA run-off load (g/Ha)	2,4-D run-off load (g/Ha)	Metribuzin deep drainage load (g/Ha)
Furrow	42.2	<0.1	0.45	5.07	0.761
Subsurface drip	2.15	<0.1	0.13	0.75	0.064

Nitrogen movement from the paddock was monitored in the deep drainage and run-off water samples, which shows that in a number of events the flux of NOX-N was greater for furrow deep drainage water samples than that of the deep drainage from subsurface drip irrigation water samples (Figure 13).

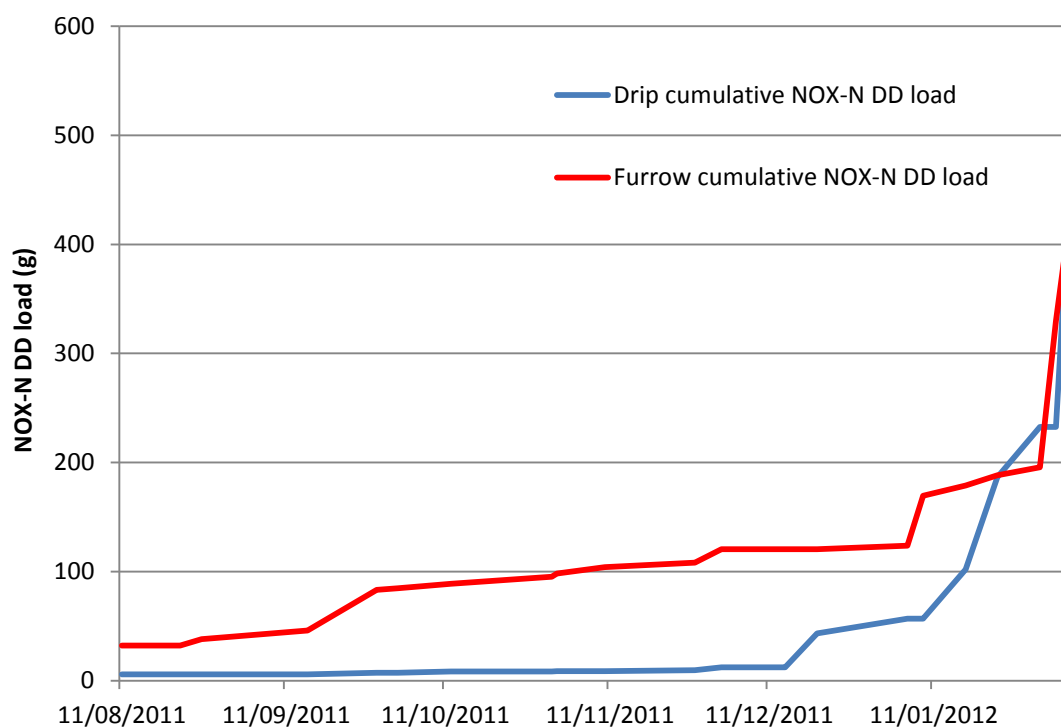


Figure 13. Flux of nitrogen (g) species under drip and furrow irrigation methods over the period of three months.

Quantities of nitrogen were monitored in the deep drainage water and suggest that N in the form of $\text{NH}_4\text{-N}$ and urea N was greater for furrow deep drainage water samples compared to that of the subsurface drip irrigation (Table 3). Similarly the filterable reactive phosphorus was also higher for the furrow deep drainage compared to that in the water leached under the subsurface drip irrigation system (Table 3).

Table 3. Quantities (g/ha) of different forms of N in the deep drainage water collected from the lysimeters installed in the ground in a sugarcane crop over the period of 2011/12 crop season.

Irrigation	Ammonium-nitrogen (NH ₄ -N)	Oxidised nitrogen (NO ₃ -N)	Urea-nitrogen (urea-N)	Filterable Reactive P (FRP)
Drip	37.2	482.8	13.4	1.4
Furrow	48.1	437.8	51.6	19.3

2) *To determine why differences in water quality arise from different management protocols (comparison of furrow with drip irrigation in the first year, followed by optimizations in the following year).*

Analysis of the water budget for two irrigation management system (furrow and sub-surface drip irrigation) showed that in all three years water input for sugarcane irrigation was far greater in furrow compared to the subsurface drip irrigation. Likewise, loss of irrigation water due to run-off and deep drainage was also larger in the furrow irrigation compared to the subsurface drip irrigation (Table 4 and Table 5).

All run-off events in subsurface drip irrigation were associated with only rainfall events. The much reduced rainfall-induced run-off with subsurface drip irrigation was due to the capacity of the subsurface drip irrigation treatment to store significant amounts of soil water in the soil profile as the soil above the drip tape (~400 mm) is reasonably dry for most of the time. This is unlikely in the furrow irrigation in which irrigation forms soil crust on the surface and the surface remain moist most of the time after irrigation, hence any rainfall during such time tends to produce substantial off-farm water movements from the paddock, either caused by rapid run-off or through deep drainage.

The associated water quality benefits with subsurface drip irrigation arise from greater spatial and temporal control of fertilizer application, and also to reduction in the dose of fertilizers with the sub-surface drip irrigation. The furrow crop exhibited larger plumes of N movement in the early establishment stage, as the whole N fertilizer dose was applied to the crop before the first irrigation, i.e., by stool splitting after the harvest of the crop, which exposes the fertilizer to loss due to run-off and wash-out by furrow irrigation.

The water mass balance analysis under the two irrigation management systems shows greater water use efficiency with drip irrigation compared to with furrow (Table 4). The higher efficiency in water use was not translated into yield, great water quality outcomes, particularly for reduced deep drainage and run-off were recorded in the tested drip irrigation method. There is still opportunity for optimization of drip and subsurface drip irrigation methods, and the second phase of the trials was dedicated to the improvement of cane yield and quality of water leaving the farm. The data in Table 5 show that with effective scheduling the deep drainage and run-off components in the SDI crop can be significantly reduced.

Table 4. Water budget for the drip and furrow irrigation measured in the field during 2011/2012 crop season.

Parameters	Drip	Furrow
Rainfall (mm)	954	954
Irrigation (mm)	458.2	861
Soil moisture, initial (mm)	35.18	35.18
Total water input (mm)	1447.38	1850.18
Soil moisture, residual (mm)	42.17	42.17
Deep drainage (mm)	221.8	293.5
Run-off (mm)	35.53	272.58
Evaporation (mm)	-	-
Crop water use (mm)	1147.88	1241.93
Nitrogen (kg/ha)	76.5	170.2
Yield (t/ha)	101	122
Water use efficiency (t/ML)	22.04	14.17
Nitrogen use efficiency (t/kg N)	1.32	0.72

Table 5. Water budget for the drip and furrow irrigation measured in the field during 2013/2014 season crop.

Parameters	Drip	Furrow
Rainfall (mm)	917.8	917.8
Irrigation (mm)	554	887
Soil moisture, initial (mm)	29.34	28.6
Total water input (mm)	1501.14	1833.4
Soil moisture, residual (mm)	32.68	34.16
Deep drainage (mm)	150	425
Run-off (mm)	31.05	203.14
Evaporation (mm)	-	-
Crop water use (mm)	1287.41	1171.1
Nitrogen (kg/ha)	120.5	165
Yield (t/ha)	72	114.3
Water use efficiency (t/ML)	13.00	12.89
Nitrogen use efficiency (t/kg N)	0.60	0.69

- 3) *To quantify long term impacts on soil stability and structure through effects on soil physical, chemical and biological properties that reduce run-off.*

Irrigation methods have effects on soil stability, structure and a range of soil properties. Installation of subsurface drip irrigation tends to keep the surface soil reasonably dry and there are also fewer weeds. As the soil surface dries out, it creates a buffer for storage of water during rainfall events, but the top soil being dry most of the time means fewer roots, unlike in furrow irrigation where root mass is concentrated in the top layer of the soil profile. Less roots and a dry environment on the surface is also evidenced by a reduced soil respiration rate with sub surface drip irrigation compared to furrow irrigation (Figure 14).

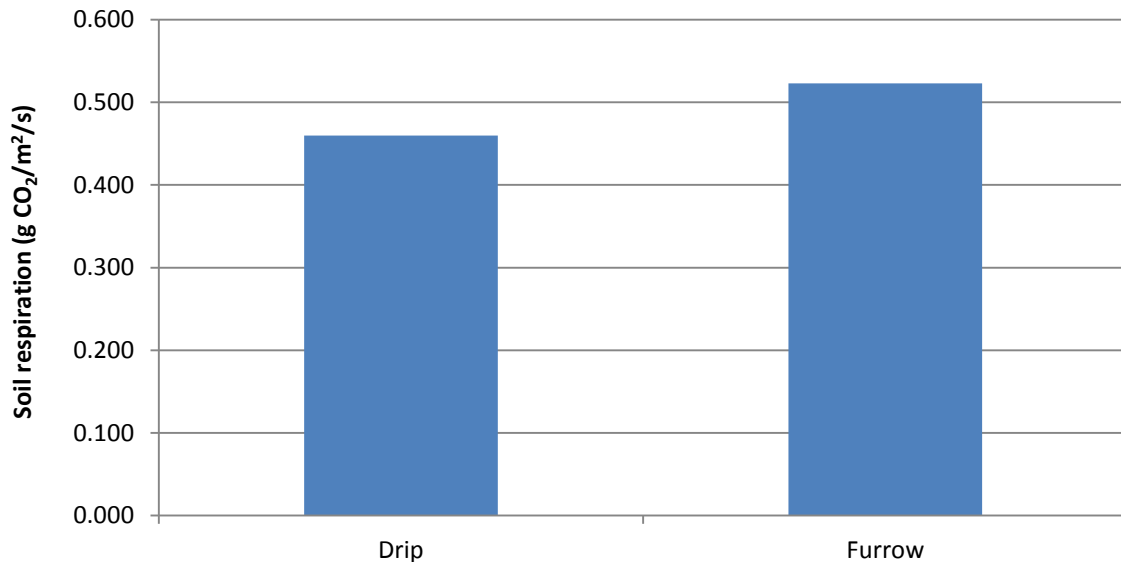


Figure 14. Soil respiration measured using Infra-red gas analyser (EGM-4) suggesting that the soil gas fluxes in the surface soil of drip irrigated crops tend to produce reduced CO₂ fluxes

- 4) *To model and quantify scaled up projected beneficial water-wise irrigation innovations and soil management practices, to farm and catchment levels.*

Unsaturated hydraulic conductivity measured prior to irrigation events in the interrow space of the crop while the canopy cover was 50%, by a mini-disc infiltrometer suggested that the hydraulic conductivity of the surface soil in drip irrigated plot (Figure 15 and Figure 16) was greater (0.000698 cm s⁻¹) than that in furrow irrigation (hydraulic conductivity 0.000349 cm s⁻¹) block.

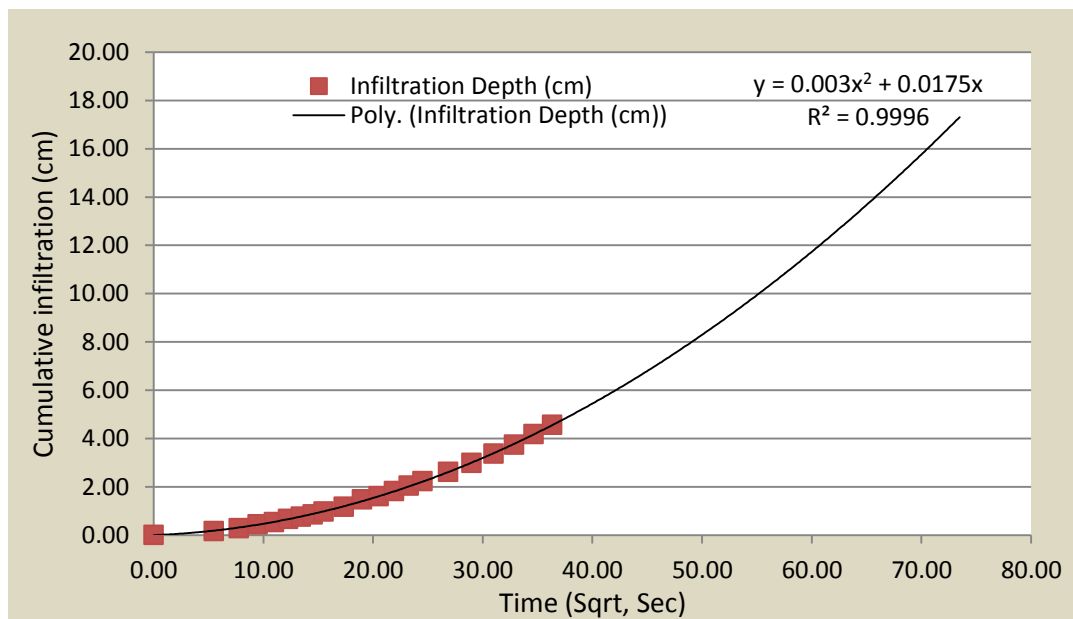


Figure 15. Hydraulic conductivity of the top soil in the subsurface drip irrigation

Low hydraulic conductivity slows infiltration though the soil profile hence provides more opportunity for the surface soil to effect run-off. Measurements with mini-disc infiltrometer provide point source data. A large variation/heterogeneity occurred in the soil that made it harder to make absolutely correct estimations of the soil infiltration rate. However, the current measurement of the soil infiltration rate suggests the greater potential capacity of drip irrigation to absorb more soil moisture into the profile.

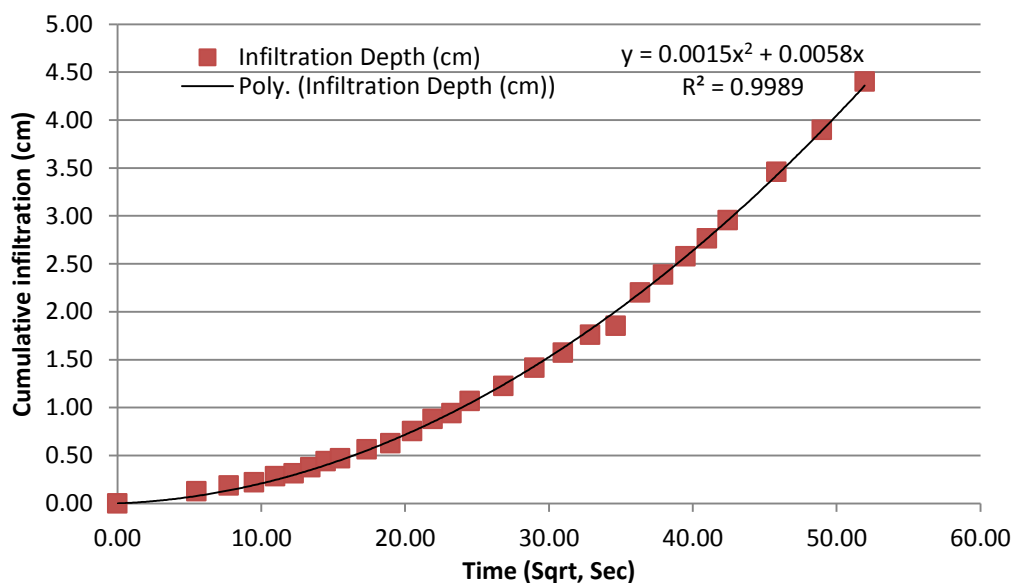


Figure 16. Hydraulic conductivity of the top soil in the furrow irrigation

Data collected in the first season were incorporated into the APSIM modelling for prediction and generation of scenarios. There is some discrepancy between the observed data and modelled data (Table 4 and 5). Optimizaton of the model by incorporating year 2 and year 3 will take place on the APSIM platform to optimise the modelling and published as journal manuscript. Data generated from three seasons of the crop is incorporated in the final publication of the manuscript.

Cane yield of 122 t/ha (13 CCS), and 101 t/ha (14.1 CCS) resulted into the irrigation water use efficiency (WUE) of 14.16 t/ML and 22.05 t/ML for cane, and 1.84 t/ML and 3.1 t/ML for sugar recorded for furrow and drip irrigation respectively. The low yield was for drip irrigation treatments. The yield gap between the furrow and drip need to be addressed in subsequent years by optimising the system. Optimization of the drip irrigation by incorporating effective drip management plan can contribute greatly to closing the yield gap of SDI sugarcane in the current farm trial site.

Subsurface drip irrigation significantly improved sugarcane crop water use efficiency (22.04 vs 14.17 t/ML Water) compared to furrow irrigation. Subsurface drip irrigation significantly improved sugarcane crop nitrogen use efficiency (1.32 vs 0.72 t/kg N) compared to furrow irrigation. In the first season the total nitrogen input was 170.2 kg/ha and 78.6 kg/ha for furrow and drip irrigation, respectively. This resulted in N use efficiency of 0.716, and 1.285 t cane per kg N applied for furrow and drip irrigation respectively. In the second season both furrow and drip crops received almost the similar amount of N (100 kg/ha for both treatments).

Slightly higher deep drainage values were observed in the furrow block (263 mm) compared to the drip irrigation block (233 mm over the season). The deep drainage (averaged over the spatial dimension-row, shoulder and interrow) increased by 13% in furrow compared to drip. Deep drainage of 263 mm for the season is considered quite high and most of these drainage events in drip irrigation were linked to rainfall events. The subsoil in the drip irrigation block is light textured compared to the furrow block where the soil type is more clayey (vertisol). Pulsing irrigation implemented for the 2013/14 season drip irrigation contributed significantly to reduce deep drainage from SDI compared to the furrow (Table 5).

- 5) *To determine the key factors for adoption of Best Management Practices, including the design of a decision support system, an analysis of socio-economic drivers and resistance for adoption, and a test of fit under a triple bottom line matrix for different methods that substantially reduce sediments and run-off loads (linking with RRRD011 and RRRD039).*

A face to face questionnaire survey (63 participants), and a key informant survey were conducted to understand the drivers and barriers for adoption of drip irrigation by sugarcane growers. The survey was carried out in the sugarcane growing areas of the Burdekin. The survey participants included sugarcane drip irrigators, other crop drip irrigators, furrow/flood irrigators, irrigation businesses, crop consultants, extension agents (community based Natural Resource Management groups) and policy makers and a large number of sugarcane growers from Home Hill and Ayr in the Burdekin region. The survey data were analysed, and published as separate report (Appendix-I). It is noted that the initial cost of investment, the need for high maintenance and lack of yield gains in drip irrigated crops compared to furrow are some of the limitations for rapid adoption of drip irrigation by sugarcane growers in the Burdekin region. The greater opportunity of automation and control of irrigation associated with subsurface drip irrigation provide attractive features for developing large scale adoption of subsurface drip irrigation for sugarcane crops when access to water is decreasing and prices for water to the farmers are increasing (full and summary report of the survey has been submitted).

Three seasons of sugarcane crop trials have been completed over the reporting period in the Burdekin comparing the subsurface drip irrigation with furrow irrigation. Subsurface drip irrigation significantly reduced the surface run-off compared to the furrow irrigation method. However, in the third season, we gradually optimised the performance of the subsurface drip irrigation by (a) crop water demand based scheduling, and (b) improved maintenance of general conditions including the control of root intrusion in subsurface drip irrigation. By optimising the drip, the deep drainage from the SDI has decreased significantly compared to the furrow irrigation. However, the yield benefit has not been demonstrated on the SDI over the furrow irrigation. Yield improvement is one of the strong drivers for the adoption of SDI by sugarcane industry.

4.2 Banana trials

For bananas, drip irrigation was compared with micro-sprinklers in Bundaberg, Queensland. Optimization of irrigation on banana was achieved by effective scheduling and real time monitoring of irrigation, rainfall and change in soil moisture in the profile, and run-off. These parameters were quantified largely by co-installation of soil water and soil moisture sensors linked with an on-site water meter and rain-gauge, and a data retrieval system that is readily accessible to the grower.

Training was provided to these are other growers for installation of on farm water monitoring devices, data download, data management and interpretation capability. The banana grower has invested in multi sensor probes (Enviropro) that record soil moisture, change in EC and soil temperature at different depths (0-80 cms), marketed by Measurement Australia Limited (MEA). Irrigation scheduling was based upon the soil moisture at 20 cm depths, and irrigation commenced when the moisture drop to refill point was set up as a criteria for the irrigation.

Irrigation scheduling was based up on the reading of soil moisture content at 20 cm depth and 20 cm away from the row. In the banana field, the crop with micro sprinkler irrigation was only two years old (in 2013) when MI compared to an older (6 years) drip irrigation crop. The micro-sprinkler crop during the third year of the project cycle has just attained the first year of bearing unlike the 3 full bearing years for the drip irrigated block. The canopy cover of the MI crop after 3 years was comparable to that of the drip irrigated bananas (6 years old plantation). Water balance and off-

farm water movement data for these two blocks are more comparable for the 2013/14 crop than the previous seasons.

The banana grower at Bundaberg is willing to continue with on-site instrumentation for monitoring soil water movement. As the crop with micro-sprinkler irrigation is still progressing towards a mature crop stand, we are willing continue some data collection from the banana trial beyond the formal project period (October 2014) to build a strong data set for robust comparison between the two irrigation methods, both for banana yield and soil nutrition and water parameters.

Comparison of drip and micro-sprinkler irrigation in Bundaberg

The banana field trial conducted in Bundaberg on a red clay loam soil (ferrosol) evaluated the effects of two irrigation methods (surface drip and micro-sprinkler hereafter referred as drip and MS) on the soil hydrological processes and banana crop (var: Cavendish) performance. Monitoring of soil water movement was undertaken in two blocks (0.7880 ha of drip, and 1 ha of MS irrigation). Monitoring of banana drip irrigation started from 10 October 2011 in an already established crop (as a superimposed trial). However, the micro-sprinkler (MS) irrigation monitoring plot was only established after a one year of data collection from the drip irrigation monitoring plot.

The 2013 flood caused some damage to in-ground sensors (lysimeter/flume/moisture sensors) in the banana site in Bundaberg; reinstallation of monitoring equipment took place immediately and further data collection continued.

This final report is organised to present results on crop water inputs, soil moisture dynamics including the, change in soil properties including infiltration, deep drainage, run-off, and gross water balance crop performance (yield), movement of nutrients, particularly nitrogen (N), and pollutants particularly herbicides in and from the paddock with the water exiting the crop rooting zone and plot.

Rainfall recorded over the growing season

The total rainfall recorded over the trial period was 29 mega liters (ML/ha = 2900 mm). There were 15 occasions when rainfall of 50 mm and above was recorded, six occasions where rainfall over 100 mm was recorded, two occasions where rainfall over 150 mm was recorded, and one occasion of rainfall over 200 mm in a 24 hour period (Figure 17). The run-off events associated with the high intensity rainfall (e.g. in excess of 100 mm), and longer duration of rain were difficult to record accurately as these event produced run-off that was in excess of the capacity of the bilge pump associated with the run-off pit traps.

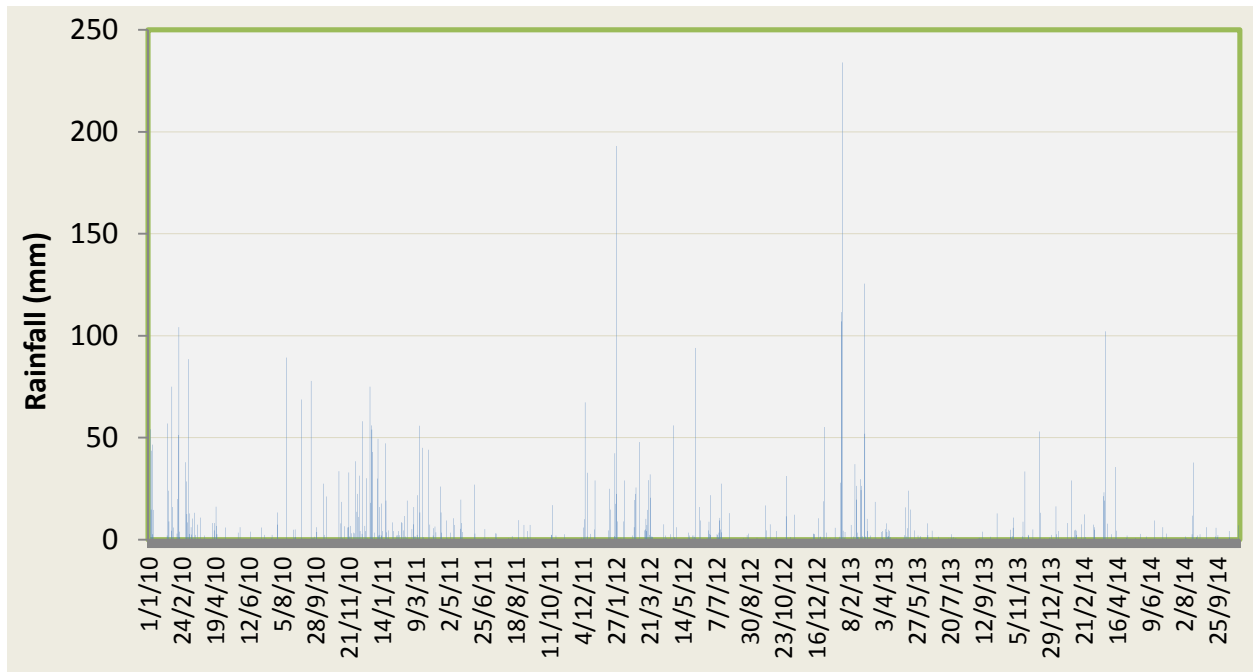


Figure 17. Rainfall intensity, pattern and distribution over the trial period for banana at Bundaberg, QLD.

Irrigation input to the crop

Cumulative applied irrigation water for drip was markedly lower (13.65 ML/ha) compared to that for micro sprinkler (17.72 ML/ha) irrigation (Figure 6). While the crop duration was shorter for MS irrigation (~ 2 years) compared to the drip irrigation (~3 years), the actual crop water used on a yearly or a monthly basis becomes larger for the MS compared to the drip irrigation, suggesting that the applied irrigation water with the MS irrigation is c. 1.5 times that of the drip irrigation for banana production in a ferrosol in Bundaberg (see Figure 18).

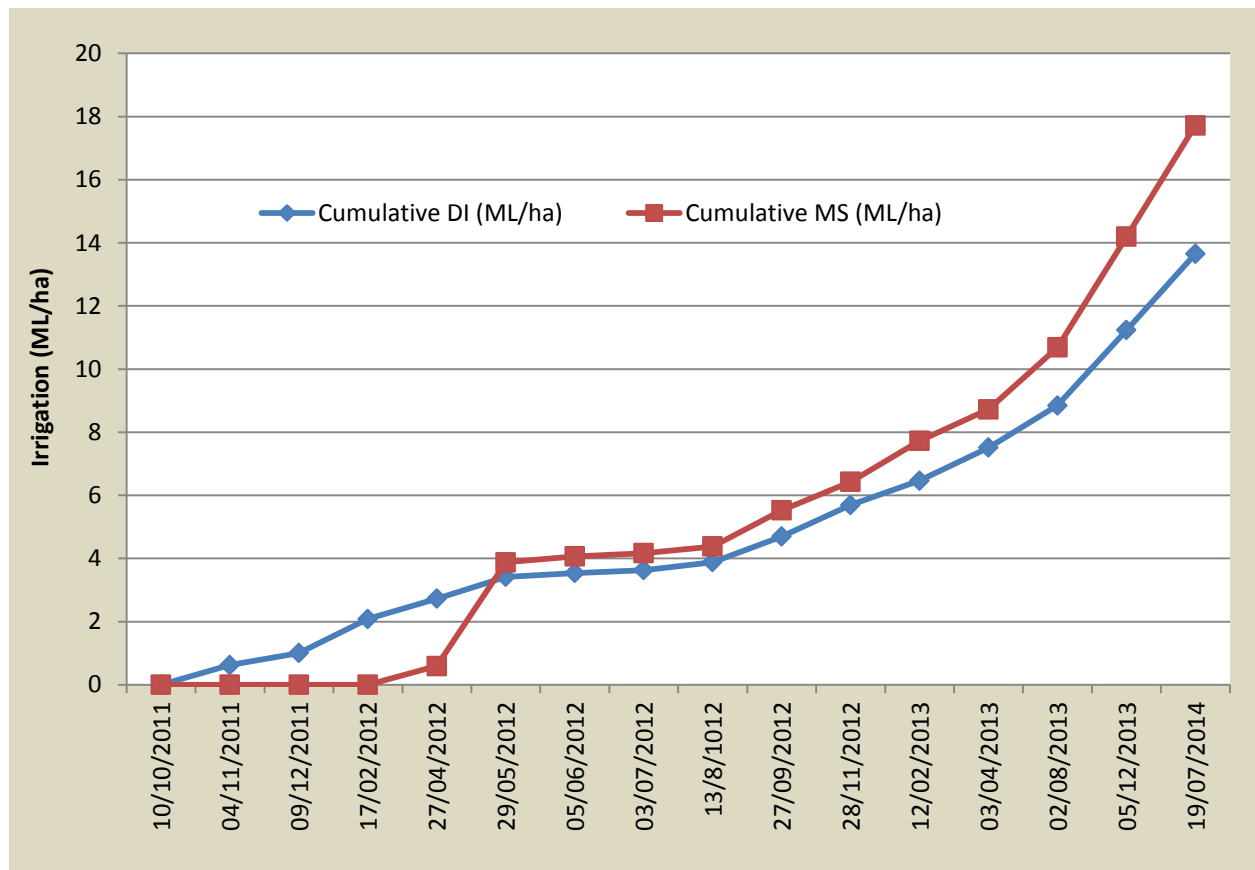


Figure 18. Cumulative irrigation water use in banana for drip and micro sprinkler irrigation systems in Bundaberg, QLD

Soil moisture dynamics

Changes in soil moisture in the profile for the drip (Figure 19 top) and MS (Figure 19 bottom) are presented in graphs. With drip irrigation, the uptake of water is more active from the top 0–20, and 20–40 cm depths whereas in the MS, active uptake has been noticed only on the top 0–20 cm. On a number of occasions the soil moisture in the MS irrigation treatments exceeded above field capacity exposing the root zone to saturation. Continuous monitoring of soil EC allowed opportunities for monitoring of nutrients in the soil profile. In MS higher EC at greater depths below the rooting zone (below 60 cm) suggested that the subsurface movement of nutrients and salts is likely to push the contaminants below the effective rooting depth, contributing to ground water contamination.

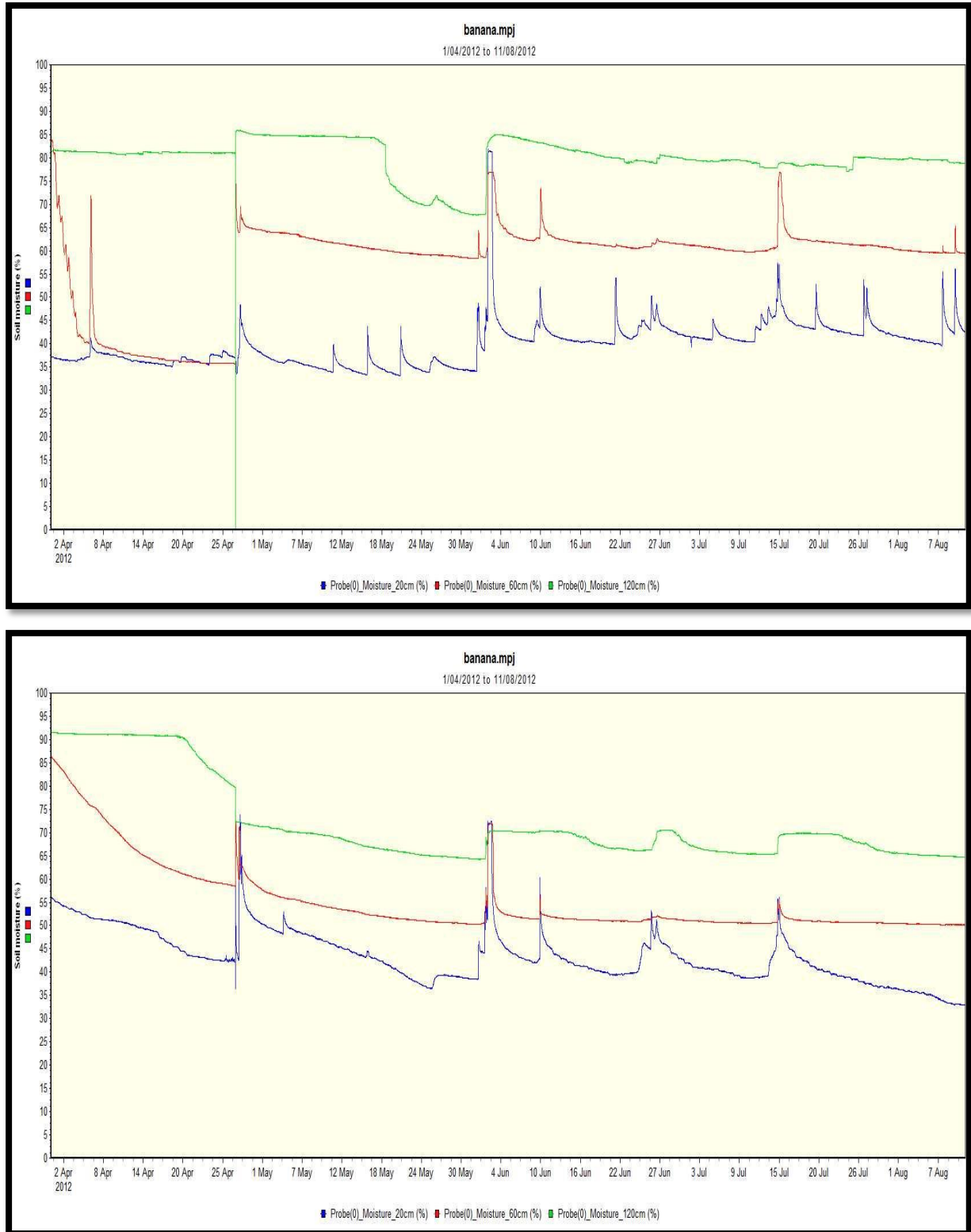


Figure 19. Changes in soil moisture in the profile (top drip irrigation and bottom MS) from April 2012-August 2013. Rapid depletion and frequent re-filling are characteristics of the drip irrigation system compared to the MS.

Soil electrical conductivity

Change in soil electrical conductivity could be a useful tracer for evaluating the flow of ions in the soil profile. Increases of EC in the zone below the rooting depth suggests signs of nutrient transport below the effective root zone of banana, i.e. 60 cm (Figure 20).

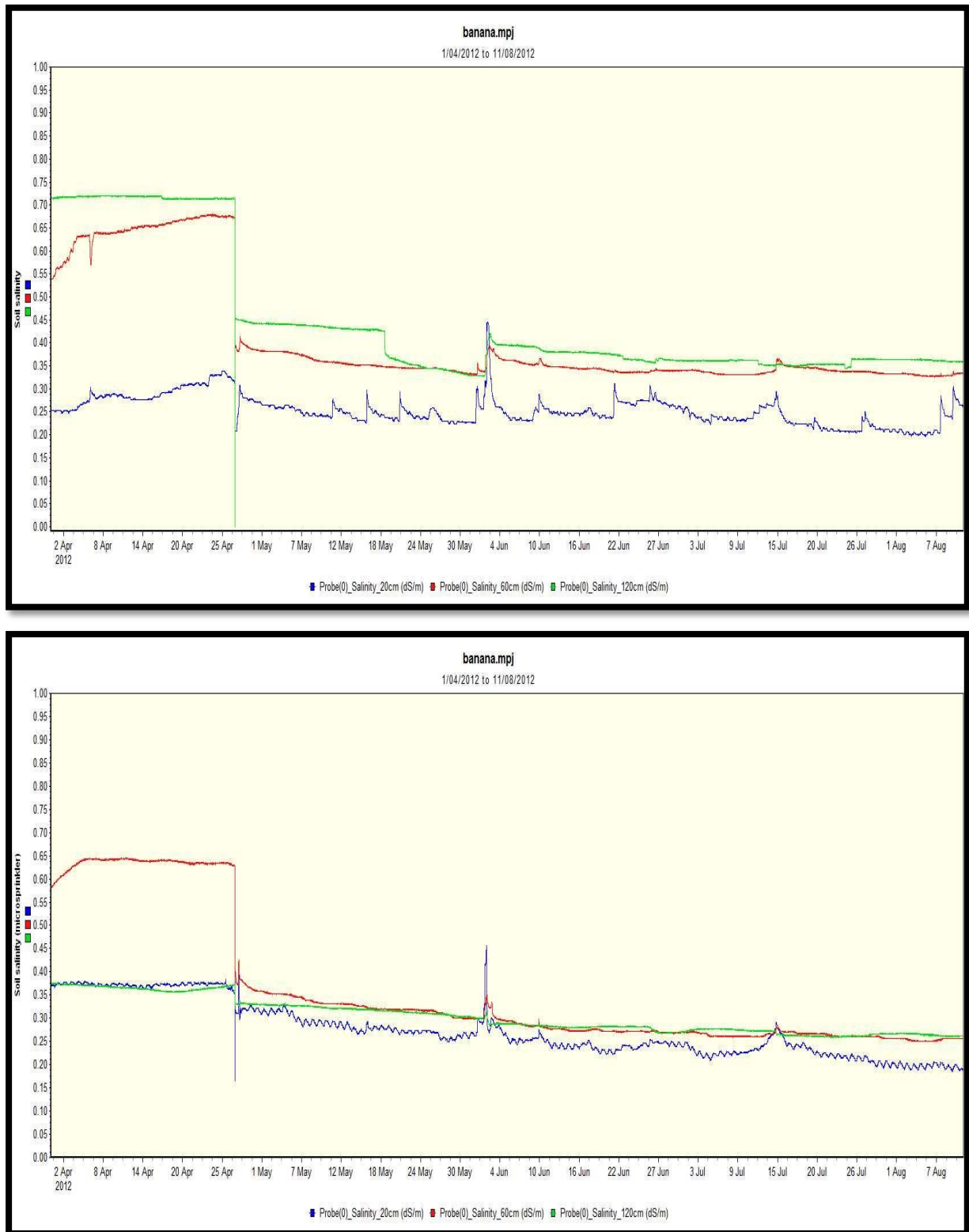


Figure 20. Changes in soil conductivity in the profile (top drip irrigation, and bottom MS) from April 2012-August 2013. A rapid change in the soil conductivity is characteristics of the drip irrigation system compared to the MS.

Water infiltration dynamics

An average soil Infiltration capacity of 24 mm was recorded for the ferrosol with a banana canopy crop cover. However, the differences in spatial patterns were prominent between two irrigation methods. For MS irrigation (Figure 21), infiltration rate gradually increased from the rows of plants, towards the shoulder and inter-row spaces, whereas for the drip irrigation treatment (Figure 22), soil infiltration was highest in the row and lowest in the inter-row and shoulders. The crop in the drip irrigation plot was already established (with a crop age of 4 years). Repeated traffic in the inter row spaces and shoulder could have potentially contributed to compaction causing the lower infiltration in the inter-row and shoulder areas of drip irrigation plot compared to the row spaces of the drip irrigation plot and MS irrigation plot.

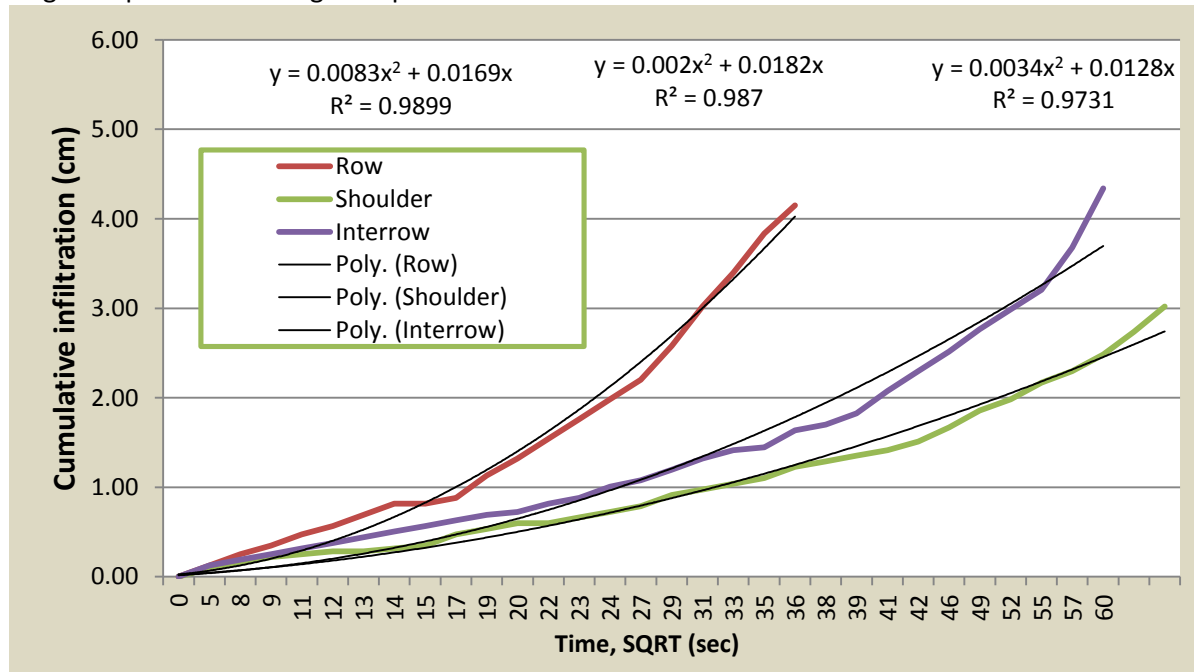


Figure 21. Infiltration under drip irrigation in Ferrosol.

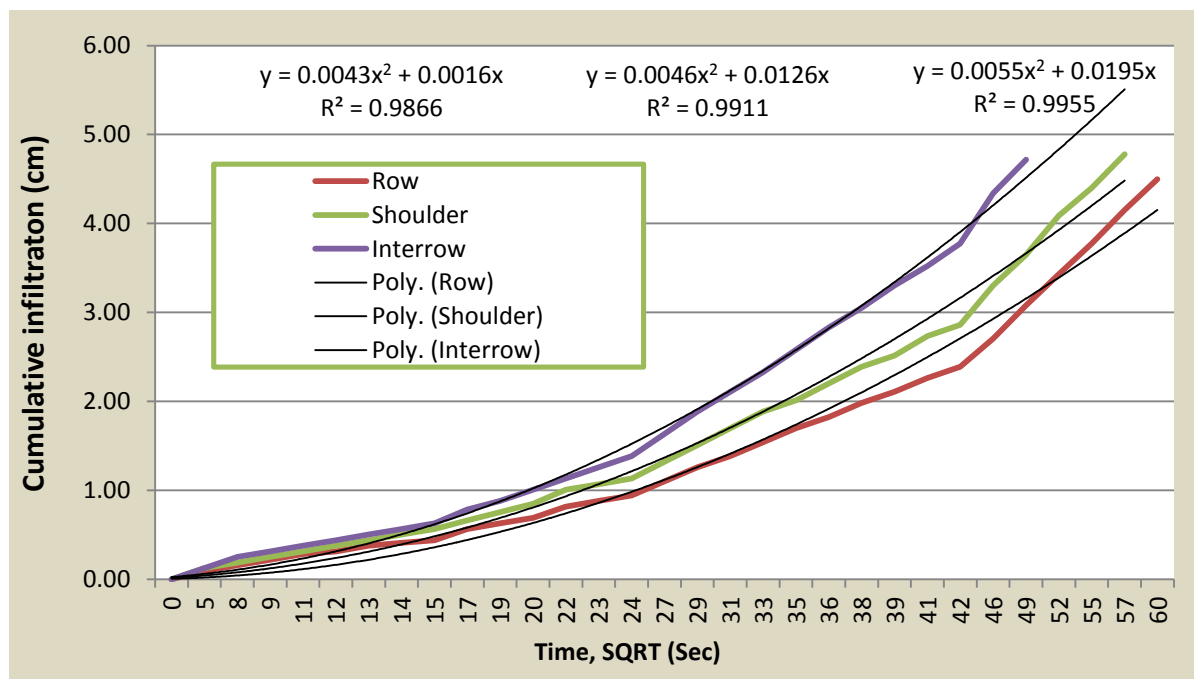


Figure 22. Infiltration under the MS irrigation in Ferrosol.

Soil compaction under different irrigation management

Soil compaction/resistance increased with increasing soil depths irrespective of the irrigation method. The shoulders of the beds were found to be more compact than the row and inter row spaces in the plot, irrespective of irrigation methods. Change in soil resistance at 20–30 cm from the surface was reasonably stable under drip irrigation (Figure 23) but increased with depth greater than 30 cm. In contrast, in MS (Figure 24) the changes in soil resistance were gradual. However, the difference between the treatments was not so obvious for the soil resistance parameters.

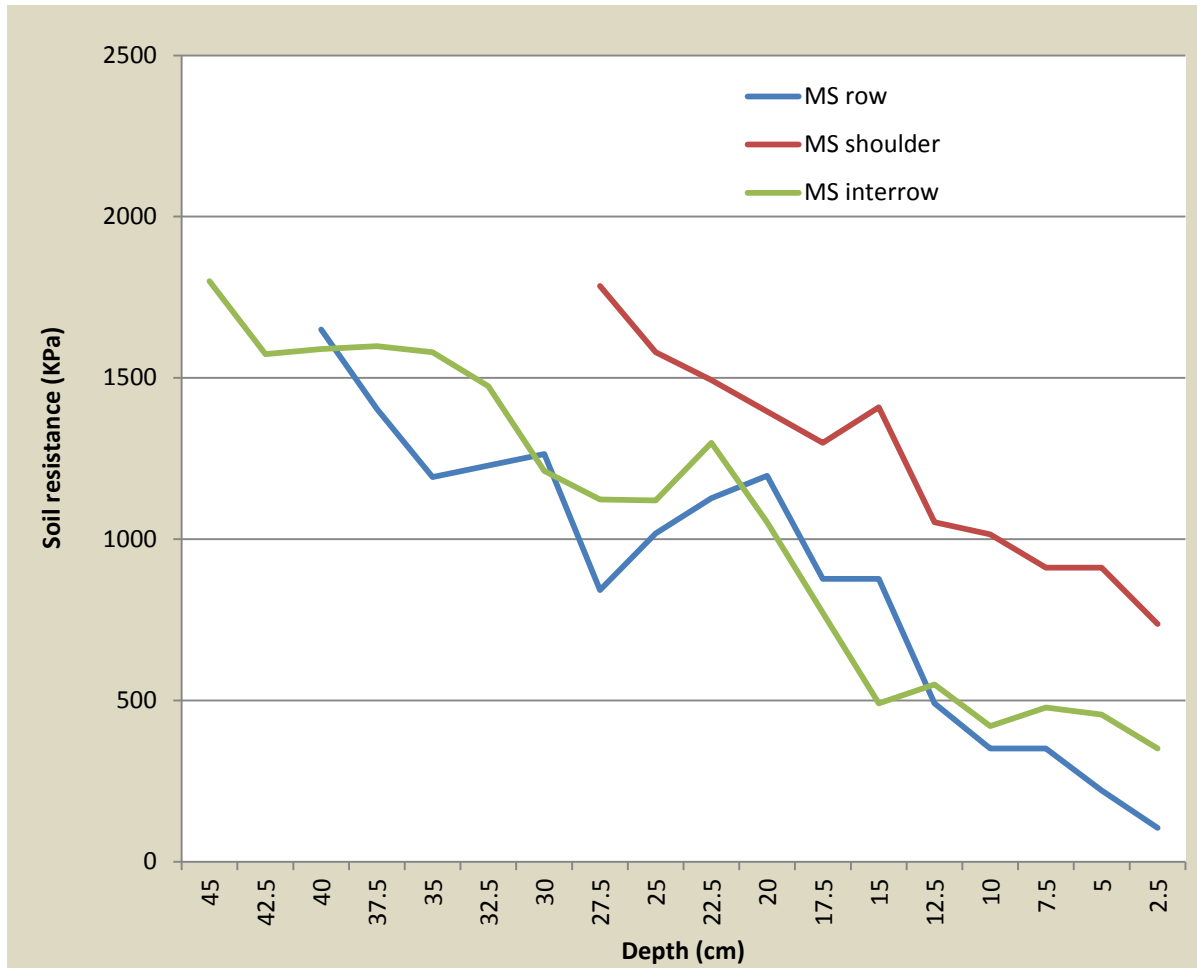


Figure 23. Soil resistance recorded in the soil profile of the micro sprinkler irrigated plot.

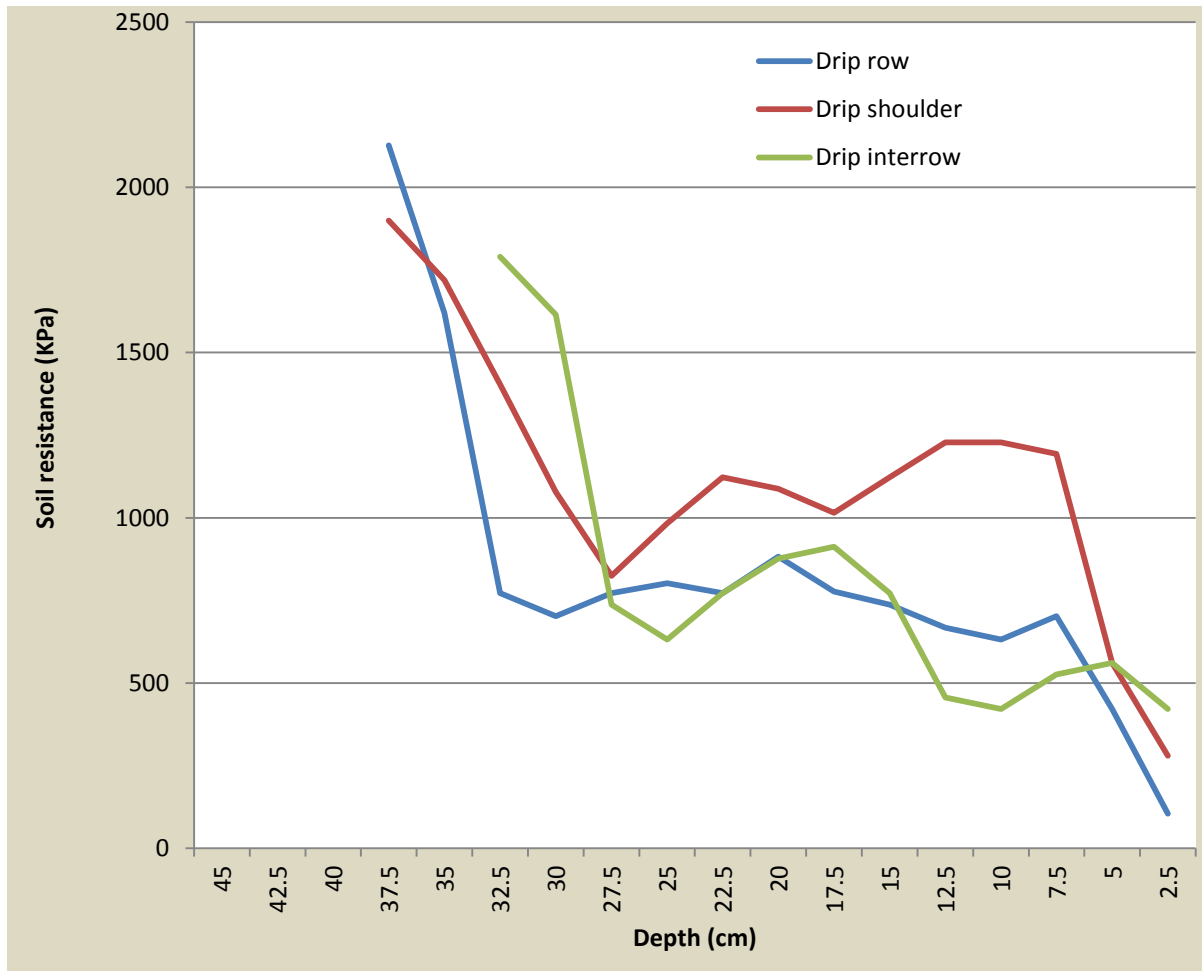


Figure 24. Soil resistance recorded in the soil profile of the drip irrigated plot.

Soil water mass balance for the two irrigation methods

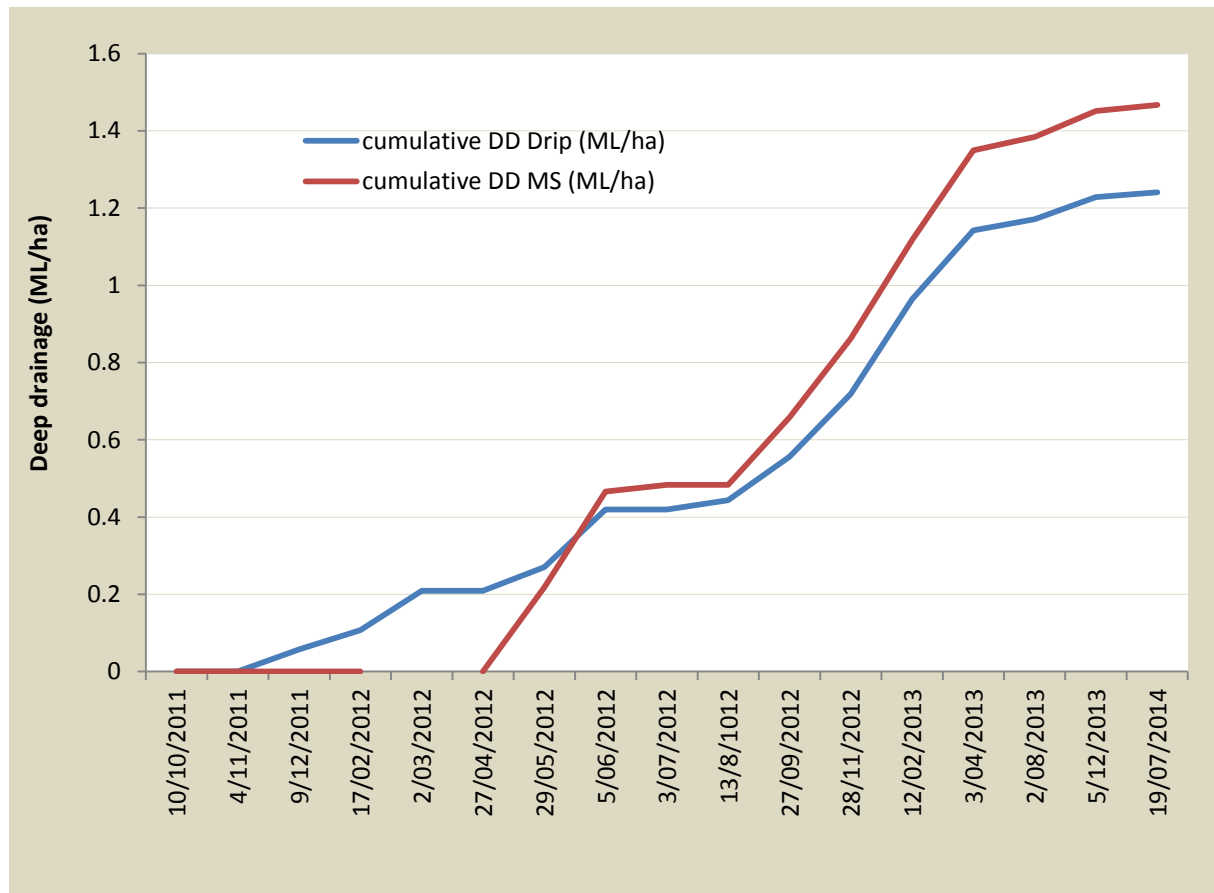
The water input for this site included precipitation, irrigation, and initial stored soil moisture in the profile. The total water input for the crop was 43 ML and 47 ML for the drip and micro sprinkler, respectively, over the period of 3 consecutive crop seasons. The irrigated components of water input comprised 32 and 38 % for the drip and MS irrigation of the total water inputs for the banana crops. Almost two-third of the water input was contributed by the rainfall, equivalent to 29 ML. Of the total water input to the plot, crop water use accounted for 88% and 84% in the drip and MS irrigation systems respectively. The remainder was either lost as deep drainage, run-off, or remained as residual soil moisture in the paddock. Losses due to deep drainage, and run-off were greater in MS compared to the drip irrigation. The combined loss due to deep drainage and run-off accounted for 12% and 16% of total water inputs to the crop for the drip and MS irrigation methods, respectively (Table 6).

Table 6. Components of water input and water outputs (from September 2011 to July 2014) from blocks representing drip and MS irrigation for banana in Bundaberg, QLD.

Components	Drip (ML/ha)	MS (ML/ha)	Contributions
Initial soil moisture	0.286	0.278	Water in
Irrigation	13.655	17.719	Water in
Rainfall	29.1587	29.1587	Water in
TOTAL WATER INPUTS (ML/ha)	43.0997	47.1557	
Deep drainage	1.1392	1.4674	Water out
Run-off	3.88	5.99	Water out
Evapotranspiration	37.8115	39.4303	Water out
Residual soil moisture	0.269	0.268	Water out
TOTAL WATER OUTPUTS (ML/ha)	43.0997	47.1557	
Annual Evapotranspiration (ML/ha)	14.391	15.007	

Deep Drainage

The cumulative deep drainage in the two treatments over the period of the experiment is presented in Figure 25. The large changes in the cumulative deep drainage is also associated with rainfall events.

**Figure 25.** Deep drainage, measured from in ground buried Decagon lysimeters in two trial plots in Bundaberg, QLD.

Greater deep drainage was recorded for the MS than the drip (Figure 25). Most of the deep drainage events were linked to rainfall events that were sizable in nature. The contribution of irrigation to the deep drainage was smaller than that by rain. This was because the grower adjusted timing of irrigation to match the flow through the soil profile, which was then set the basis for scheduling the irrigation.

Run-off from the irrigated paddocks

Cumulative run-off from micro sprinkler irrigation plots was greater than that from the drip irrigation block (Figure 26).

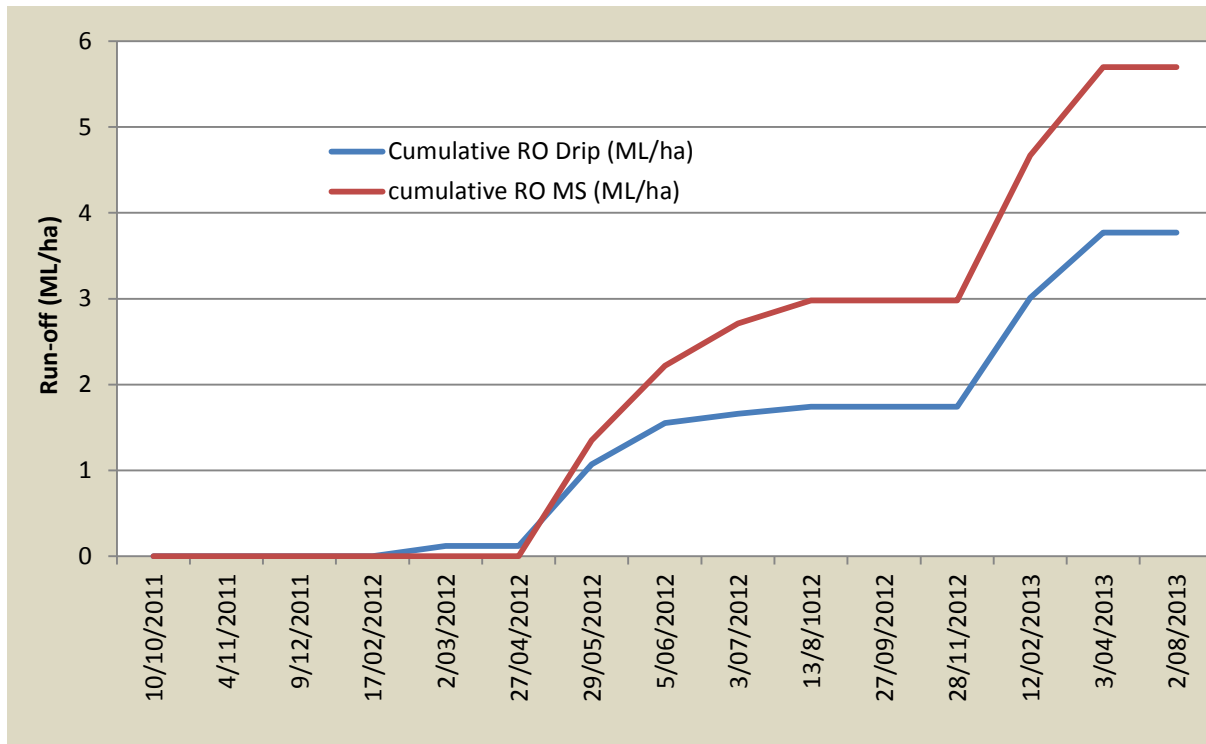


Figure 26. Volumes and date of run-off events recorded for the drip and MS irrigation in ferrosol over the duration of crop cycle.

Water table dynamics

Piezometers were installed in the site to monitor changes in the ground water table and to sample water for herbicide residue. The fluctuation in the water table height was quite rapid in both plots (Figure 27). The water table height ranged between 1 - 2.5 m from the ground surface. The change was largely influenced by rainfall inputs into the plot. During the wetter season, the water table heights were close to the surface and during dry season receded quickly to lower levels. The block with drip irrigation recorded the water table height near one meter from the surface, and the pattern was also similar for the MS plot. Shallow ground water table nearing 1 m and deep crop rooting (up to 70 cm depth), may enhance the ground water - surface water interactions happening in this site with both the treatments. Capillary rise of water from ground water to the rooting zone may occur when the soil moisture deficits can occur in the rootzone when plant transpiration pull for water from rhizosphere is faster.

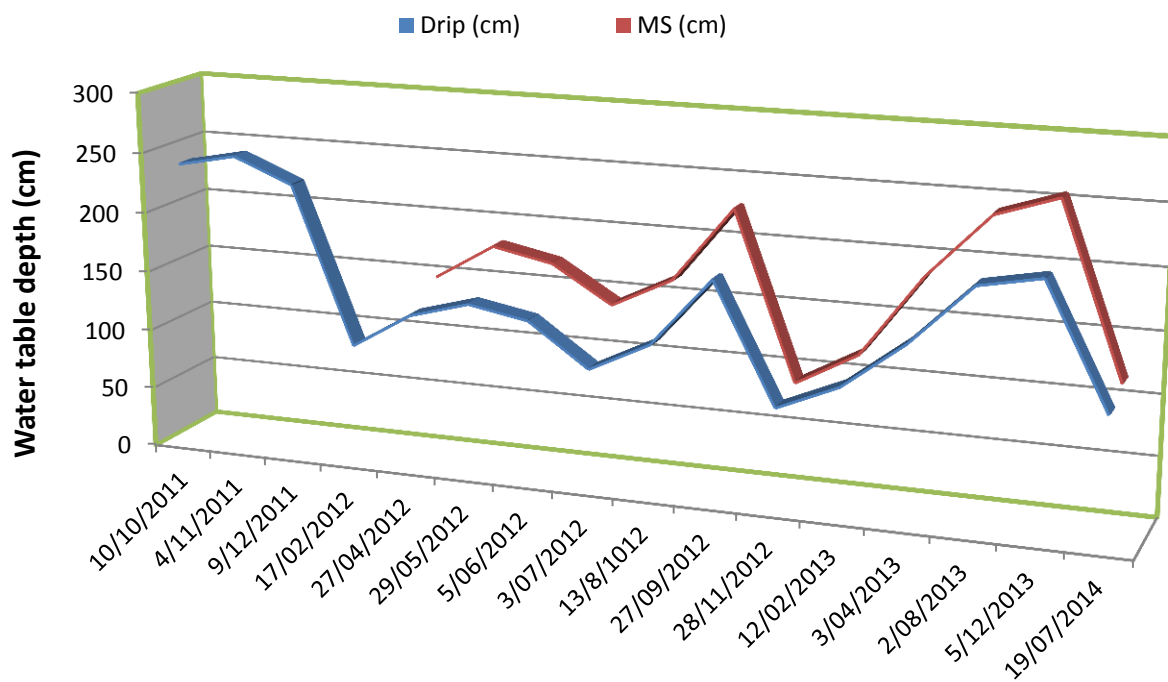


Figure 27. Change in the water table height for the two different irrigation treatments in the banana field trial site in Bundaberg.

Agrochemicals in irrigated banana

Herbicides application in banana

The site generally received four sprays of gramoxone (Paraquat) at the rate of 2.5 L/ha or 3 sprays of Paraquat plus one spray of Basta (glufosinate ammonium) at the rate of 3 L/ha. The details of herbicides application to the trial site over the three year period is outlined in Table 7. Crops received a total of 35-37 kg of herbicides over the three growing seasons. The list of herbicides applied to the soil are shown in Table 7.

Laboratory screening for 40 different herbicides using LCMS methods in a QLD Health laboratory was carried out on ground water collected from drip and sprinkler irrigation plots and also for water samples from irrigation sources at banana trial site at the Bundaberg. Traces of Atrazine and Metolachlor were recorded in the irrigation water source; Imidacloprid was recorded in the ground water from the drip irrigation plot whereas Diuron, Imidacloprid and Metolachlor were recorded for the ground water samples from micro-sprinkler irrigation (Table 8), although these products were not incorporated in the soil during the trial years. The residue from the previous application or the transport of these compounds through shared run-off or aquifers is the likely cause for such cross contamination.

Table 7. Herbicides application to the banana crop at Bundaberg.

Chemical	Rate	Drip (kg/ha)	MS (kg/ha)	Drip (kg/plot)	MS (kg/plot)	Drip area
PARAQUAT DICHLORIDE 250g/L	2.5	2.5	2.5	1.97	2.5	0.788
PARAQUAT DICHLORIDE 250g/L	2.5	2.5	2.5	1.97	2.5	0.788
Paraquat (paraquat dichloride)-11.5% and Diquat (diquat dibromide)-9.8%	3	3	3	2.364	3	0.788
Fluazifop-p-butyl	3	3	3	2.364	3	0.788
PARAQUAT DICHLORIDE 250g/L	2.5	2.5	2.5	1.97	2.5	0.788
PARAQUAT DICHLORIDE 250g/L	2.5	2.5	2.5	1.97	2.5	0.788
PARAQUAT DICHLORIDE 250g/L	2.5	2.5	2.5	1.97	2.5	0.788
Paraquat present as PARAQUAT DICHLORIDE 250g/L	3	3	3	2.364	3	0.788
Paraquat (paraquat dichloride)-11.5% and Diquat (diquat dibromide)-9.8%	3.2	3.2		2.5216		0.788
Paraquat (paraquat dichloride)-11.5% and Diquat (diquat dibromide)-9.8%	3	3	3	2.364	3	0.788
Glufosinate- ammonium 200 g/L	2.5		2.5		2.5	0.788
Glufosinate- ammonium 200 g/L	2.5	2.5	2.5	1.97	2.5	0.788
Glufosinate- ammonium 200 g/L	2.5		2.5		2.5	0.788
Glufosinate- ammonium 200 g/L	2.5	2.5	2.5	1.97	2.5	0.788
PARAQUAT DICHLORIDE 250g/L	2.5	2.5	2.5	1.97	2.5	0.788
		35	37	28	37	

Herbicide screening of 40 different herbicide following the LCMS method in the QLD Health laboratory was carried out for ground water from drip and sprinkler irrigation plots and irrigation source water samples from the banana trial site at Bundaberg. Traces of Atrazine and Metolachlor were recorded in the irrigation water source; Imidacloprid was recorded in the ground water from the drip irrigation plot, whereas Diuron, Imidacloprid and Metolachlor were recorded for the ground water samples from micro-sprinkler irrigation plot (see Table 8).

Table 8. Groundwater, and irrigation water samples analysed for pesticide concentrations at Bundaberg in December 2012 (using HLCMS protocol). Red highlights show values above detection limit.

Sample Description	Method	Units	Reporting Limit	Micro sprinkler	Drip	Irrigation water
Ametryn	29937	µg/L	0.001	<0.001	<0.001	<0.001
Atrazine	29937	µg/L	0.001	<0.001	<0.001	0.018
Bromacil	29937	µg/L	0.001	<0.001	<0.001	<0.001
Desethyl Atrazine	29937	µg/L	0.001	<0.001	<0.001	<0.001
Desisopropyl Atrazine	29937	µg/L	0.001	<0.001	<0.001	<0.001
Diuron	29937	µg/L	0.001	0.001	<0.001	<0.001
Fluometuron	29937	µg/L	0.001	<0.001	<0.001	<0.001
Hexazinone	29937	µg/L	0.001	<0.001	<0.001	<0.001
Imidacloprid	29937	µg/L	0.001	0.007	0.004	<0.001
Metolachlor	29937	µg/L	0.001	0.003	<0.001	2.4
Prometryn	29937	µg/L	0.001	<0.001	<0.001	<0.001
Simazine	29937	µg/L	0.001	<0.001	<0.001	<0.001
Tebuthiuron	29937	µg/L	0.001	<0.001	<0.001	<0.001
Terbutryn	29937	µg/L	0.001	<0.001	<0.001	<0.001
2,4-D	29938	µg/L	0.004	<0.004	<0.004	<0.004
2,4-DB	29939	µg/L	0.004	<0.004	<0.004	<0.004
Acifluorfen	29940	µg/L	0.004	<0.004	<0.004	<0.004
Clomazone	29941	µg/L	0.001	<0.001	<0.001	<0.001
Cyanazine	29937	µg/L	0.001	<0.001	<0.001	<0.001
Ethametsulfuron methyl	29937	µg/L	0.001	<0.001	<0.001	<0.001
Fluroxypyr	29937	µg/L	0.01	<0.01	<0.01	<0.01
Flusilazole	29937	µg/L	0.001	<0.001	<0.001	<0.001
Haloxyfop (acid)	29937	µg/L	0.004	<0.004	<0.004	<0.004
Imazethapyr	29937	µg/L	0.001	<0.001	<0.001	<0.001
Isoxaflutole	29937	µg/L	0.004	<0.004	<0.004	<0.004
MCPA	29937	µg/L	0.004	<0.004	<0.004	<0.004
MCPB	29937	µg/L	0.004	<0.004	<0.004	<0.004
Mecoprop	29937	µg/L	0.004	<0.004	<0.004	<0.004
Mesosulfuron methyl	29937	µg/L	0.001	<0.001	<0.001	<0.001
Metsulfuron methyl	29937	µg/L	0.001	<0.001	<0.001	<0.001
Napropamide	29937	µg/L	0.001	<0.001	<0.001	<0.001
Propachlor	29937	µg/L	0.001	<0.001	<0.001	<0.001
Propazin-2-hydroxy	29937	µg/L	0.001	<0.001	<0.001	<0.001
Sethoxydim (including Clethodim)	29937	µg/L	0.008	<0.008	<0.008	<0.008
Sulfosulfuron	29937	µg/L	0.001	<0.001	<0.001	<0.001
Terbutylazine	29937	µg/L	0.001	<0.001	<0.001	<0.001
Terbutylazine desethyl	29937	µg/L	0.001	<0.001	<0.001	<0.001
Total Imazapic	29937	µg/L	0.05	<0.05	<0.05	<0.05
Triclopyr	29937	µg/L	0.004	<0.004	<0.004	<0.004
Trifloxysulfuron	29937	µg/L	0.004	<0.004	<0.004	<0.004

Fungicides

The crop was sprayed with Tilt at the rate of 400 ml/ha with banana spray oil at 5 L/ha. It was generally applied twice in a year, late in December and early in February. The run-off, deep drainage and irrigation source water were not analysed for detection of contamination with fungicides.

Insecticides

Telstar is generally applied to the base of the plant in early April at the rate of 3.5 L/ha. Industry practice is also to use Fiacam dust applied to the bunches at time of covering at the rate of 10 g/bunch. Fiacam dust is applied to the bunch and then covered with the bag for bunch ripening. With the estimated 1000 bunches harvested per year per hectare, total Telstar use can be as much as 10-20 kg/ha/year in banana farms.

Nutrients movement in the soil with different irrigation methods

Nitrogen is a major fertilizer in the banana industry. Different formulations are applied (potassium sulphate, urea, Calcium-ammonium - Banana Tropics, Banana phoska) at various stages of the crop cycle. Table 9 outlines the calculations for N mass balance for the two irrigation methods. Out of the total 584.2 kg N/ha, N removal by fruits only accounts for 22 - 28% of applied N in drip and MS respectively (Table 9). A significant loss of N is due to run-off and deep drainage, for both irrigation methods. In drip 25% of the total applied N was lost, whereas in MS 37% of the applied N was lost by run-off and deep drainage. Run-off and deep drainage losses were related to the wet weather and rainfall. High intensity heavy rainfall events early in the life of the young banana crop in MS was the reason for a greater loss from MS compared to the drip irrigation. Except for the fruits, all biomass is recycled in the soil by the banana industry. Hence N depravation was not a major issue.

Table 9. Nitrogen mass balance for two irrigation system.

Nitrogen pools	Drip (kg/ha)	MS (kg/ha)
Initial soil N	65.34	58.74
Removal by crop (in fruits)	130.65	45.71
Residual soil N	227.238	250.8
N in standing plants	15.911	13.448
N applied (kg)	584.2	584.2
Run-off and deep drainage	145.061	215.502

Fruit yield/industry yield

A three years cumulative yield of 101 t/ha fruit bunches for drip were much greater than that of MS crop (15.85 t/ha) since MS variety only commenced in 2013. Therefore, MS yield represents one year of harvest only. Average yearly yield is calculated to be 33.67 t/ha for drip and 15.85 t/year for MS. The MS crop was still not at the full bearing stage (Figure 28).

The industry practice in Bundaberg is to harvest only bunches and fruit stems and incorporate the remaining bunches and pseudo stem back into the soil in the same paddock (Figure 29).

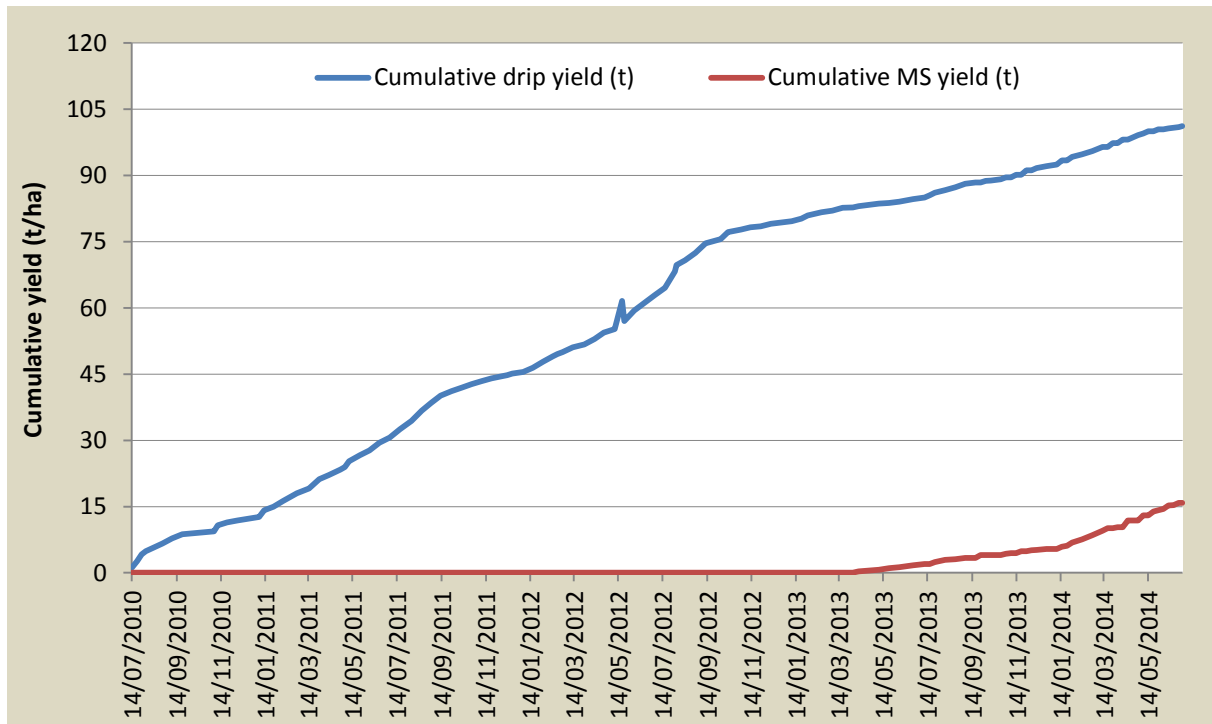


Figure 28. Cumulative bunch yield of banana (t/ha) for drip and micro sprinkler irrigation in Bundaberg in a red clay loam soil.



Figure 29. Industry practice for harvesting, separation and grading of fruits for market. Only whole bunches are collected from field, hand separated and packed into paper boxes for market destination. Photo provided by Grower 3, Bundaberg.

5. Discussion

5.1 *Reflections from trials (Sugarcane and banana)*

The following reflections were drawn from the project trials:

- Grower participation in the research was very active. Collaborators are willing to continue monitoring of soil moisture, changes in ground water and deep drainage.
- Growers are also keen to continue monitoring of water use and movement of water in the soil, as a guide to tracking the movement of nutrients and pesticides.
- Growers continue to use the information from the soil based sensors for managing irrigation and keenly observe the effect of the dose and duration of irrigation for recharge of soil moisture and the contribution to the deep drainage.
- Ground water - surface water interactions could be important factor in the control and movements of the nutrient/pesticides in the banana system where water table was near surface.
- Optimization of drip irrigation for correct timing and dosing of nutrients and water will be ongoing, this is crucial for the banana industry into the future.
- Participating grower in developed confidence and skills to independently manage soil water monitoring devices and to become more involved. This will have positive impact on managing the nutrients and pesticides on farm and generate positive outcomes for the reef and farm.

Participating growers gradually became more engaged and independent in implementation of the irrigation treatments, and there was improved understanding for optimization of drip irrigation at the trial sites. For example, the grower in Home Hill sugarcane site in Ayr, is now fully involved in scheduling the drip irrigation, regular maintenance of drip irrigation and managing it to suit the crop. This aspect is extremely important for achieving the best results from drip irrigation to best harness its power to deliver water use efficiency and water quality outcomes with the drip irrigation.

Similarly the grower at the Bundaberg banana trial site has also realised the value of soil moisture multi sensors and its direct effects on improving water savings and water quality benefits. The grower has started down-loading the data on his own computer using telemetry, then using these data to guide him to make decisions on control of irrigation. Upon installation of a sensor, gains are made in minimizing water input, and off-farm movement of pesticides and nutrients have been achieved by optimizing the systems performance.

In spite of the reported benefits of drip irrigation in other crops, the yield gain in sugarcane with drip has not been fully realised. Optimization of drip irrigation, not only to reduce the off-farm movement of pollutants, but also to maximise the water use efficiency and yield of marketable sugarcane is very important to any future expansion of drip in sugarcane industry. In other countries such as Thailand, the yield of drip irrigated cotton is much higher than in furrow irrigation. Hence long term trials site(s) comparing drip and furrow irrigation, that is largely researcher managed' will allow generation of robust data and produce the crop to the full potential of the drip irrigation; this way it will have impact on rapid adoption of the drip.

Drip irrigation led to reduced run-off during rain events when compared to furrow irrigated sugarcane across the years. This is because SDI which maintains a dry top soil which stores substantial soil moisture during small to medium intensity rainfall events, hence there is less run-off than with furrow irrigation treatments.

Occurrence of deep drainage was more frequent and evident on sugarcane in the Burdekin than for banana. Hence, irrigation management to control deep drainage is as important as management of run-off and discussions with the growers is in place to alter irrigation practices. In the second and

third seasons, optimization of drip irrigation was achieved by scheduling the irrigation based on the crop water use. This way the contribution to deep drainage was reduced significantly.

5.2 Limitations

Effectiveness/ Appropriateness/ Efficiency

Research activities met the target, according to plan. An additional site on banana was equipped for relevant monitoring [banana site at Bundaberg with micro-sprinklers]. This plot started bearing during the last year of the project, therefore we included only one year of yield data from the banana site to compare both treatments within the stipulated time frame of this project.

From a researcher-perspective all activities to date have been appropriate, the outputs and impact were viewed for appropriateness at the first wrap up meeting with sugarcane growers and industry in October 2014. At that meeting [final-project] we also informed participants the gist of the socio-economic survey outcomes, to inform and feedback responses from users of the drip and alternative irrigation methods on this crop.

At the current stage the drip irrigation systems are operating sub-optimally, suffering from root intrusion in sugarcane and practical clogging in Bundaberg. Growers are aware of the efficiency of their irrigation system and willing to keep the system running normally in the forthcoming season. However, allocation of financial support for the work beyond the project phase has not been built in the project, growers are willing to continue on the drip on the trial sites, which gives us opportunity for some data collection beyond the project period.

Comparison of banana run-off, DD and water quality parameters in 2012 was not strongly reflective of the irrigation practices as the crop age, stand and canopy cover are very different. As the micro sprinkler crop has matured and started fruiting with respect to full stand and canopy cover, more comparable data were collected in 2013 and 2014.

The only issue in the banana trial was that crops differ in age between the drip irrigation and mini-sprinkler system. Drip irrigation was superimposed on the crop planted in 2006, while the crop under the micro-sprinkler was planted on November 2011. This creates a major difference in leaf area index, canopy cover, residual crop biomass in the floor and intensity of root density and foraging in the soil, all of which have direct effects on potential run-off and deep drainage. Therefore, direct comparison between the drip and micro-sprinkler irrigation treatments needs to be made with caution.

The sugarcane field site at Home Hill has not been operating under optimised drip irrigation. Two levels of interventions are in place to optimize the irrigation set up. The first approach has been the scheduling of the irrigation so that the crop do not experience water stress between irrigations and the second the maintenance of subsurface drip irrigation using hydrogen peroxide to deter root intrusion, and all plant, soil and water data have been collected, analysis of these data has been agreed as a priority by all collaborators.

5.3 Future Directions

For sugarcane, the impacts on minimizing run-off and deep drainage are significant and positive with drip irrigation. There are parallel benefits in water use efficiency and nitrogen use efficiency with drip irrigation compared to furrow. However, the cane yield in the drip irrigation was not higher or even equal to that with the furrow irrigation in the current trial site. Reviewing the yield of sugarcane from other countries shows that the drip irrigated sugarcane produces higher yield than furrow when it is optimised. Therefore optimisation of drip irrigation may bring the yield of drip irrigated crop to equal

with or higher than furrow irrigation. In fact the optimisation of drip irrigation started in the Home Hill site where work for automation of fertigation and regular cleaning of drip tape was in progress.

Adoption of drip is globally rapid for sugarcane irrigation, unlike in Australia. Drip can significantly increase WUE and NUE, which can be a strong competitive edge for drip/ subsurface drip irrigation, and also offers means for containing pollutants in the farm, therefore with potential benefit/reef outcomes. However, the current installation of drip irrigation is not fully optimised for pulsing of water, nor with the ability to inject the fertilizer precisely with respect to limiting volumes and placement of nutrients in the soil profile. There is a significant opportunity to optimise the drip irrigation for sugarcane production that leads to further improvement in the yield of sugarcane and associated improvements in WUE and NUE. In consultation with irrigation business/industries and growers, we suggest that future research on sugarcane irrigation should critically examine the opportunity for optimization of drip irrigation and use the optimised drip/subsurface drip for improvements in yield, WUE and NUE that generate positive reef outcomes.

5.4 Conclusions

The potential of drip irrigation to minimize the off-farm movement of water and its associated water quality benefits has been shown by the trial activities in sugarcane. Run-off from the drip irrigated plot was significantly lower compared to furrow irrigation for all three seasons. None of the run-off events in the drip irrigated crop was associated with irrigation, unlike in the furrow. Of the total 78 rainfall events contributing a total of 954 mm of rainfall, the rainfall induced run-off occurred only in three major rainfall events that recorded rainfall of 100 mm or more in a single or cumulative rain in consecutive days in year 1. In smaller rainfall events of less than 100 mm, the rainfall was intercepted into the soil which tends to be generally dry in the surface and between the rows of drip tape for the sub-surface drip irrigated crop. This important observation and evidence through data collected over the first season of cane crop, clearly demonstrated the potential for reducing rainfall induced run-off during moderate rain events from drip irrigated crops compared to furrow irrigated sugarcane. The degree to which the soil can intercept and store the rainwater in drip irrigated soil and its ultimate effect on reducing run-off depends on the background soil moisture, surface sealing, and soil compaction prior to rainfall events. Hence detailed prediction must be developed for low, medium and high rainfall events for different background soil moisture regimes in different soil types generating scenarios for run-off in APSIM.

The occurrence and intensity of deep drainage is as high as or greater than the run-off and surface movement of water and has been noted as frequent on sugarcane in the Burdekin and for banana in Bundaberg. Unlike the strong association of rainfall with run-off, almost to the exclusion of irrigation impact on run-off, deep drainage has been notably linked to both irrigation or rainfall. As much as 15% of the total water input into the drip irrigation (222 mm deep drainage out of 1447 mm of irrigation and rain), and 16% the total water input into the furrow irrigation (294 mm deep drainage out of 1850 mm of irrigation and rain) has been recorded as deep drainage in sugarcane trials. Hence, irrigation management to control deep drainage is as important as management of run-off and discussions with the growers are in place to improve the management practices that minimize both run-off and deep drainage in sugarcane and banana farming.

The drip irrigation at the current stage is not fully optimised for control of water and nutrients. Cane yield in the first harvest season on the whole plot harvest basis showed that greater yields were recorded in the furrow irrigation compared to the drip irrigation plots (122 vs 101 t/ha). However, higher sugar content was recorded in drip irrigation cane (CCS 14.1 vs. 13.0). This result in the sugar yield of 15.86 ton/ha and 14.24 ton/ha for furrow and drip irrigated canes respectively.

6. References

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