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Driving better vegetable irrigation through profitable practice change

Final Report

Craig Henderson *et al.*

Horticulture & Forestry Sciences
Agri-Science Queensland
Department of Employment, Economic Development and Innovation (DEEDI)

HAL Project VG07023

Project Leader: Craig Henderson
Principal Horticulturist
Department of Employment, Economic Development and Innovation
Gatton Research Station
LMB 7, M/S 437
Gatton, QLD 4343

ph: 07 54662214
fax: 07 54623223
email: craig.henderson@deedi.qld.gov.au

Key Research Personnel:

Adrian Hunt	(Horticulturist, DEEDI, Gatton Research Station)
Greg Finlay	(Experimentalist, DPI&F, Gatton Research Station)
Neil Huth	(Scientist, CSIRO Ecosystem Services, Toowoomba)
Allan Peake	(Scientist, CSIRO Ecosystem Services, Toowoomba)
Sarah Limpus	(Horticulturist, DEEDI, Gatton Research Station)
Tony Napier	(District Horticulturist, NSWI&I, Yanco Research Station)
Jack McHugh	(Senior Research Scientist, NCEA, Toowoomba)

This report summarises the process and outcomes of a three year project, investigating technologies for improving vegetable irrigation efficiency that are useful, practical, profitable and adoptable. It provides recommendations for root zone monitoring, and the science behind those guidelines. It also details information on optimising drip irrigation infrastructure, and diagnostic tools suitable for irrigation consultants. It describes the development of crop models for sweet corn, broccoli, green beans and lettuce, as well as economic analytical tools, outlining their strengths and potential uses. It also provides recommendations for further research and extension of project results.

The research team gratefully acknowledges the generous financial support of Horticulture Australia Limited and the vegetable levy payers, the Department of Employment, Economic Development and Innovation (DEEDI), NSW Industry and Investment, and CSIRO. We also acknowledge the collaboration of the National Centre for Engineering in Agriculture.

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Table of contents

Acknowledgements

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To all the growers and consultants who let us work on their farms, who asked us the tough questions at field days and workshops, and who told us what they really thought, we are particularly grateful. Without that industry involvement, it would be too easy to get caught up in theoretical exercises, and not focus on the key issues. Your genuine interest, participation and helpful comments were a big part of us staying the distance in such a major undertaking. You made it all seem worthwhile.

To all the folk in the Lockyer Valley, who suffered terribly in the disastrous floods of January 2011, our hearts go out to you. We hope that you can continue to show the resilience, courage, determination and spirits we have seen and lived with for the past few months.

Craig W Henderson

Craig Henderson

Principal Horticulturist, Agri-Science Queensland, DEEDI

Media summary

Despite recent flooding in eastern Australia, the availability/quality of irrigation water is a long-term issue for Australian vegetable growers. To survive, producers are told to implement new technologies. However, there is often little practical information investigating which improvements could make a real difference, and keep production profitable.

In an Horticulture Australia Ltd three year project, scientists from the Department of Employment, Economic Development and Innovation (QLD), CSIRO, Department of Industry and Investment (NSW), and the National Centre for Engineering in Agriculture, evaluated practical irrigation improvements. We conducted experiments and case studies on farms in southern Queensland and Riverina vegetable districts, with over 100 extension events, including irrigation workshops, conferences, and field days.

FullStop™ wetting front detectors were excellent for monitoring root zone conditions in vegetables. They helped understand where water, salts and nitrogen were moving in the soil; particularly beneficial when irrigating with poor quality water, or fine-tuning fertigation. Soil Solution Extraction Tubes were useful for detecting salts or nutrients in deeper soil zones. Because of expertise and labour required, we recommend using these tools to address specific problems, or periodic auditing, not for routine monitoring.

Locating drip irrigation tube close to crop rows (<8 cm), made irrigation management easier. It improved nitrogen uptake, water use efficiency, and reduced risk of crop stress during establishment. If too costly, an alternative would be to push crop rows closer to the drip tube.

The vegetable crop models we developed are good at predicting crop phenology (e.g. harvest date), input use (water, fertiliser), environmental impacts (nutrient, salt movement) and total yields. We are working with industry on two immediate applications - manipulating harvest dates and nitrogen movement in vegetable cropping systems.

In analysing the economics of technologies, accurately assigning yield and price ranges is critical. These variables are the major drivers of accumulated farm profit. In most vegetable systems, reducing required inputs (e.g. irrigation, fertiliser requirement) is unlikely to influence profitability dramatically. However, with a restricted resource (e.g. available irrigation water), it is usually most profitable to maximise return per unit of that resource.

Through web-based information packages, and ongoing consultation with industry, the project team hopes to ensure ongoing adoption of these practical irrigation technologies.

Technical summary

The availability and quality of irrigation water has become an issue limiting productivity in many Australian vegetable regions. Production is also under competitive pressure from supply chain forces. Producers look to new technologies, including changing irrigation infrastructure, exploring new water sources, and more complex irrigation management, to survive these stresses. Often there is little objective information investigating which improvements could improve outcomes for vegetable producers, and external communities (e.g. meeting NRM targets). This has led to investment in inappropriate technologies, and costly repetition of errors, as business independently discover the worth of technologies by personal experience.

In our project, we investigated technology improvements for vegetable irrigation. Through engagement with industry and other researchers, we identified technologies most applicable to growers, particularly those that addressed priority issues. We developed analytical tools for ‘what if’ scenario testing of technologies.

We conducted nine detailed experiments in the Lockyer Valley and Riverina vegetable growing districts, as well as case studies on grower properties in southern Queensland. We investigated root zone monitoring tools (FullStop™ wetting front detectors and Soil Solution Extraction Tubes - SSET), drip system layout, fertigation equipment, and altering planting arrangements. Our project team developed and validated models for broccoli, sweet corn, green beans and lettuce, and spreadsheets for evaluating economic risks associated with new technologies. We presented project outcomes at over 100 extension events, including irrigation showcases, conferences, field days, farm walks and workshops.

The FullStops™ were excellent for monitoring root zone conditions (EC, nitrate levels), and managing irrigation with poor quality water. They were easier to interpret than the SSET. The SSET were simpler to install, but required wet soil to be reliable. SSET were an option for monitoring deeper soil zones, unsuitable for FullStop™ installations. Because these root zone tools require expertise, and are labour intensive, we recommend they be used to address specific problems, or as a periodic auditing strategy, not for routine monitoring. In our research, we routinely found high residual N in horticultural soils, with subsequently little crop yield response to additional nitrogen fertiliser. With improved irrigation efficiency (and less leaching), it may be timely to re-examine nitrogen budgets and recommendations for vegetable crops.

Where the drip irrigation tube was located close to the crop row (i.e. within 5-8 cm), management of irrigation was easier. It improved nitrogen uptake, water use efficiency, and reduced the risk of poor crop performance through moisture stress, particularly in the early crop establishment phases. Close proximity of the drip tube to the crop row gives the producer more options for managing salty water, and more flexibility in taking risks with forecast rain. In many vegetable crops, proximate drip systems may not be cost-effective. The next best alternative is to push crop rows closer to the drip tube (leading to an asymmetric row structure).

The vegetable crop models are good at predicting crop phenology (development stages, time to harvest), input use (water, fertiliser), environmental impacts (nutrient, salt movement) and total yields. The two immediate applications for the models are understanding/predicting/manipulating harvest dates and nitrogen movements in vegetable cropping systems.

From the economic tools, the major influences on accumulated profit are price and yield. In doing ‘what if’ analyses, it is very important to be as accurate as possible in ascertaining what the assumed yield and price ranges are. In most vegetable production systems, lowering the required inputs (e.g. irrigation requirement, fertiliser requirement) is unlikely to have a major influence on accumulated profit. However, if a resource is constraining (e.g. available irrigation water), it is usually most profitable to maximise return per unit of that resource.

Introduction

Vegetable producers are continually contending with changes in their natural, economic, technological, social and political irrigation environments. Drought across Australia, potential influences of climate change, increasing urban water demand, rising water supply costs and deteriorating water quality, means irrigation water has become a productivity-limiting resource in many vegetable growing regions. At the same time, vegetable production is under immense competitive pressure from supply chain forces. These include reduced buyer diversity, loss of export markets, and increasing vegetable imports. Vegetable producers have looked to new technologies, including changing irrigation infrastructure, exploring new water sources, and more complex irrigation management, in an endeavour to survive these natural and commercial stresses (Hickey et. al., 2006). At the same time, there are social and political pressures, (through increased water regulation, natural resource improvement targets, and community expectations of 'best practice' implementation).

Preliminary interviews with vegetable business managers (Henderson 2006) found the decisions to invest in infrastructure and/or practice change did not follow a recipe. They were generally complex; and involved accounting for their particular business in their locality. In many instances, they were 'gut instinct' decisions; a capacity evolved during many years surviving in a competitive industry.

Producers have sought advisory and financial support from sources such as equipment suppliers, industry extension programs (e.g. the QLD Government-funded 'Water for Profit' service operated by Growcom P/L), NRM bodies, government incentive schemes, and public and private R&D and consultancy services. The solutions arrived at reflect the complexity of the operating environments, the availability of the various advisory/support mechanisms, and suitability of technologies or practice change to the individual vegetable producers. However, often there is no clear information on which technology improvements could markedly improve outcomes for vegetable producers, and external communities (e.g. meeting NRM targets, or water use efficiency benchmarks).

The processes have led to inefficiencies in resource utilisation (public and private investment in inappropriate technologies), and costly repetition of errors (as each individual business independently finds out the pros and cons of technologies and techniques by personal experience).

Many extension and incentive programs are currently in place to encourage practice change in vegetable businesses. The assumptions underlying some of these programs are that solutions already exist, and it is simply a matter of grower learning and perhaps a minor financial carrot, for successful adoption.

Research by Henderson (2003) clearly demonstrates that the 'obvious' solutions are not necessarily profitable; depending on the underlying factors such as input costs and availability, output prices, and market volume. Pannell et al. (2006) reviewed adoption of practices by rural landholders, and similarly determined that slow or negligible adoption is most commonly due to the unprofitable nature of the advocated changes 'at the business level', and/or the complexity of making the practices work, (or even able to be trialled).

The aim of this project was to work with R&D partners, to investigate irrigation technology improvements that can make worthwhile changes in the performance of irrigation systems and practices. Through engagement with industry and other researchers, we sought to identify those technologies that were most applicable to vegetable growers, particularly those that addressed priority issues.

A significant area of project effort was to develop analytical tools that could help conduct ‘what if’ scenario testing of technologies. Our CSIRO project partners considered they could develop vegetable biophysical models using the APSIM platform currently focussed on broad acre crops. We also wanted to build economic tools that could examine the likely profitability/adoptability of selected technologies.

Using experimental evaluations, workshops and producer case studies, we were looking to see which technologies were practical, gave meaningful results, and delivered desirable outcomes for both the producer and the broader community. We were also looking to reduce constraints that make technologies less adoptable.

It was important to engage relevant industry partners, including vegetable producers, irrigation equipment and service suppliers, and technology organisations. Our intent was to build a core of industry and commercial expertise in these technologies that would persist beyond the life of the project.

At the end of the project, we aimed to have determined which irrigation improvement technologies made sense in particular growing circumstances. We wanted to provide information on how to best use them, and the practical considerations, nuances and risks associated with their adoption. We wanted to develop analytical tools that could predict the impacts of technologies on crop performance, environmental impacts, and economic outcomes for producers.

We also looked to inform policy makers (governments, water suppliers, NRM bodies) on the reality around the likely impacts of irrigation improvements, and the practicalities associated with adoption.

References

Henderson CWL (2003). High priority reasons for vegetable producers to adopt improved irrigation management strategies. RWUEI Project 18 Final Report. http://www.nrw.qld.gov.au/rwue/pdf/research/fr2003proj18.pdf

Henderson CWL (2006). Maximising returns from water in the Australian vegetable industry: Queensland report. NSW Department of Primary Industries, Orange NSW.

Hickey, Hoogers, Singh, Christen, Henderson, Ashcroft, Top, O’Donnell, Sylvia and Hoffmann (2006). Maximising returns from water in the Australian vegetable industry: national report. NSW Department of Primary Industries, Orange NSW.

Pannell DJ, Marshall GR, Barr N, Curtis A, Vanclay F, and Wilkinson R (2006). Understanding and promoting adoption of conservation practices by rural landholders. Australian Journal of Experimental Agriculture 46 (11), 1407-1424.

Project research

Because this project involved a broad range of component activities, we describe each of these in a separate section. We have presented them in descending order of intensity of effort and result. This intensity reflected both the priorities we received during feedback at field days and showcase events (see Extension activities), and the progress we made during the project. The research is only summarised here; more information is available from the project leader.

At the lead of each section is a report on key findings from that project activity. Following is a brief description of the focus of that activity, and then reports on experiments and case studies associated with the activity.

Managing solutes in vegetable root zones

Key findings

- Because of the time-consuming nature of using these root zone tools in short-term vegetable crops, in their current versions these tools are more about problem identification and solution development, rather than routine monitoring technologies.

- FullStop™ wetting front detectors are an excellent tool for monitoring root zone conditions. Their triggering, and the information from their extracted solutions, are easier to interpret than values from Soil solution extraction tubes (SSET). FullStop™ instruments should be installed in pairs, a shallow instrument within the main root zone, and a second below the root zone (but no deeper than 60 cm). The shallow instrument should be installed at a depth that regularly triggers after each significant irrigation; err on the side of being too shallow.

- Soil Solution Extraction Tubes (SSET) are best used to indicate changing trends over time, rather than providing absolute values. SSET only work effectively when the soil is moist-wet. SSET are a good option for monitoring soil solutes beyond the depth range of the FullStops™. SSET instruments should be installed in pairs, a shallow instrument within the main root zone, and a second below the root zone.

- In drip irrigated crops, FullStops™ or SSET are best located under the drip line. In overhead-irrigated vegetables, locate the instruments as close as possible to the crop row.

- It was always easier to interpret root zone solute measurements if we had other strands of information. If using SSET, it is vital to have a measurement of soil water status, preferably a measure of soil water tension (e.g. tensiometer). A useful suite of information is FullStop™ triggering, EC and nitrates from FullStop™ extractions, soil water tension, and sap analysis.

- Managing/leaching salts with drip irrigation is complex, particularly if the leaching water is itself poor quality. Root zone tools can indicate if leaching is being effective. Sometimes results are counter-intuitive.

- With effective root zone management, even sensitive vegetable can be grown with poor quality water (we grew a good lettuce crop with 4.5 dS/m irrigation water on a black, cracking clay soil).

- All the case study growers were doing relatively well managing water and nutrients. In most instances, there was some room for improving efficiency of irrigation, and reducing nitrogen use.

- In most of the experimental and grower case study situations we encountered, inherent nitrogen levels were relatively high. We never got a yield response to additional nitrogen beyond the lowest levels used in our experiments. On several occasions, we achieved maximum yields of sweet corn with no side dressings. With more work, there may be opportunities for lower nitrogen rates in many crops, provided we successfully manage irrigation.

- In several instances, we found high surface EC levels associated with use of composted soil amendments. Producers need to be aware of the analysis of their composts.

Activity focus

In initial consultations at extension activities, and in discussions with individual growers and consultants, there was significant interest in root zone monitoring tools. At the time, there were significant water shortages in vegetable growing regions throughout Australia. Vegetable growers were resorting to using poorer quality water, using drip systems, and really trying to conserve their irrigation by watering sparingly. Consequently, our project team felt it was very important to provide tools and information that could drive profitability in those circumstances. Producers needed to be confident of achieving good yields under those conditions, as well as not be setting themselves up for environmental issues into the future. These could include problems with salt build up, or excessive movement on nitrogen off-site.

Our project team had the opportunity use both FullStop™ and Soil Solution Extraction Tubes (SSET) to monitor root zone conditions, along with more conventional methods of soil and plant sampling. At field days, group presentations and in individual requests, these were the tools and information we were most often asked about.

As we conducted this work, we did not anticipate several spin-off outcomes. We are continually being requested to provide information and advice on the use of the FullStop™ for a range of situations. Following discussions with our research team, the tools have been used to monitor movements of soil-applied insecticides in sweetpotato cropping, nitrate movements in banana cropping, and more recently, nitrate balances under improved capsicum root system architecture.

Projecting into the future, as nitrogen management becomes even more scrutinised, due to greenhouse-gas abatement requirements, the use of these types of tools will become even more critical. Likewise, despite recent flood events, efficient use of irrigation water, including effective management of salts and nutrients, will remain a national and international priority. The experiences and expertise detailed here will provide useful information for both producers and scientists as we move into that future.

The following introduction (Soil solute sampling in irrigated vegetables; FullStop™ wetting front detector; Soil solution extraction tubes) has been extracted from the three project factsheets relating to root-zone solute monitoring in vegetable crops (see Publications under Extension activities). It provides a brief background into why monitoring root zone solutes is important, and the key knowledge required to successfully implement these technologies.

Because of the time-consuming nature of using these root zone tools in short-term vegetable crops, these tools are more about problem identification and solution development, rather than routine monitoring technologies. For example, using root zone monitoring tools showed farms as diverse as a capsicum grower on the sandy Granite Belt, and a cabbage grower on clay loam Lockyer soils, were both efficiently managing nitrogen, despite different irrigation strategies and water qualities.

Following the introductory information are several reports written during the project, outlining various experiments and grower case studies. They demonstrate a range of issues and findings associated with monitoring and interpreting solute signatures in irrigated vegetable crops.

Soil solute sampling in irrigated vegetables

Introduction

Ranges of solutes are dissolved within soil water. Solutes can positively affect plant growth when at sufficient levels, or negatively impact when deficient or excessive. Monitoring soil solute concentrations, in relation to crop growth stages, soil conditions, management practices and weather events, may be an opportunity to improve our farming systems.

Tools for solute sampling

A variety of solute sampling tools can be used for monitoring changes in vegetable root zone conditions during cropping. FullStop™ wetting front detectors and soil solute extraction tubes (SSET) are two systems that have been used for collecting solute samples in several horticultural industries.

The FullStop™ wetting front detector is built around a buried funnel that concentrates wetting fronts into a reservoir. Collected solution triggers a flag to indicate that the wetting front has arrived. The solution can then be withdrawn via a tube. A FullStop™ wetting front detector requires a hole 20-25 cm in diameter and 15-60 cm deep to be excavated and refilled, for its installation and recovery.

SSET have a ceramic tip on the base, which is buried below ground. In contrast to wetting front detectors, the SSET we use only require a 19 mm diameter hole for root zone insertion. A rubber bung on the top creates an airtight seal. In-situ, suction is applied to the tube, which extracts water through the ceramic tip from the surrounding soil. This infiltration can take hours/days. A sample can then be removed and analysed.

Each tool has advantages and disadvantages. For instance, FullStop™ wetting front detectors sample from a larger area, and can be more easily related to specific irrigation or rainfall. SSET are generally easier to install than wetting front detectors. The cumulative time required for installing, monitoring, interpreting and retrieving sampling tools on a regular basis can be substantial. Users should evaluate how well this may fit with their other cropping operations. Potentially cost-effective automation systems for sampling are being developed, but are not yet widely available.

The recommended sampling strategy generally involves installing one sampler mid root zone, with a second unit below the root zone. Variability between samplers means that several replicates are recommended for each crop being assessed.

Sample analysis

Total salt levels and nitrate are the two solute measurements most likely to be of interest to vegetable growers.

Electrical conductivity (EC) is regularly used as an index of the total concentration of salts in solution. It is easily measured in the field with a hand-held conductivity meter.

Nitrate concentrations can be determined using a range of nitrate test strip products, selective ion electrodes or sent away for laboratory analysis. Some changes in nutrient concentrations can occur due to natural microbial and chemical activity in the collected sample. In order to prevent these changes from occurring, samples for nitrate determinations can be stored in a freezer prior to analysis.

Note that freezing can precipitate some ions. Therefore testing for electrical conductivity is best carried out prior to freezing. Where processing on the day of sampling is not practical, or where samples are likely to get hot in transit from the field, storage for up to one day in a fridge or esky is acceptable.

Opportunities

Soil solute concentrations constrain biological systems, including microbiological activities, nutrient uptake, and ultimately vegetable performance. They can also influence soil condition and offsite environments, including groundwater, riverine and marine aquatics. Soil solute sampling offers us an opportunity to better understand how farm management practices impact on solute movements in our production systems and the broader environment.

In the short term, benefits from monitoring soil solute concentrations are most likely to accrue where changes within a cropping season are large, with potential to limit vegetable crop growth or detrimentally impact on the environment. Typically, this would occur in areas with coarse-textured, permeable soils that are inherently susceptible to leaching. Other common scenarios are conditions likely to lead to salt accumulation in the topsoil, such as irrigation water with significant salt or nutrient levels, deficit irrigation in low rainfall environments, or production systems with few leaching opportunities.

As instrumentation and monitoring systems are refined, soil solute measurement has the potential to be a key feedback mechanism for a range of management inputs.

Interpretation

Tracking changes in soil solute concentration should ideally be integrated with other records of influence. Examples include irrigation timing (quality and volume), rainfall, fertiliser program, and crop growth stage.

In using these tools, we have found trends in solute concentrations over time, rather than precise concentration values, to be the most easily interpreted and actionable information. For example, if mid root zone EC is increasing over time, it suggests salts are accumulating in the root zone. This could eventually be detrimental to crop performance. Depending on the rate of accumulation, relative crop tolerance, and time to harvest, this may be unimportant for the current crop. It may however require a plan for removal before the next crop is planted. This could involve simply waiting for a leaching rain, or implementing a specific leaching irrigation. Another easily interpreted signal is where root zone nitrate levels fall, whilst nitrate levels below the root zone rise following a substantial irrigation (indicating leaching).

The impact of nitrate concentration and salinity on crop yield and quality varies greatly between vegetable crop species and cultivars. It even differs with the stage of crop development. This variability makes the development and use of solute concentration guidelines difficult. Instead, we recommended using solute concentrations through time as learning tools. Look at trends in solute concentration as crops grow, and in response to management decisions and environmental influences, rather than seek prescriptive, inflexible decision points.

Conceptually, salinity levels in the root zone are kept low to minimise impacts on plant growth, while nitrogen levels are maintained at sufficient levels to meet crop demand. Excess nitrogen may be wasteful and have potentially negative environmental impacts.

Other resources

Falivene. S, 2008, "Soil Solution Monitoring in Australia" CRC for Irrigation Futures Matters Series No 04/08. NSW Department of Primary Industries and IF Technologies. Australia.

www.fullstop.com.au

FullStop™ Wetting Front Detector

The FullStop™ wetting front detector is built around a buried funnel that concentrates wetting fronts into a reservoir. Collected solution triggers a flag to indicate that the wetting front has arrived. The solution can then be withdrawn via a tube.

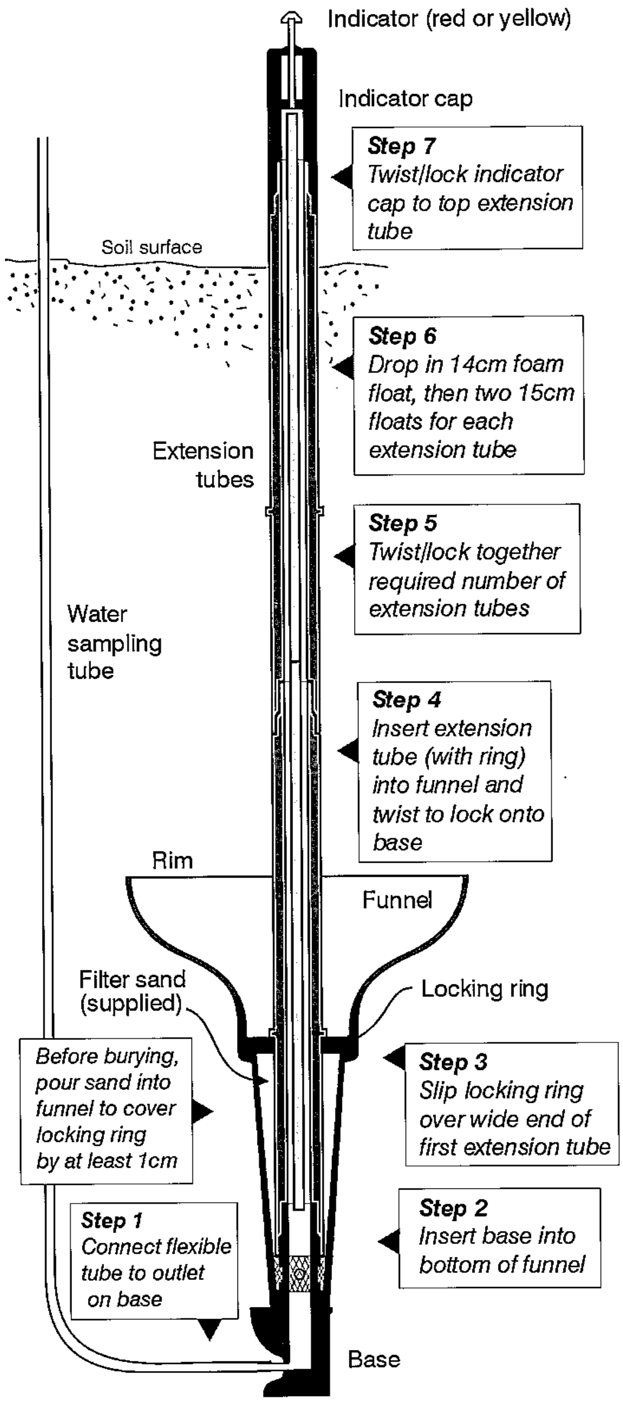
Installation

There is a direct relationship between installation depth and sensitivity of a FullStop™ wetting front detector to irrigation or rain. Deeper installations will usually have fewer trigger events in a given time period. Generally, detectors are installed in pairs. We recommend one detector roughly mid-rooting depth. Install the second detector in the lower root zone, up to 60 cm below the surface. Installation below 60 cm may result in few triggering events, with most irrigation wetting fronts likely to be too weak. In drip irrigated vegetables, place both FullStop™ detectors directly under emitters. This will maximise the chance of detecting wetting fronts.

Prior to installation, check the FullStop™ for leaks and function. Ensure that adding water to the funnel triggers the float/indicator flag.

Before installation, pour filter sand into the FullStop™, to a level 1 cm above the locking ring. To install the FullStop™, auger or dig a hole (at least 22 cm diameter) to the intended placement depth. The installation depth is the distance between the locking ring in the core of the funnel and the soil surface. Take care to retain the removed soil in a way that allows for its return to the hole to rebuild the soil profile. Auger a second, 6 cm diameter hole in the centre of the initial extraction, to a depth 20 cm below the initial hole. Lower the FullStop™ into the excavation to check the depth.

Then back fill soil to re-establish the profile as close as possible to its previous sequence and structure. Gentle firming down by hand whilst re-filling the hole will help with this. Generally, some soil will be left over when re-filling the hole. Place this soil on top and next to the hole - subsidence over the next few weeks should leave the soil level. Connect the solute sampling tube to a plastic stake above ground level, to prevent any contaminants from entering the tube.



Solute sampling and interpretation

When the indicator flag has been triggered, there should be a solution sample stored in the base of the FullStop™ ready for collection. To remove the solution, attach a syringe to the sample extraction tube and suck the solution out. Then manually reset the indicator flag.

Wetting front detectors can be used to gain information about the soil water and salt/nutrient movement implications of rain or irrigation.

The presence of a strong wetting front tells us where water has reached in the vegetable root zone. A triggered detector positioned within the root zone indicates that sufficient water has been applied to wet that part of the root zone. Where detectors positioned below the root zone are triggered, this indicates that more water was applied than was required to refill the root zone.

Management and interpretation of the solute signal are as outlined in the previous general solute sampling section.

Soil Solution Extraction Tubes

Soil solution extraction tubes (SSET) have a ceramic tip on the base, which is buried below ground. A rubber bung on the top creates an airtight seal. In-situ, suction is applied to the tube, which extracts water through the ceramic tip from the surrounding soil. This infiltration can take hours/days. A sample can then be removed and analysed. Tracking changes in the concentrations of extracted solutes over time may give insights into the impact of crop management practices (such as irrigation and fertiliser application) on the crop root zone.

Pre-installation

Inspect soil solute extraction tubes (SSET) for damage in the tube or ceramic tip. If you immerse the SSET tip in a bucket of water, it should hold applied suction for several minutes. Alternately, pump air into the SSET and place under water. A rapid stream of large bubbles will indicate if there is a leak, and its location.

Installation

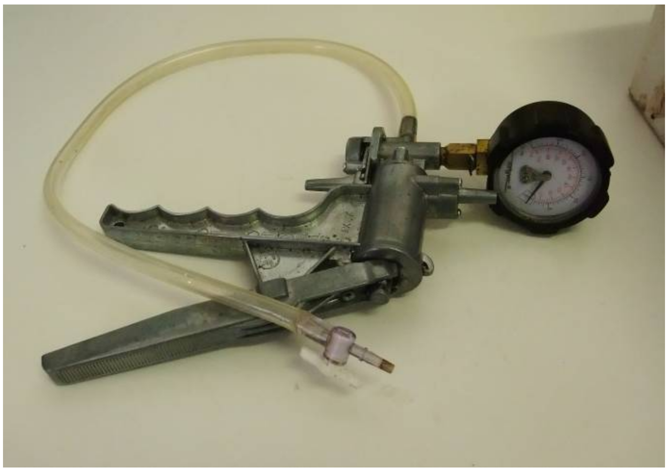
SSET are general installed in pairs, with one tube roughly mid root depth, and the second Installed below the expected root zone. Placing SSET in areas that are frequently moist (such as close to drippers) will yield samples more reliably. Placement should also be close to plants, to sample solutes where they are most likely to impact on growth.

Successful installation of a SSET is dependent on establishing good contact between the porous ceramic tip and surrounding soil. On fine textured soils, it may be sufficient to auger a hole that is a tight fit and insert the SSET to the bottom. Use a small amount of water as lubricant, and to help establish soil water contact with the tip. Cleaning the hole out properly is critical. Obstructing material will make it difficult to insert the SSET

In other soils, you may need to auger an oversized hole (e.g. 50 mm diameter) to the requisite depth. Lightly pack a well-moistened, putty-like consistency of local soil at the base of the hole, and then insert the SSET. Once good contact with the tip is established, refill the hole as close to the original profile distribution as possible.

Applying suction

You should apply consistent suction for each sampling event. A hand operated vacuum pump (with gauge attached), such as those produced by Mitivac™ will help with consistency, especially where taking a large number of samples.



As an alternative, to reach a suction of ≈ 60 kPa, the amount of air needing to be removed using a 60 ml syringe is:

- 30 cm deep SSET = 2*60 ml extractions
- 60 cm deep SSET = 3*60 ml extractions
- 90 cm deep SSET = 4*60 ml extractions

The SSET then needs sufficient time to extract soil water solution from surrounding soil. The time taken will depend on the soil water content, texture, structure, and volume of solution required. Getting a testable volume may take only a few hours in wet, loamy soils. Drier clay soils may take several days. Samples are most readily extracted when the surrounding soil is at a low soil water tension. Therefore, periods after irrigation or rainfall are generally best. As with applied suction pressures, try to be consistent.

Collecting samples

Once a sample has collected in the bottom of the SSET, it can be removed by connecting a syringe to the tap and withdrawing the solution. Use a clean syringe for each sample to prevent cross contamination.

Management and interpretation of the solute signal are as outlined in the previous general solute sampling section.

Electrical conductivity of root zone soil water, and marketable yield of an iceberg lettuce (*Lactuca sativa*) crop, irrigated with different water qualities.

(Experiment report prepared for Irrigation Australia Limited Conference, Sydney 2010.)

Adrian Hunt[1*], Craig Henderson[1], Greg Finlay[1]

[1] Agri-science Queensland, Queensland Department of Employment Economic Development and Innovation

* Corresponding and presenting author, adrian.hunt@deedi.qld.gov.au

Abstract

Declining irrigation water availability and quality are common features of many Australian horticultural regions. This is a concern for irrigators as it may lead to an accumulation of salts in the root zone. FullStop™ wetting front detectors and soil solute extraction tubes (SSET) have previously been used for assessing soil solutes in perennial crops (Falivene, 2008). Iceberg lettuce (Lactuca sativa) is a short season, shallow rooted crop; moderately sensitivity to irrigation water/soil salinity (Grattan, 2002, Mass and Hoffman, 1977). In 2009, we grew iceberg lettuce using irrigation treatments of (i) bore water with an EC of 3 dS/m and (ii) bore water with additional NaCl, delivering an irrigation water EC of 4.5 dS/m. The site was a well-drained, black, self-mulching clay soil at Gatton Research Station in southeast Queensland. We installed FullStop™ wetting front detectors and JKG Tech soil solution extraction tubes (SSET) at 15 cm and 60 cm below the soil surface.

Lettuce yield was unaffected by the increase in irrigation water salinity of 1.5 dS/m. However, irrigating with higher salinity water reduced total plant mass (results not reported), and marketable head mass by 7%. The reduction in head weight was significant ($P<0.001$), however for many production systems this may be economically unimportant, as heads are priced on a piece basis. The EC of wetting front detector samples at 15cm from plots treated with higher salinity increased to a difference of greater than 2 dS/m at harvest. By late in the season, few deep wetting front detectors from higher salinity irrigated treatment provided samples, while all standard irrigated replicates provided samples (despite receiving the same irrigation volumes). In contrast, trends in soil water EC from the suction samplers were similar at all depths, and independent of irrigation water quality. The lack of an apparent economic yield penalty from increasing irrigation water salinity to 4.5 dS/m indicates that in the short term, some producers may still grow high yielding lettuce crops on drip irrigation of this quality. The monitoring of soil solutes within a vegetable cropping system is complex. Any one tool used in isolation is unlikely to provide sufficient information to successfully manage a vegetable crop.

Introduction

Declining irrigation water availability and quality are common features of many Australian horticultural regions. The reduction of irrigation volumes to closely match plant consumptive requirements diminishes leaching fractions, which in combination with poorer water quality, could exacerbate root zone salinity issues. Irrigators may choose to monitor root zone solutes during a cropping cycle, in an endeavour to make more informed management decisions to address this build up of salts. Methods of assessing soil solute salinities as they relate to crop performance would need to be convenient and reliable for management of irrigation through a cropping season. This is especially the case in vegetable cropping systems, which are often based on short cropping cycles, staggered planting and strict market quality specifications. Growers managing these complexities tend to be time poor and thus would need to see clear benefits associated with any additional monitoring and management effort.

In Australia, FullStop™ wetting front detectors and soil solute extraction tubes (SSET) have previously been used for assessing soil solutes in perennial crops (Falivene, 2008). FullStop™ wetting front detectors consist of a buried funnel that concentrates wetting fronts into a small reservoir. Foam floats within the reservoir trigger an indicator flag. The collected wetting front solution can then be extracted via a tube, which is accessible from the soil surface. An SSET consists of a ceramic tip through which the solute is extracted joined to a tube with a rubber bung placed in the other end. In order to take a sample, suction is applied and the solution extracted after sufficient time has passed for the solution to accumulate at the bottom of the tube.

Our research is evaluating various soil solute-monitoring tools in vegetable cropping systems. Iceberg lettuce (*Lactuca sativa*) is a short season, shallow rooted crop; moderately sensitivity to irrigation water/soil salinity (Grattan, 2002, Mass and Hoffman, 1977). Grattan (2002) reported that a yield reduction of 50% would be expected where irrigation water with an EC of 3.4 dS/m were used for irrigating lettuce long term based on a 15 to 20% leaching fraction. In practice lettuce is a relatively short-term crop, generally grown in rotation with other crops. The potential for rain generated leaching events both in and out of the production season further complicates application of these guidelines to commercial practice.

In 2009, we grew iceberg lettuce using two different irrigation water quality treatments to asses their impact on yield. We installed soil solution monitoring tools within and below the root zone, which we monitored regularly as the crop developed. We sought to assess the practical benefits of these tools for producers concerned about root zone soil water salinity in similar cropping scenarios.

Methods and materials

In mid-July 2009, we transplanted three rows of lettuce seedlings (cultivar Titanic) into 1.5 m wide beds, with a 33 cm intra-row plant spacing. The site was a well-drained, black, self-mulching clay soil at Gatton Research Station in southeast Queensland. We installed two lines per bed of pressure-compensated, no-drain drip tube (dripper spacing 200 mm, output of 7.7 L/m/h per line), between the plant rows. Farm staff applied overhead sprinkler irrigation during the first eight days after transplanting, to establish the crop. Subsequent irrigation treatments consisted of (i) bore water with an EC of 3 dS/m and (ii) bore water with additional NaCl, delivering an irrigation water EC of 4.5 dS/m (we noted a drop of one dS/m across treatments for the last three irrigation events, due to a change in water source). The experiment also included three nitrogen treatments (factorial design); however, we are not reporting those nitrogen results here. We replicated the six treatments (salinity * nitrogen) three times in blocks, with each plot comprising a treatment bed and a buffer bed on either side. We installed FullStop™ wetting front detectors at 15 cm and 60 cm below a drip tape line, with solute samples taken after each detected front. JKG Tech soil solution extraction samplers (SSET) were installed vertically at depths of 15 cm and 60 cm, adjacent to tensiometers. On a weekly basis, we applied suction (60 kPa using a hand-operated suction pump) to the SSET for 48 hours, generally a day following irrigation, to maximise the probability of collecting sufficient sample volume for analysis. Analysis of EC was conducted using hand held conductivity meter (Eutech ECTester11+). Irrigation was scheduled using tensiometers installed at 15 cm and 60 cm, with irrigation applied to maintain target soil water tensions in the shallow tensiometers less than 35 kPa.

For each plot, we counted the number of marketable heads in 8 m of bed. On a subsample of 15 heads, we measured head and total plant mass. Statistical analysis was carried out using ANOVA and summery statistic functions of Genstat software 11th edition.

Results

Lettuce yield (92% of planted seedlings producing a marketable head) was unaffected by the increase in irrigation water salinity of 1.5 dS/m. However, irrigating with higher salinity water reduced total plant mass (results not reported), and marketable head mass by 7%. Although this reduction in head weight was significant ($P<0.001$), for many production systems this may be economically unimportant, as heads are priced on a piece basis.

Following most irrigation events, we successfully collected solute samples from the 15 cm FullStop™ wetting front detectors. Once drip irrigation started, samples from plots treated with higher salinity water gradually increased in EC (Fig. 1a). Near harvest, this difference was greater than 2 dS/m. In contrast, samples from wetting front detectors at 60 cm were rare, with no samples collected between 20 and 40 days after planting (Fig. 1b). By late in the season, few replicates from higher salinity irrigated treatment provided samples, while all standard irrigated replicates provided samples (despite receiving the same irrigation volumes).

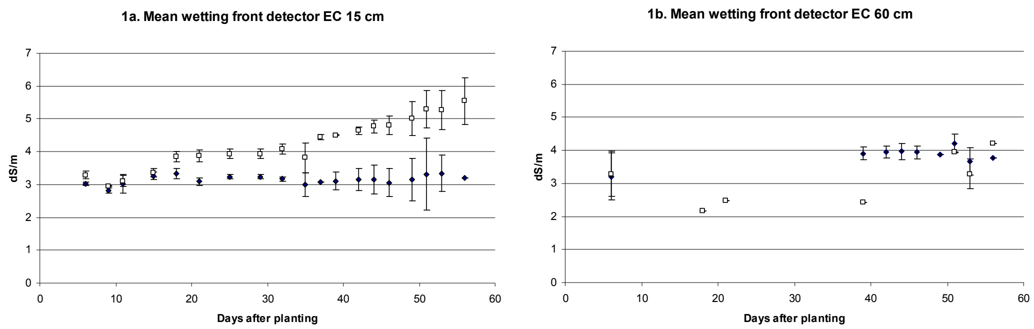


Figure 1. **Mean wetting front detector sample electrical conductivity at (a) 15 cm and (b) 60 cm. ♦=bore water, □=bore water + NaCl. Error bars indicate SEM.**

In contrast, trends in soil water EC from the suction samplers were similar at all depths, and independent of irrigation water quality, with an increase in EC starting at around 40 days after planting (Fig. 2a and 2b).

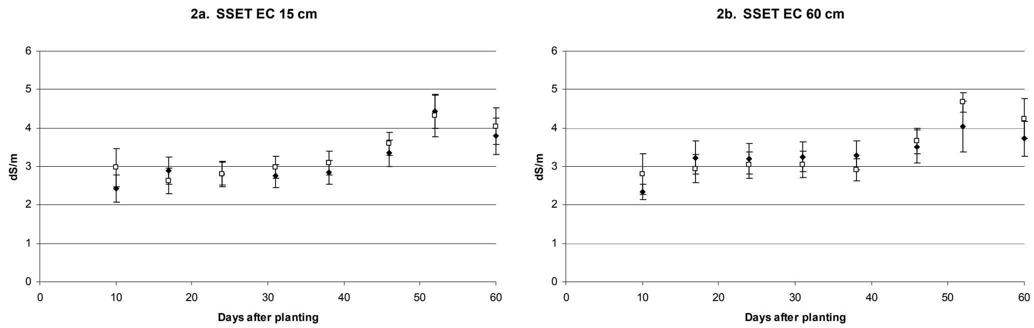


Figure 2. **Mean soil solute extraction tube sample electrical conductivity at (a) 15 cm and (b) 60 cm. ♦=bore water, □=bore water + NaCl. Error bars indicate SEM.**

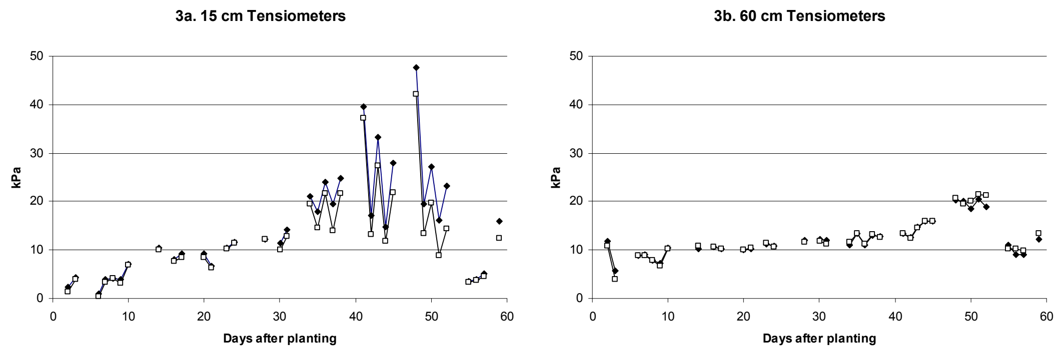


Figure 3. **Mean soil water tension at (a) 15 cm and (b) 60 cm. ♦=bore water, □=bore water + NaCl.**

Soil water tension exceeded our target range of <35 kPa at 15 cm on 2 occasions (due to operational restrictions). Subsequent irrigation events brought the tension back below 35 kPa. Soil water tension at 15 cm was several kPa higher in the bore water treated plots from 35 to 52 days after planting. Soil water tension readings at 60 cm were stable in comparison with those at 15 cm, with tension remaining below 20 kPa.

There was a total of 112 mm of drip irrigation applied thought the season. Rainfall contributed an additional 50 mm with over 80% falling on the 53rd day after planting.

Discussion

Given the characterisation of iceberg lettuce as a moderately saline sensitive crop (Grattan, 2002, Mass and Hoffman, 1977), we were anticipating that the addition of NaCl to the irrigation water would be associated with a substantial decline in yield. This did not turn out to be the case. Growers may be able to grow a lettuce crop, at least in the short term, using irrigation water with a conductivity as high as 4.5 dS/m. However, if the 7% reduction in weight brought heads below the market specification cut-off, or buyers were choosy (due to excessive lettuce availability), this reduction in head weight may become economically important. Our study highlights the complexities of using guidelines from studies on the impacts of long-term saline irrigation water use on a specific crop, and the actual biological and economic impacts in a commercial production system.

In a review of vegetable crop salinity tolerance, Shannon and Grieve (1999) described a range of salinity tolerances for iceberg lettuce and that salt tolerance differs among cultivars. This further makes the use of general guidelines for irrigation water quality in lettuce production problematic. If conservative limits are rigorously used, then some producers may not grow a crop when they could have, or if higher limits are used, some growers may produce unacceptably low yields. Lettuce growers might do best to use crop salinity tolerance guidelines as indicators of where problems might arise and risk management strategies may be required.

The lack of deep wetting front detector triggering events in NaCl treatments suggests that these treatments may have adversely affected soil water permeability. This could become an issue in the longer term, particularly during periods of wet weather when drainage is especially important. Because the wetting front detectors used only yield samples when a significant wetting front event has occurred, the depth at which they are installed is a critical component of their successful use.

Conclusion

The lack of an apparent economic yield penalty from increasing irrigation water salinity to 4.5 dS/m indicates that in the short term, some producers may still grow high yielding lettuce crops using drip irrigation with relatively poor quality water. The monitoring of soil solutes within a vegetable cropping system is currently complex and time consuming. More effort in simplifying the installation and use of these tools is needed to enhance the likelihood of commercial adoption in vegetable cropping systems. Any one tool used in isolation is unlikely to provide sufficient information to successfully manage a vegetable crop.

Acknowledgements

We sincerely thank Horticulture Australia Limited for supporting this research.

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Managing root zone nitrogen and salts in a sweet corn crop

(Experiment report prepared for circulation via online placement)

Adrian Hunt, Craig Henderson and Greg Finlay

Gatton Research Station, Agri-Science Queensland

Key findings

- In conjunction with other tools (e.g. pre and post-plant soil testing, sap monitoring), soil suction extraction tubes (SSET) can aid in understanding salt and nutrient movements in vegetable crops. However, used alone, their resulting output can be difficult to interpret. It is unlikely they can be used as an in-season fertigation scheduling tool.

- It was possible to grow a sweet corn crop yielding 19 t/ha of marketable cobs with no additional nitrogen fertiliser, using the residual nitrogen retained in the soil profile at the start of the season (35 ppm in the top 30 cm).

- Irrigating with 3 dS/m water built up EC and particularly chlorides in the root zone of the sweet corn. Surface EC very much reflected rainfall events, which effectively leached salts from the upper soil profile. With drip irrigation, increasing irrigation volumes by 50% increased, not decreased, chloride concentrations in soil profile. Leaching with drip irrigation is a complex, three-dimensional process. Root zone tools may help with establishing how to leach root zone effectively.

Plate 1. Drip tube placement in the sweet corn experiment.

Introduction

It is important for sweet corn producers to supply enough nitrogen to satisfy the crops requirements. Traditionally, scheduling of applied nitrogen fertilisers has been based on rule of thumb or pre-plant soil tests in most vegetable cropping systems. A recommendation is then given to supply sufficient nutrients to the crop. Although it is likely that these recommendations based on pre-plant tests are generally sufficient, the amount of excess nitrogen may occasionally be substantial. This can lead to unnecessary expenditure on fertiliser and adverse environmental impacts. In order to further refine nutrient application to reduce these excesses, growers need a robust tool, which would allow them to know immediately if a crop is being under supplied with nitrogen. They could then take action to remedy it. Without the security of such a tool, the tendency may be to over apply the nutrient as a type of insurance. This recognises that the direct economic impact on the grower of undersupplying a nutrient may be significantly larger than oversupplying it.

The use of in-situ soil solution collection has predominantly been in perennial horticulture, for monitoring concentrations of salt and nitrate. This has allowed for analysis of trends over a time scale of several years. Adjustments to irrigation and fertiliser strategies have then been made, based on observed trends, with some successes (Stirzaker, Stevens et al. 2009). The use of these devices for the monitoring of annual vegetable cropping has not been explored in as much detail. The relatively small time scale over which most vegetable crops are grown means that there is comparatively little time to observe trends and take corrective action. Fallow periods between cropping cycles mean that a proportion of the solutes will be leached by some rain events. Currently, it is not possible (using current techniques) to leave the monitoring tools in the paddock during fallow and land preparation periods, as the equipment will be destroyed. For these reasons, we decided to focus on soil solution monitoring within a single season, and evaluate the usefulness of the solute monitoring tools in this time frame.

Soil solution extraction tubes (SSET), some times referred to as suction cups or suction lysimeters, consist of a porous ceramic cup joined to a tube. The opposite end is sealed and a smaller tube inserted, to allow for the extraction of samples. Installation involves inserting the samplers into a specified depth, with good contact between the tips and surrounding soil. Suction is then applied to the sampler for a period of hours/days, after which the collected sample is removed for analysis. The period of time required to gather a sufficient sample varies, depending on the soil water tension, soil texture, porosity, permeability, suction applied and volume of sample required.

We decided to investigate whether these in-situ soil solution sampling methods were suitable for the scheduling of nitrogen fertiliser side-dressings in a sweet corn crop. To do this, we chose a range of nitrogen treatments, to contrast results between nitrogen deficient and sufficient systems.

Materials and methods

The experiment was carried out on the Queensland Department of Employment, Economic Development and Innovation (DEEDI) Gatton Research Station. The soil was a black, moderately to strongly self-mulching heavy clay topsoil with slightly alkaline pH. A soil test prior to planting indicated that nitrate nitrogen was present at concentrations of 34 mg/kg, Colwell Phosphorus 140-160 mg/kg, and Potassium 0.85 meq/100g.

We planted the sweet corn (cultivar Hybrix 5 from Pacific Seeds) on the 28 January 2010. Beds were 1.5 m centre to centre and 10 m long. Six treatment combinations were evaluated in a randomised block design, with three blocked reps. Five nitrogen fertiliser treatments were assessed. We also added an over-watering treatment, which received an additional 50% irrigation at all irrigation events (other than fertigation). A basal fertigation was added at 15 days after planting. Two further side dressings were added via fertigation at 43 and 57 days after planting. Each experimental plot bed had a buffer bed on either side that received the same treatment. Every seventh bed was set aside to allow for spray machinery access, with a total of 62 beds planted. We planted two rows per bed, with the rows sown 30 cm from the bed centre, and an intra row plant spacing of 20 cm, using an air seed drill.

Table 1. Nitrogen treatments.

Total applied nitrogen (kg/ha)	Basal N (kg/ha)	Side dressing kg/ha (at each of two fertigations)
0	0	0
40	20	10
80	40	20
120	60	30
120 (1.5 times irrigation)	60	30
220	120	50

Irrigation was supplied using Plastro Hydro PCND (pressure compensated, no drain) tube with 150 mm emitter spacing. The emitter output specification was 1.15L/hr for an equivalent linear output of 7.67L/m/h. JKG Tech Soil Solution Extraction Tubes (SSET) were installed at depths of 15 cm and 60 cm, in line with the plant row in all of the plots. SSET were suctioned to 60 kPa and allowed to gather a sample for two days before collection each week. Solution samples were tested for electrical conductivity (EC) using a hand held conductivity meter. Nitrate analyses were carried out using a Merck RQeasy Nitrate Meter and 250 ppm nitrate-nitrate test strips. Where required, samples were accurately diluted to bring samples within range.

Irrigation scheduling was carried out using tensiometers installed inline with the plant row, at depths of 15 and 60 cm. Scheduling aimed to keep the shallow tensiometers at <50 kPa, with deep tensiometers steady or slowly rising to 40 kPa. Irrigation volumes were fine tuned using observed rainfall and calculated ETo (FAO56) from the Australian Bureau of Meteorology Irrigation SILO website patch point data (http://www.longpaddock.qld.gov.au/silo/), with crop factors adjusted based on tensiometer response patterns. Irrigation run times, pressures and volumes were recorded each time a plot was irrigated. Fertigation was carried out at four leaf and tasseling stages of development, using a proportional inline injection system (Netafim®, Dosatron, D 45 RE 3).

The crop was treated with 1.7 L/ha of Dual Gold (S-metolachlor) directly after planting. No overhead irrigation was required due to rain soon after planting. We applied two sprays of Sucsess2® (400 ml/ha) and two sprays of zinc and boron during the growing period.

Six whole plant samples from the normal nitrogen treatment rows were used for sap sampling of nitrate, potassium and phosphorous at the four leaf stage. Four whole plant samples were also collected from the same plots for dry sample assessment. At tasseling and at harvest, four stem segment samples were taken from each plot for sap sampling and leaf samples were taken for dry nutrient analysis.

The final harvest was carried out on 19 April 2010, 81 days after planting. Cobs were harvested from eight metres of both rows from the experimental beds. The number of plants within the harvested area were counted, cobs were graded into marketable and unmarketable according to specifications from Woolworths (Woolworths Supermarkets 2007). Cobs were segregated into primary (initial cob) and secondary cobs. The number and mass of marketable and unmarketable cobs was recorded. A one metre section from each row in each experimental bed was harvested separately, with plants also removed. The total fresh weight of the plants and cobs from these sections was recorded, and then a subsample used for assessment of dry weight. Cobs that were undersized, or had obvious external defects or damage, were designated as unmarketable, with the rest considered marketable. A sub-sample of ten marketable cobs was graded for tip fill.

Statistical analysis was carried out using GenStat™ software 11th edition via two way ANOVA and summary statistic functions.

Results

Yields

The mean plant density at harvest was 58,000 plants per ha. We did not find any significant differences (P=0.05) in yield from any of the applied treatments, in either number or weight of cobs per ha (Table 2).

Table 2. Mean yield of sweet corn cobs (± SEM).

	Number of marketable cobs/ha	**Number of unmarketable cobs/ha**	**Mass of marketable cobs t/ha**	**Mass of unmarketable cobs t/ha**
Primary	51018 ± 766	5555 ± 555	16.4 ± 0.2	1.1 ± 0.2
Secondary	10879 ± 727	17083 ± 1072	2.6 ± 0.2	2.5 ± 0.2
Total	61898 ± 109	22638 ± 1182	18.9 ± 0.3	3. 6 ± 0.3

In-season sap testing

Sap nitrate concentrations were all similar at the start of the experiment (Fig. 4). By the time the last sample was taken at harvest, there were differences between treatments. Treatments differentiated from highest to lowest sap nitrate content in the same order as the nitrogen treatments, with the exception of the 120 kg/ha nitrogen + 1.5 irrigation, which was less than the 80 kg/ha treatment.

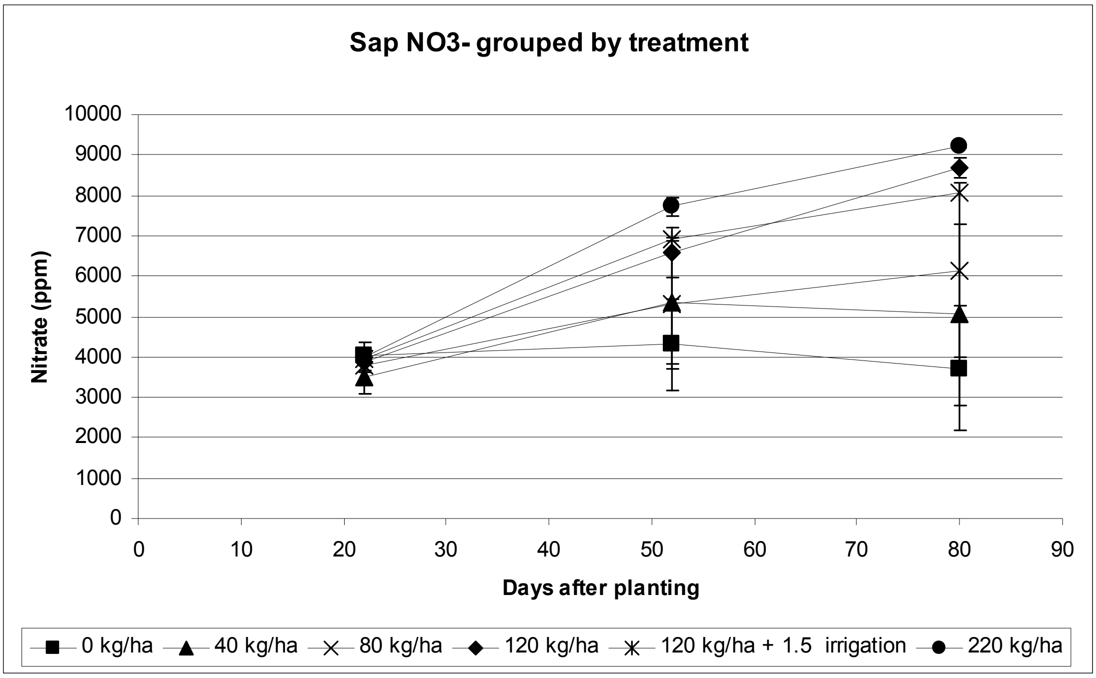

Figure 4. Mean sap nitrate content during development. N=3 Error bars indicate SEM.

SSET sampling

The electrical conductivity of SSET samples at 15 cm started at 2.3 dS/m and trended downwards to 0.5 dS/m for the first 46 days (Fig. 5). They then increased to 1.9 dS/m by the time the last sample was taken. On the other hand, electrical conductivities in 60 cm samples were comparatively more stable. They started at 2.2 dS/m and decreased gradually to 1.8 dS/m by the final sampling. Similar to the shallow SSET, the lowest EC values were around 45 days after planting.

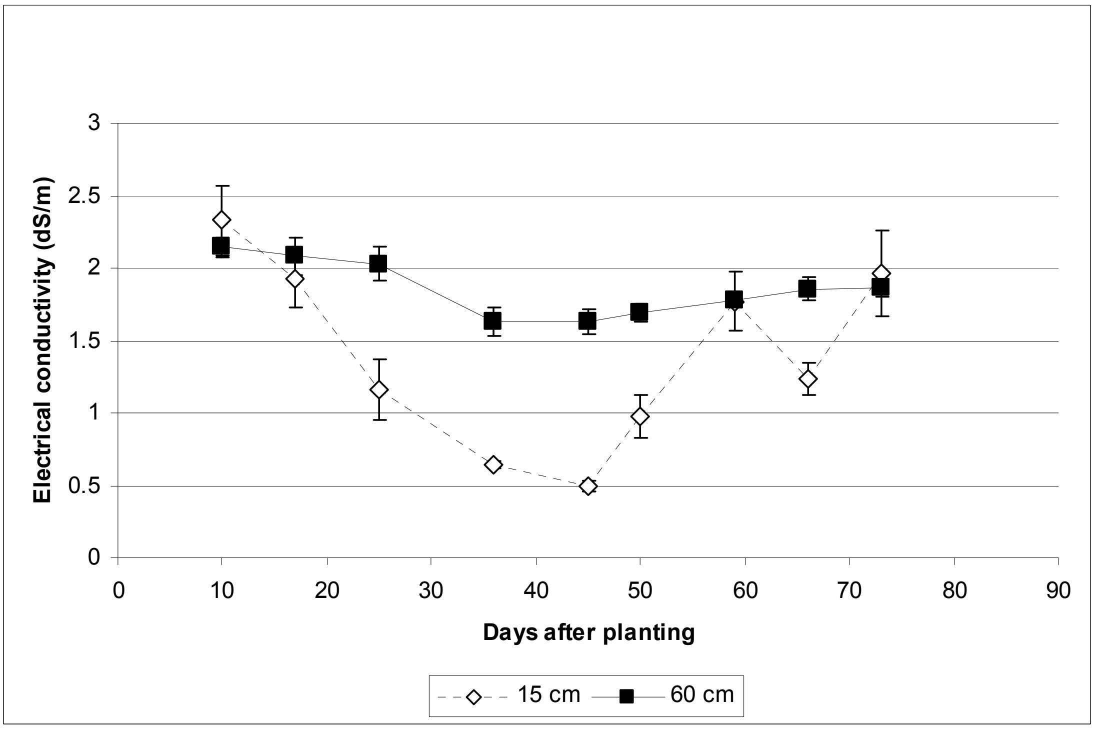

Figure 5. Electrical conductivity of the SSET samples. Error bars indicate SEM.

The concentrations of nitrate nitrogen decreased quickly in the SSET samples from 15 cm over the early stages of crop development (Fig. 6). Concentrations were at, or close to, 0 ppm by 36 days after planting. There was a slight increase in nitrate nitrogen concentrations on the last sampling date, possible because of mineralisation of organic N.

Samples from SSET at 60 cm (Fig. 7) had nitrate nitrogen concentrations significantly less than the samples at 15 cm. The concentrations remained below 50 ppm throughout the sampling period. There was a general increase over the first 46 days after planting. The low nitrogen treatments then trended towards lower concentrations. The 120 kg/ha nitrogen treatment samples remained stable at around 25 ppm while the 220 kg/ha treatment increased in concentration. The order from highest to lowest was the same as the order from highest to lowest nitrogen treatment with the exception of the 120 kg/ha nitrogen + 1.5 irrigation treatment, which was slightly lower than the 80 kg/ha treatment. The 0 kg/ha treatment had reached the lower limit of detection by the last sampling event.

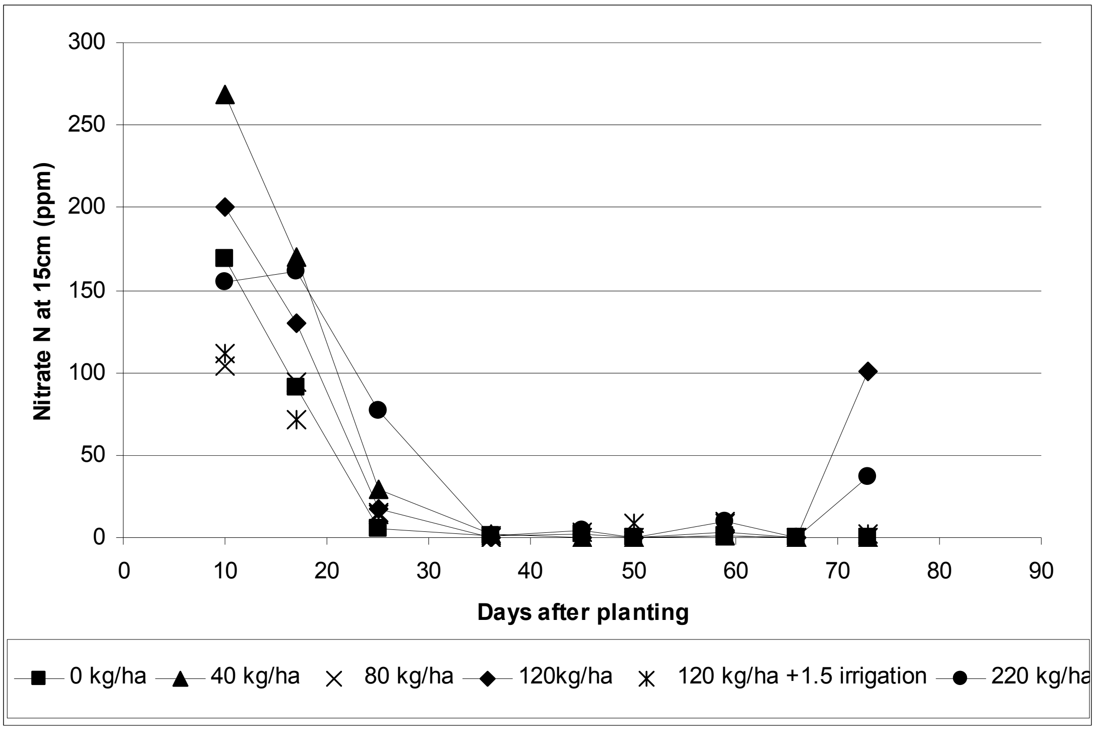

Figure 6. SSET sample Nitrate nitrogen at 15 cm.

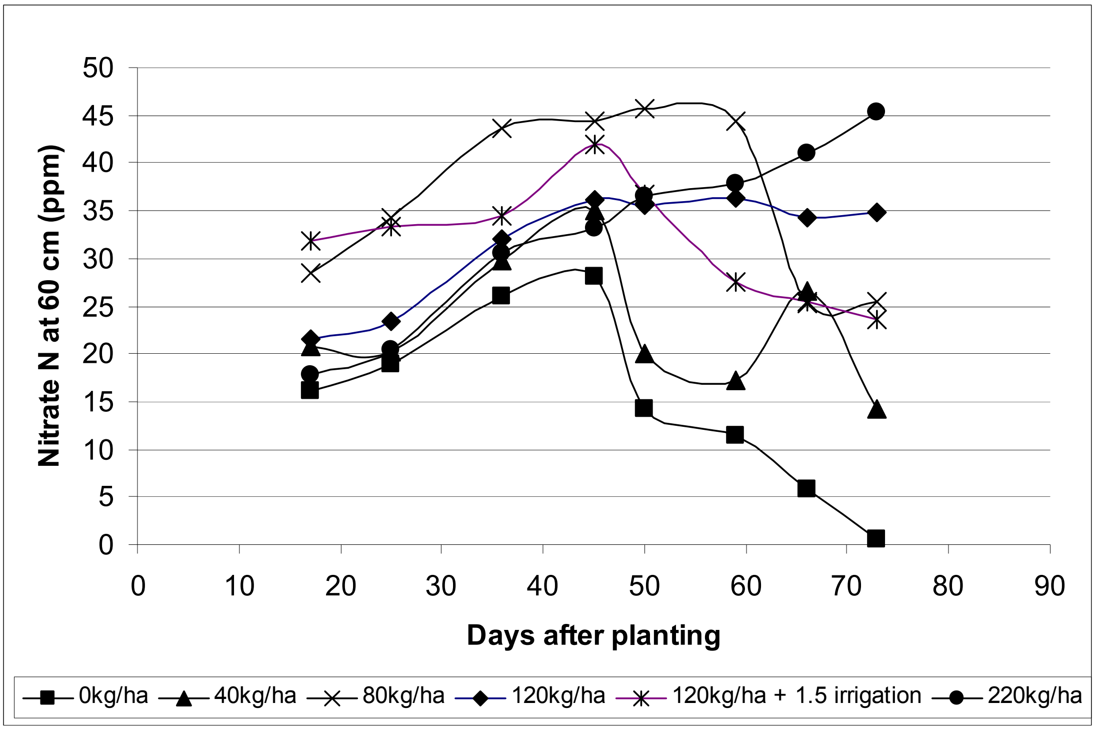

Figure 7. SSET nitrate nitrogen at 60 cm.

Soil sampling

The pre-plant nitrate concentrations were highest in the top 30 cm (27-34 mg/kg) of the soil profile (Fig. 8). They decreased to less than 5 mg/kg below 60 cm. All of the core samples for five of the treatments had less than 5 mg/kg of soil nitrate through the entire profile at the end of the crop. The exception was the highest N rate of 220 kg/ha, which had much higher nitrate concentrations than the other treatments through to 120 cm in depth.

The 1:5 soil water electrical conductivity (Fig. 9) shows little difference between samples, although surface values were higher in the highest N rate, or where there was additional irrigation. Interestingly, post-plant surface chlorides (Fig. 10) were highest in the treatment that received 50% more irrigation.

The picture from this data indicates there was substantial nitrate N available at planting, which was depleted by the growing sweet corn crop. The very high N rate did leave substantial residual nitrate in the soil profile. The high EC (around 3 dS/m) irrigation water did increase chlorides in the soil profile, particularly in the treatment that received the additional 50% irrigation. We also observed the heavy rain flushing mid depth chlorides lower into the soil profile.

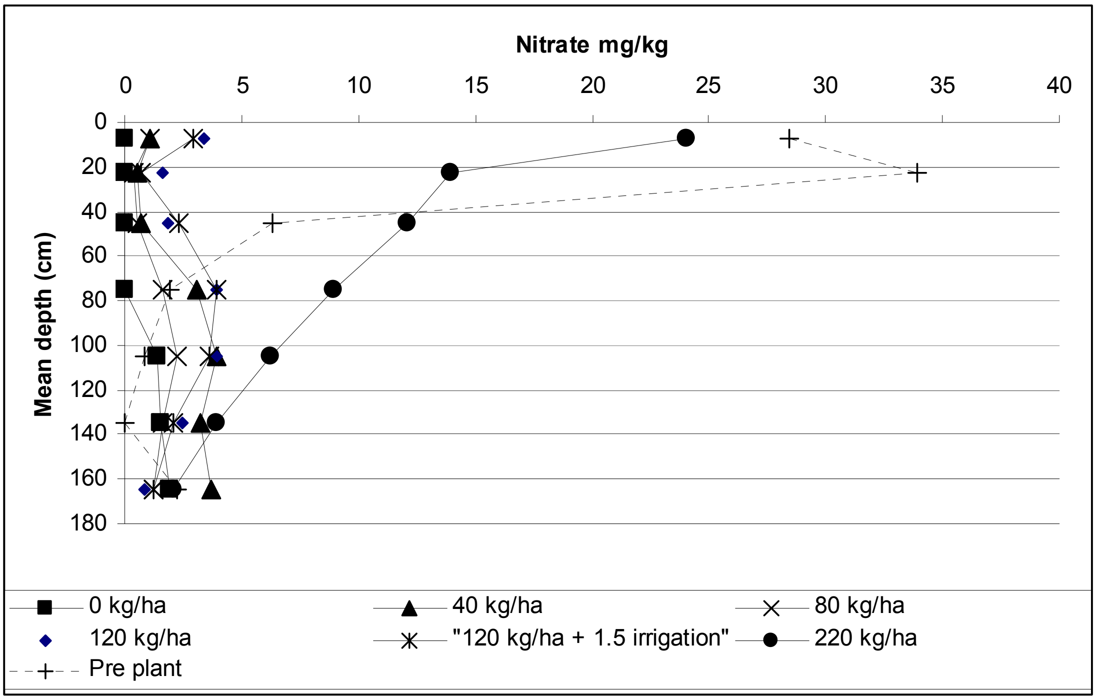

Figure 8. Deep soil core nitrate in soil samples.

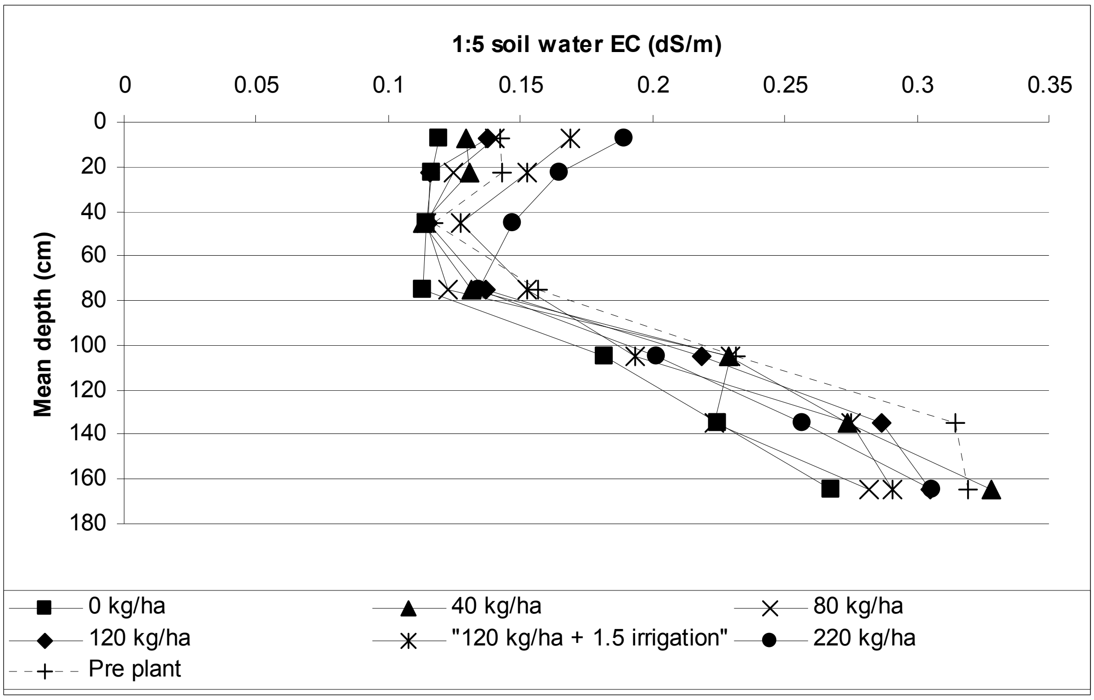

Figure 9. Deep soil core sample 1:5 soil water electrical conductivity in soil samples.

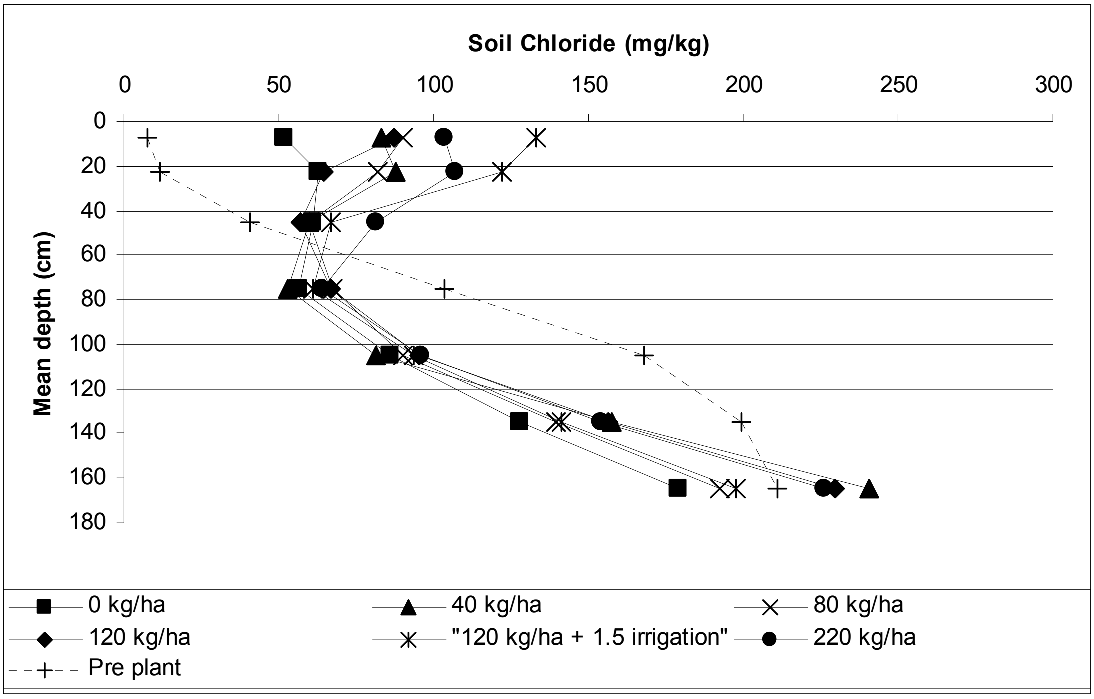

Figure 10. Deep soil core sample chloride concentrations in soil samples.

Irrigation and soil water status

The crop water balance was dominated by several large rainfall events (Fig. 11). Four fifths of the water that went on to the field was rain. The combined rain and irrigation exceeded the ETo by 150 mm, and would have exceeded the ETc by an even larger amount (Fig. 12). Much of the rainfall would have run off the plots, as it exceeded the infiltration rate. There were some problems with drainage early on in the experiment (Fig. 13), with plots 1-3 showing evidence of water logging (perhaps leading to additional leaching).

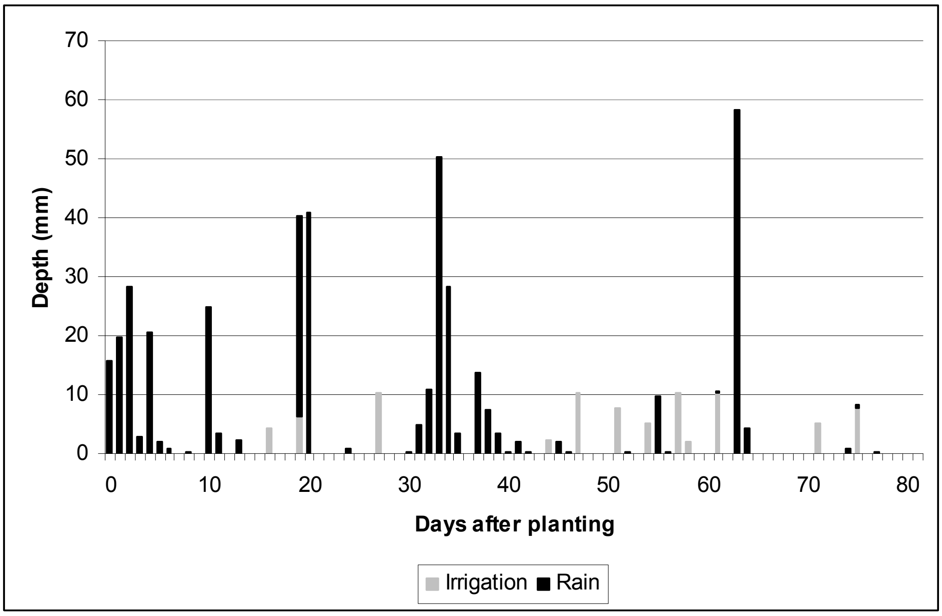

Figure 11. Daily irrigation and rain events.

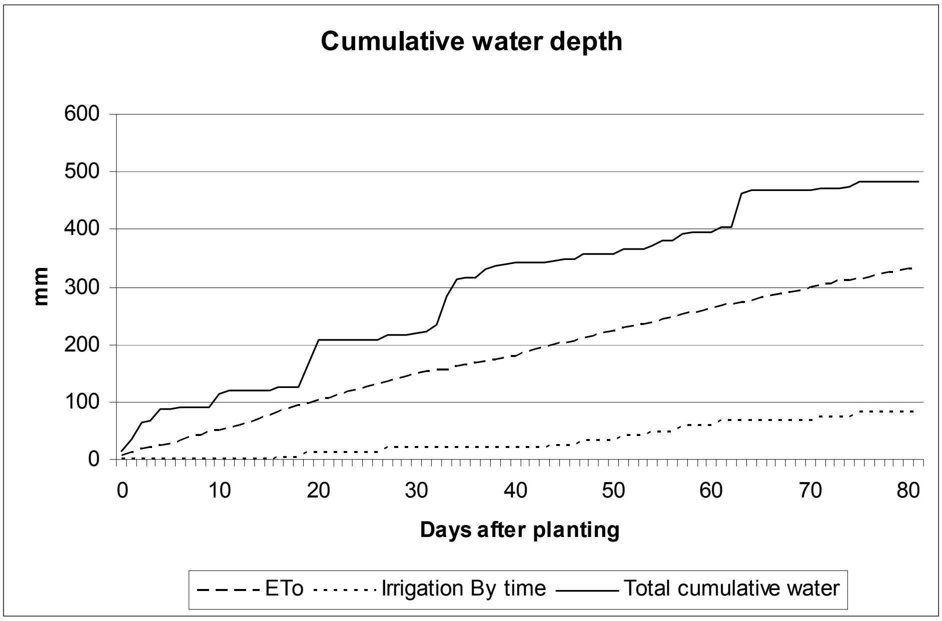

Figure 12. Cumulative water depth

Figure 13. Field showing water logging at one end after a rainfall event.

For all five of standard irrigation treatments, we allowed the soil to dry beyond the 50 kPa soil suction target that we had originally set (Fig. 14). Conscious that following the heavy rainfall there was still plenty of water available deeper in the profile, we only applied moderate amounts of irrigation to reduce surface deficits, whilst encouraging utilisation of water from deeper in the soil profile. Note that from around 45 days after planting, the soil water suction at 15 cm was lower in the plots with the 50% additional irrigation most of the time.

As we intended, the soil water tension at 60 cm started to increase from 55 days after planting. The increase was less pronounced in the additional irrigation treatment (Fig. 15), which remained wetter until 67 days after planting. At that point, heavy rain reset the whole profile back to a saturated condition.

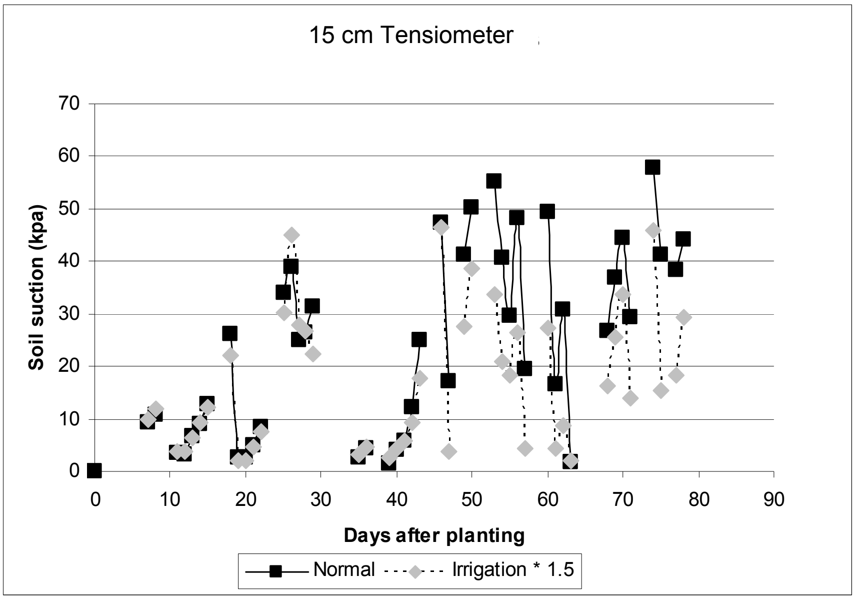

Figure 14. Soil water suction at 15 cm.

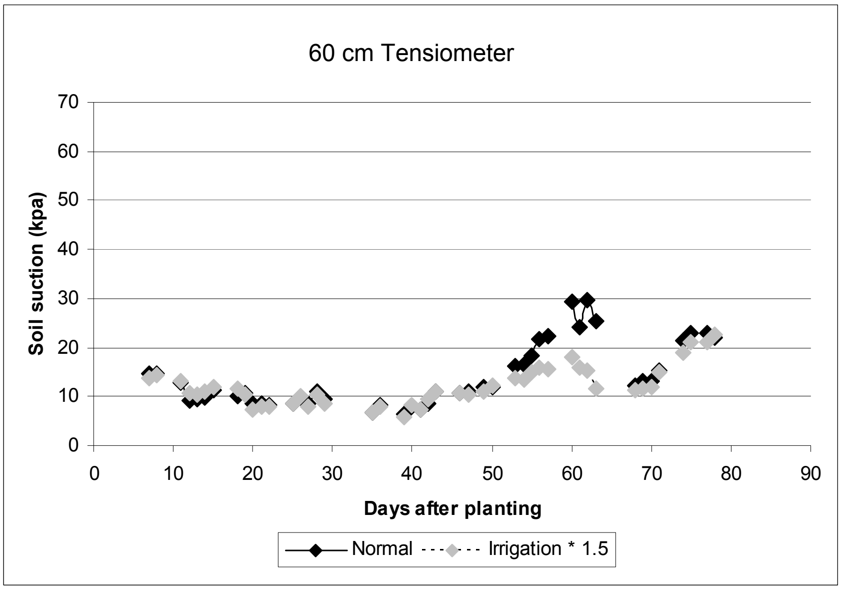

Figure 15. Soil water suction at 60 cm.

Discussion

The lowest nitrogen application rates were chosen because we expected to see a yield penalty due to insufficient available nitrogen. Unfortunately, there were no significant differences in the yields of any of the applied treatments. This means that there must have been sufficient residual nitrogen in the plots that received no additional nitrogen fertiliser to yield optimally.

Although we did not see differences in yield from the applied nitrogen treatments, we did observe other differences. Both sap nitrate concentrations and the amount on nitrate picked up by the deeper SSET were proportional to the rates of nitrogen application. Thus, it appears we were getting both luxury uptake of N, and increased movement of nitrate through the soil profile as we increased the N fertigation. Differences in total nitrate post-harvest was less stark, although the highest nitrogen application treatment showed a much higher concentration of nitrate in the top 90 cm of soil than other treatments.

Based on the results that we gathered we could not endorse the use of SSET nitrate concentration testing as a primary measure for scheduling of nitrogen fertilisers in sweet corn production. It may be that the location at 15 cm was too shallow for the arrangement of drip tapes and planting row. However, in conjunction with other tools, they may be useful for getting an improved understanding on nitrate movements through the profile. Given that the low N fertiliser rates yielded similarly to the other treatments, it also seemed that sweet corn could perform well with SSET nitrate concentrations in the order of 50 ppm (under the conditions we used for sampling).

We found that SSET and tensiometers positioned at 15 cm were occasionally unreliable at yielding data. As we intentionally let the shallow soil dry out in response to the early heavy rain, there may have been some cracking near the soil surface, causing a break in contact between the ceramic tips and the surrounding soil.

The rain and irrigation combined exceeded the crop water requirement significantly. Some of this excess will have leached solutes deeper in to the profile while the remainder will have been field runoff. This rain and some wind lead to some lodging of the crop and made accessing the field in order to take samples, measurements and perform other agronomic activities difficult. The water logging that occurred at one end of the field was a concern and probably caused some additional leaching in these plots.

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Stirzaker, R., J. Stevens, et al. (2009). "Stages in the adoption of a wetting front detector." Irrigation and Drainage.

Woolworths Supermarkets (2007). Produce Specifications, Corn. http://www.woolworths.com.au/resources/corn.pdf, Woolworths Supermarkets.

Managing root zone nitrogen and salts in a NSW lettuce crop

(Experiment report prepared for circulation via online placement)

Adrian Hunt[1], Craig Henderson[1], Tony Napier[2] and David Troldahl[2]

[1] Gatton Research Station, Agri-Science Queensland

[2] Yanco Research Station, Industry and Investment, New South Wales

Key findings

- FullStop™ wetting front detectors will not provide information if they are never triggered. It is better to err on the side of installing them too shallow than too deep.
- SSET root zone tools work best in situations with moist soil conditions. They can be difficult to interpret as soils dry out, and soil solutions concentrate.
- There may be opportunities for less nitrogen fertiliser use in horticultural soils. Soil testing, or root zone monitoring, may indicate those opportunities.
- Vegetable producers need to be aware of potential issues of high salt levels in composts, or other soil amendments.

Plate 2. Presenting lettuce experimental results at a Yanco Field Walk, October 2009.

Introduction

The monitoring of soil solutes has been receiving renewed attention lately, as concern has risen about water use efficiency, salinity and nutrient use efficiency. The use of in-situ soil solution collection has predominantly been in perennial horticulture, for monitoring concentrations of salt and nitrate. This has allowed for analysis of trends over a time scale of several years. Adjustments to irrigation and fertiliser strategies have then been made, based on observed trends, with some successes (Stirzaker, Stevens et al. 2009). The use of these devices for the monitoring of annual vegetable cropping has not been explored in as much detail. The relatively small time scale over which most vegetable crops are grown means that there is comparatively little time to observe trends and take corrective action. Fallow periods between cropping cycles mean that a proportion of the solutes will be leached by some rain events. Currently, it is not possible (using current techniques) to leave the monitoring tools in the paddock during fallow and land preparation periods, as the equipment will be destroyed. For these reasons, we decided to focus on soil solution monitoring within a single season, and evaluate the usefulness of two solute monitoring tools in this time frame.

Soil solution extraction tubes (SSET), some times referred to as suction cups or suction lysimeters, consist of a porous ceramic cup joined to a tube. The opposite end is sealed and a smaller tube inserted, to allow for the extraction of samples. Installation involves inserting the samplers into a specified depth, with good contact between the tips and surrounding soil. Suction is then applied to the sampler for a period of hours/days, after which the collected sample is removed for analysis. The period of time required to gather a sufficient sample varies, depending on the soil water tension, soil texture, porosity, permeability, suction applied and volume of sample required.

FullStop™ wetting front detectors were developed by Richard Stirzaker and Paul Hutchinson as a tool for both irrigation scheduling and soil solution monitoring(Falivene 2008). The FullStop™ wetting front detector consists of a buried funnel with a sand filter media. Soil solution from the wetting front is collected in the base of the funnel, which triggers an indicator flag at the top of a rigid tube protruding from the surface via a series of foam floats. The collected sample is then removed using a thin flexible tube, which runs from the base of the funnel to above the soil surface.

We decided to investigate whether these in-situ soil solution sampling methods would provide us with useful information in an irrigated lettuce crop. To do this we chose a range of nitrogen and compost treatments, to compare trends in solute sample concentrations over time.

Materials and Methods

The experiment was carried out on a red duplex soil at the NSW Yanco Research Station. The experiment comprised six nutrient treatments replicated four times using the lettuce cultivar *Casino* and three nutrient treatments replicated four times using the cultivar *Silverado*. The cultivars were assessed in separate blocks. Treatments were arranged in a randomised block design. Each plot had one bed, 10.8 m long. A pre-planting application of 300 kg/ha Nitrophoska Blue and 300 kg/ha Single Super was applied to all of the replicates. This provided a base level of 36 kg/ha nitrogen across the experiment. Compost treatments were applied at planting; the synthetic treatment side dressings of nitrogen were applied 29 days after transplanting.

Table 3. Lettuce experiment nitrogen side dressing treatments.

Titanic	Side-dressing	Nitrogen
	0 kg/ha	0 kg/ah
	30 kg/ha Urea	13.8 kg/ha
	100 kg/ha Urea	46 kg/ha
	200 kg/ha Urea	92 kg/ha
	11.5 t/ha Compost	23 kg/ha*
	23 t/ha Compost	46 kg/ha *
Silverado	**Side-dressing**	**Nitrogen**
	30 kg/ha Urea	13.8 kg/ha
	100 kg/ha Urea	46 kg/ha
	200 kg/ha Urea	92 kg/ha

* Based on the assumption that 10% of the nitrogen will be available to the crop in the first year.

FullStop™ Wetting Front Detectors were installed at 15 and 60 cm in the *Casino* 100kg Urea/ha side dressing treatment plots. SSET were installed in both the *Casino* 100kg Urea/ha and the *Casino* 23 t compost/ha treatment plots. Lettuces were transplanted into the experiment on 26 August 2009. The experiment was irrigated using overhead sprinklers.

Results and discussion

General observations

The crop appeared to initially grow well, with no obvious differences between treatments that could be determined by a cursory visual assessment. However, it later became evident that a significant proportion of the crop was stunted and/or yellow due to viral infection.

We had little success with the FullStop™, as they only triggered once during the experiment. We suspect this was due to inexperience with installation; they were potentially buried at 25-30 cm, rather than the intended 15 cm.

Lettuce growth and yield

None of the imposed treatments had a significant effect on final harvest yield of marketable heads mass (p=0.05). *Casino* yielded mean marketable heads of 1145 ± 45 g (SEM), from total plant sizes of 1340 ± 48 g. *Silverado* averaged 844 ± 37 g heads from plants of 1155 ± 53 g. Only 68% of the *Casino* plants were marketable at harvest, compared to 56% of *Silverado*. Lettuce necrotic yellows virus infection appeared to be the main factor limiting the yield of marketable heads. There were however some indications that the compost impeded lettuce development. The highest rates of compost had smaller plants than the other treatments at 28 and 41 days after planting (Fig. 16, Fig. 17).

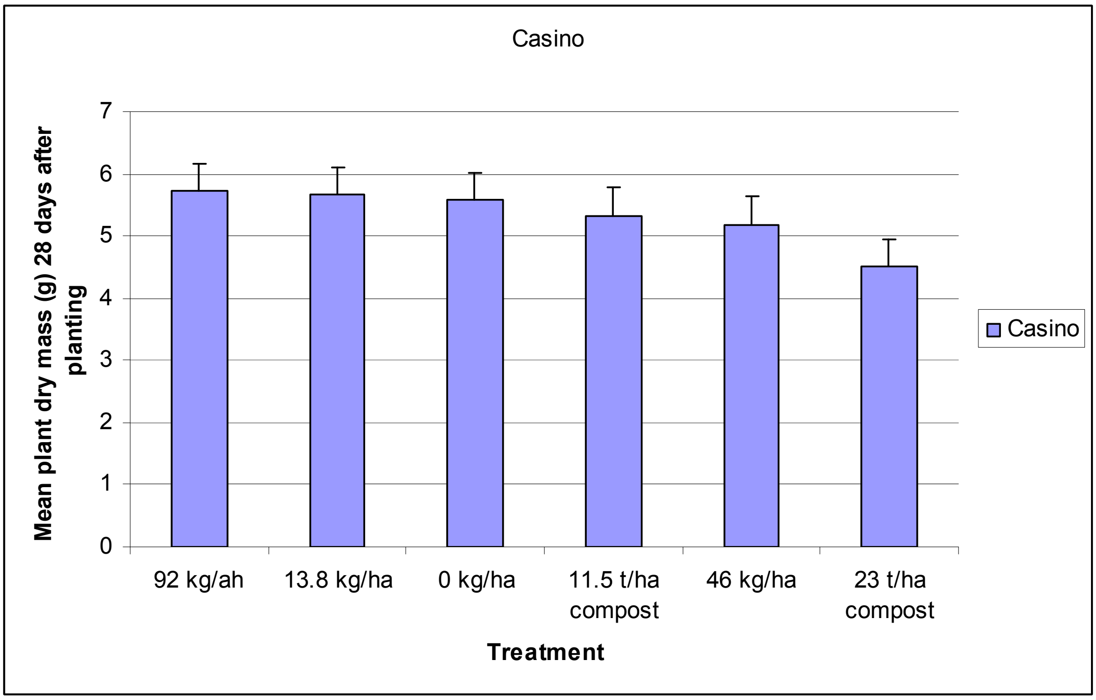

Figure 16. High rates of compost reduce lettuce growth at 28 days after planting.

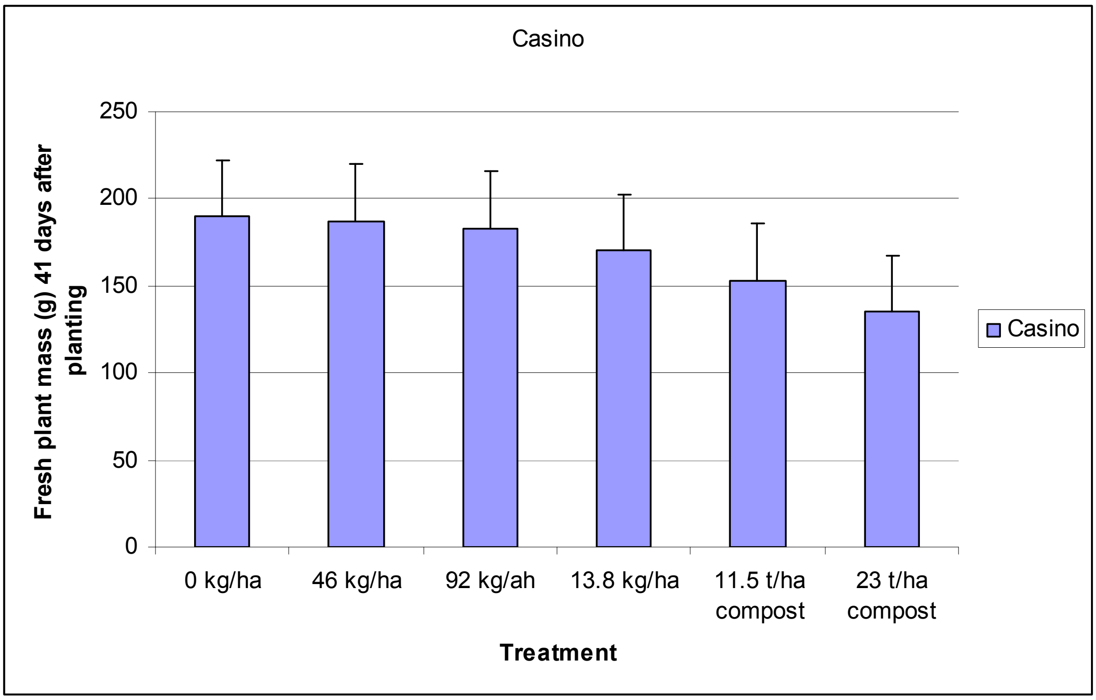

Figure 17. High rates of compost reduce lettuce growth at 41 days after planting.

Irrigation and root zone solute concentrations

The irrigation of the experiment appears well below what we anticipate would be required for a lettuce crop in that area (Fig. 18). The water applied as a proportion of ET (less than 40%) seems very low. It may be that there was considerable antecedent soil moisture – we are still awaiting the analysis of that data. Dry root zone conditions are also indicated by issues with consistently extracting samples from the SSET, and the fact that the FullStop™ instruments did not trigger.

The EC values for the soil profiles were relatively high (Fig. 19), compared to values we have observed elsewhere. As soils dry, the EC of extracted solutes can often rise, without any substantial change in the inherent EC of the soil. Thus, the trends of increasing EC over time for the side dressed treatments were not specifically concerning. However, the values for the composted treatments were very high. This was particularly the case for the solutions extracted from the surface layers; over 10 dS/m. It is quite likely that the compost material had an inherently high EC. This is something that all intending user of organic amendments should check. It is likely that the high EC levels we recorded in the extracted solutions were reflected in the reduced initial growth of the lettuce, due to salt toxicity.

The nitrate levels from the SSET were similarly very high (Fig. 20). Given those values recorded before the side dressing, it is not surprising that there were no nitrogen fertiliser effects observed in either cultivar experiments. In a commercial enterprise, we would have probably not undertaken any side dressing if we had observed those levels.

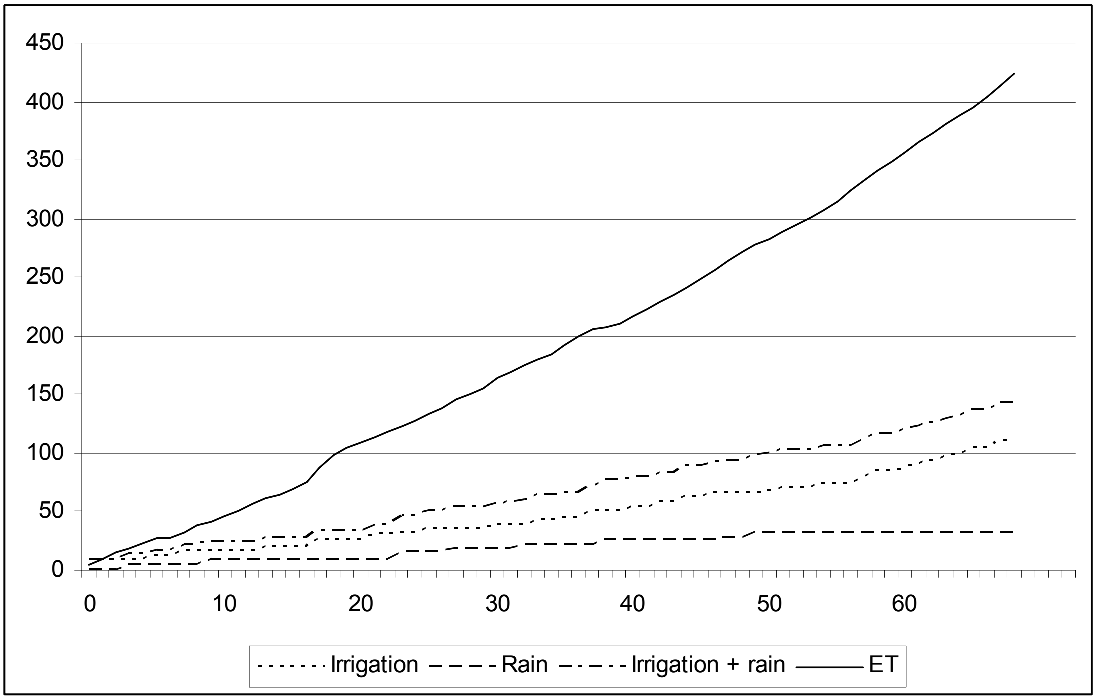

Figure 18. Water application rates in relation to evapotranspiration.

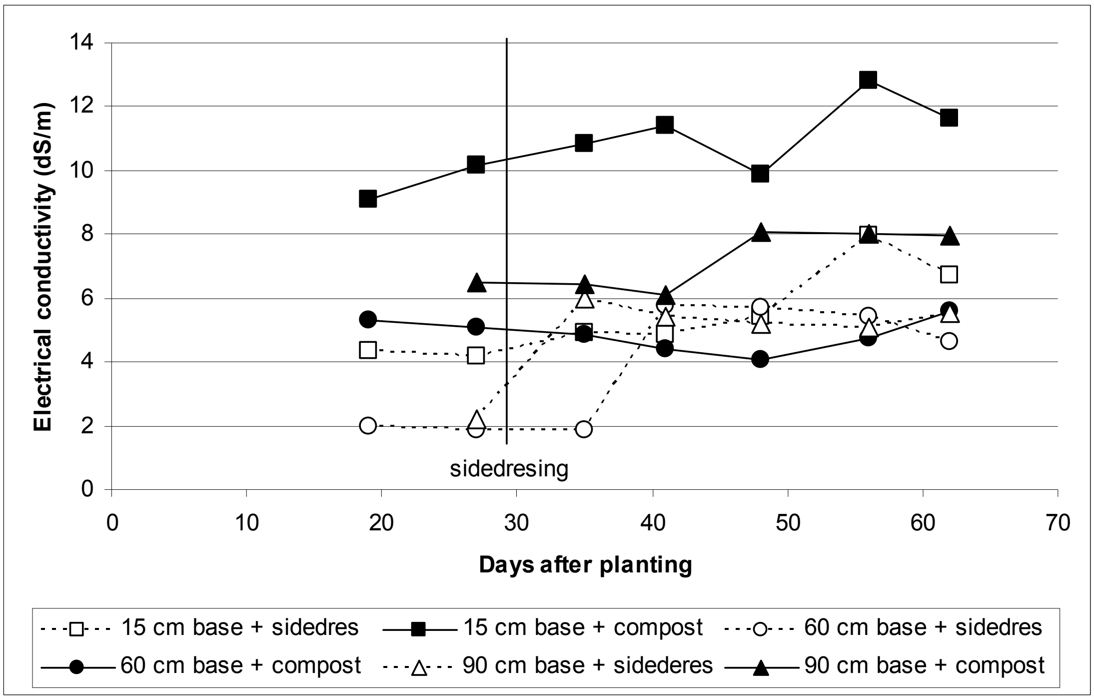

Figure 19. EC of solutions collected from SSET during the lettuce cropping period.

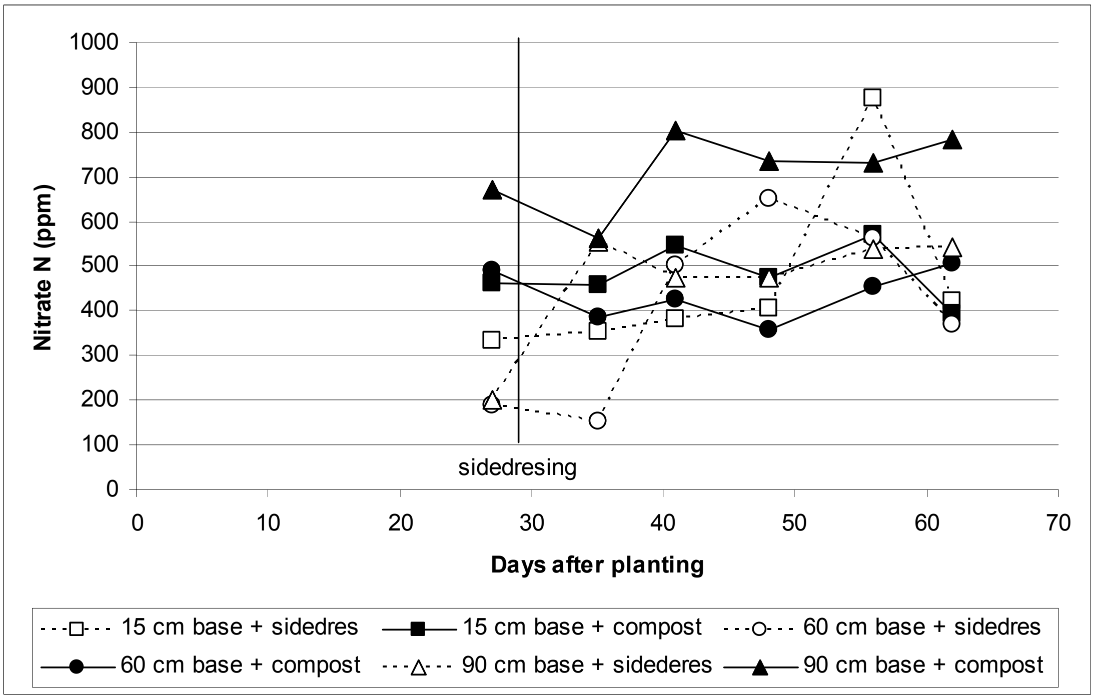

Figure 20. Nitrate concentrations of solutions collected from SSET during the lettuce cropping period.

Managing root zone nitrogen and salts in a NSW sweet corn crop

(Experiment report prepared for circulation via online placement)

Adrian Hunt[1], Craig Henderson[1], Tony Napier[2] and David Troldahl[2]

[1] Gatton Research Station, Agri-Science Queensland

[2] Yanco Research Station, Industry and Investment, New South Wales

Key findings

- It is essential to have some measure of soil water status in conjunction with SSET solute measurements, otherwise it can be very difficult to interpret the results.
- Given good pre-plant levels of soil N, it is possible to grow high yielding sweet corn crops with no additional side-dressings of fertiliser.
- Sweet corn yield, and thus efficiency of input use (e.g. water; nitrogen) is strongly influenced by the population density of healthy plants.
- Relying on a single tool, or measurement, to make management decisions (such as nitrogen additions) is fraught with risks. Better to have several, independent strands of information to correlate with each other, and give a fuller picture of what has occurred, and is likely to occur in the future.

Plate 3. Checking sweet corn growth in a field experiment, Yanco, February 2010.

Introduction

It is important for sweet corn producers to supply enough nitrogen to satisfy the crops requirements. Traditionally, scheduling of applied nitrogen fertilisers has been based on rule of thumb or pre-plant soil tests in most vegetable cropping systems. A recommendation is then given to supply sufficient nutrients to the crop. Although it is likely that these recommendations based on pre plant tests are generally sufficient, the amount of excess nitrogen may occasionally be substantial. This can lead to unnecessary expenditure on fertiliser and adverse environmental impacts. In order to further refine nutrient application to reduce these excesses, growers need a robust tool, which would allow them to know immediately if a crop is being under supplied with nitrogen. They could then take action to remedy it. Without the security of such a tool, the tendency may be to over apply the nutrient as a type of insurance. This recognises that the direct economic impact on the grower of undersupplying a nutrient may be significantly larger than oversupplying it.

The use of in-situ soil solution collection has predominantly been in perennial horticulture, for monitoring concentrations of salt and nitrate. This has allowed for analysis of trends over a time scale of several years. Adjustments to irrigation and fertiliser strategies have then been made, based on observed trends, with some successes (Stirzaker, Stevens et al. 2009). The use of these devices for the monitoring of annual vegetable cropping has not been explored in as much detail. The relatively small time scale over which most vegetable crops a grown means that there is comparatively little time to observe trends and take corrective action. Fallow periods between cropping cycles mean that a proportion of the solutes will be leached by some rain events. Currently, it is not possible (using current techniques) to leave the monitoring tools in the paddock during fallow and land preparation periods, as the equipment will be destroyed. For these reasons, we decided to focus on soil solution monitoring within a single season, and evaluate the usefulness of the solute monitoring tools in this time frame.

Soil solution extraction tubes (SSET), some times referred to as suction cups or suction lysimeters, consist of a porous ceramic cup joined to a tube. The opposite end is sealed and a smaller tube inserted, to allow for the extraction of samples. Installation involves inserting the samplers into a specified depth, with good contact between the tips and surrounding soil. Suction is then applied to the sampler for a period of hours/days, after which the collected sample is removed for analysis. The period of time required to gather a sufficient sample varies, depending on the soil water tension, soil texture, porosity, permeability, suction applied and volume of sample required.

We decided to investigate whether these in-situ soil solution sampling methods would provide us with useful information in an irrigated sweet corn crop. To do this we chose a range of nitrogen treatments, to compare trends in solute sample concentrations over time.

Materials and methods

The experiment was conducted at the NSW Yanco Research Station. Four nitrogen treatments were replicated four times in four blocked reps with two cultivars (*Sentinel* and *Magnum*). Each plot was one bed, 18 metres long, with two rows, 75 cm apart, per bed. We sowed the sweet corn on 12 January 2010 using a manual sowing machine. Plants were thinned by hand to five plants per metre at the three-leaf stage.

Irrigation was provided with 23 mm diameter DRIPTUBE 1.0 l/h 500 mm spacing (939290500 NAAN SOL) placed next to each crop row. The actual measured output was 1.25 litres per dripper per hour.

A basal application of fertiliser containing 800 kg/ha of single super, 172 kg/ha of muriate of potash and 33.3 kg/ha of zinc sulphate was applied to all treatments prior to planting. There was a base dressing of 46 kg nitrogen to the whole experiment, followed by two side dressings of nitrogen, implementing the treatments (Table 4).

Table 4. Nitrogen fertiliser treatments

Total Nitrogen	Base fertiliser	First side-dressing (21 DAP)	Second Side-dressing (41 DAP)
46 kg/ha	100 kg/ha Urea (46 kg/ha N)	0 kg/ha Urea (0 kg/ha N)	0 kg/ha Urea (0 kg/ha N)
109 kg/ha	100 kg/ha Urea (46 kg/ha N)	100 kg/ha Urea (46 kg/ha N)	37 kg/ha Urea (17 kg/ha N)
184 kg/ha	100 kg/ha Urea (46 kg/ha N)	200 kg/ha Urea (92 kg/ha N)	100 kg/ha Urea (46 kg/ha N)
276 kg/ha	200 kg/ha Urea (92 kg/ha N)	300 kg/ha Urea (138 kg/ha N)	100 kg/ha Urea (46 kg/ha N)

SSET were placed at 15 and 60 cm in the 46 and 184 kg/ha nitrogen treatments. They were suctioned to 60 kPa, with samples extracted the following day. These extractions were conducted on a weekly basis. Biomass and dry plant samples were taken at 20, 42 and 62 days after planting. Sap samples were tested for nitrate concentration at 35, 49, 63, 69 and 78 days after planting for all treatments. We applied three sprays of Success2™ for insect control.

We harvested the sweet corn crop 76 days after planting. Cobs from eight metres of both rows on each bed (12 m^2) were harvested with primary cobs (first initiated) harvest counted separately. Plants were also graded into healthy, stunted and damage (mainly lodging). Soil tests were taken at 0-15cm, 15-30 and 30-50 depth from each block prior to planting and then again from each plot after harvest.

Results and discussion

Yield

The nitrogen application treatments did not have an effect on yield ($p=0.05$) for number of cobs, nor weight of cobs (with or without husks) for either cultivar. *Magnum* had a final mean yield of 58,180 ± 1400 cobs per ha, weighing 20.3 t/ha with husks on. *Sentinel* had a final mean yield 67,080 ± 580 cobs per ha, weighing 20.6/t/ha husks on. *Sentinel* had 17% more cobs/ha than *Magnum*. Much of this can be attributed to a 12% higher plant population density by harvest. *Sentinel* had no lodging, whilst only 2% of plants were stunted and unproductive. In contrast, 3% of the *Magnum* plants lodged, with a further 4% stunted and unproductive. In some compensation for lower plant densities, the *Magnum* cobs were 6% heavier than the *Sentinel* cobs with husks removed.

As we have determined in other experiments, this result confirms that sweet corn yield is strongly linked to productive plant population. Any factors that influence plant population should be given a high priority. Note that in this instance, plants were thinned to a desired population, so poor plant performance was related to either genetic pre-disposition, or insect/disease influence post-emergence.

Electrical conductivity

The EC of solutes extracted from the 15 cm depth were relatively low for the first 70 days after planting, although they were slightly higher for the treatment receiving less nitrogen in the side dressings (Fig. 21). Interestingly, they remained consistent for that lower nitrogen treatment, right through until harvest, however for the higher N rate the solute EC rose to around 4 dS/m in the final two samples. As previously discussed, this could have been due to drier soil conditions at the time of sampling, which concentrates solutes in the soil water. The electrical conductivity of SSET samples at 60 cm were much more consistent (Fig. 22). For the first 40 days after planting, EC steadily increased to around 4 dS/m, and then just as steadily declined to around 1.5 dS/m by harvest.

Interestingly, soil sampling showed EC of all plots increased from pre-planting through to post-harvest (Fig. 23), suggesting accumulation of salts from irrigation and fertiliser inputs. This contrasts with the results from the SSET at 60 cm, which at first glance suggests deep EC had fallen during the latter stages of the experiment. This demonstrates why it can be difficult to understand solute movements based on a single strand of information (e.g. SSET, or soil sampling). In this circumstance, it would have been useful to have soil tension values as well, to give an indication of soil moisture conditions at the time of sampling. We are still awaiting analysis of some electronically collected soil moisture data, which may clarify this picture.

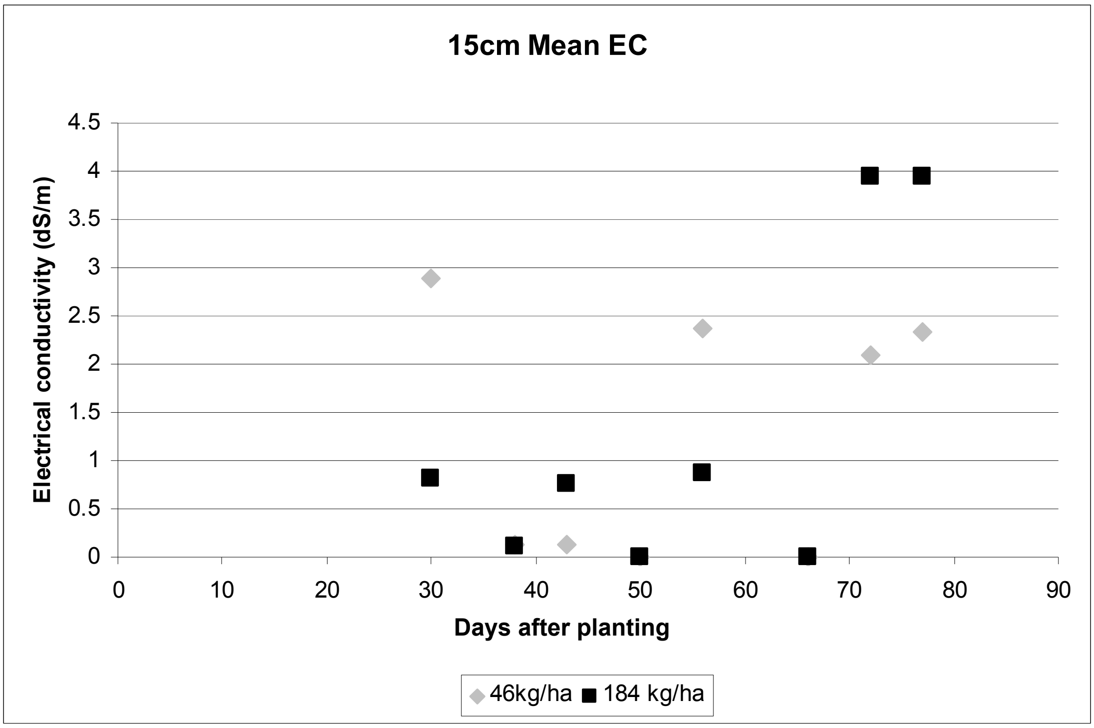

Figure 21. Electrical conductivity of SSET samples at 15 cm

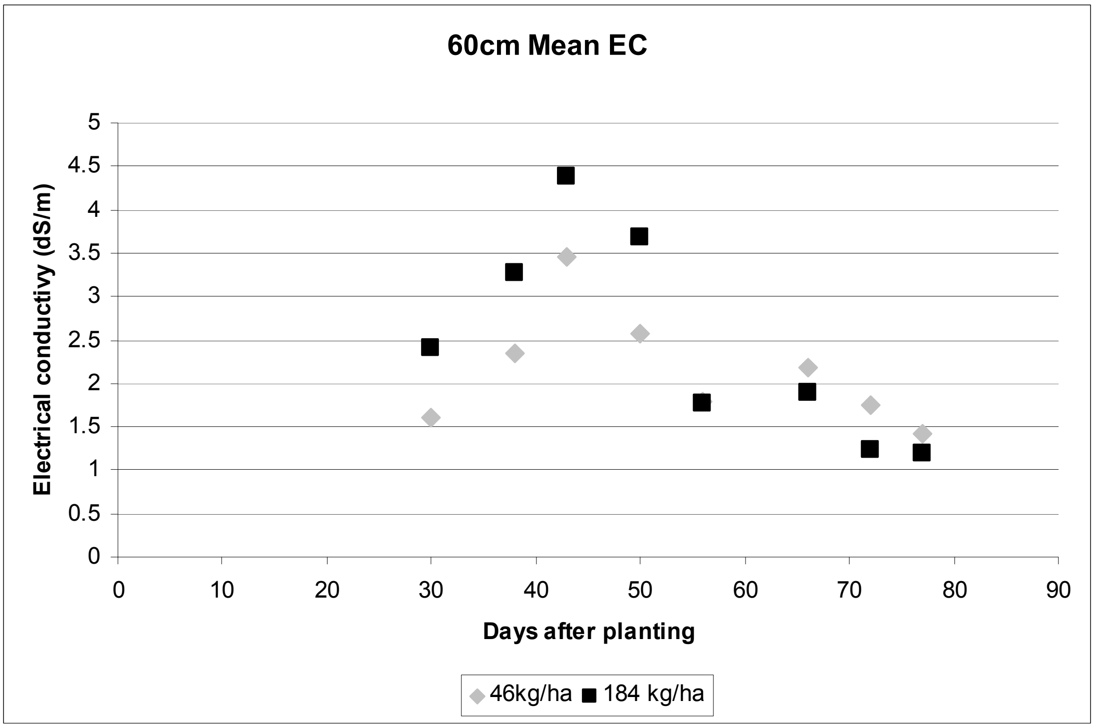

Figure 22. Electrical conductivity of SSET samples at 60 cm

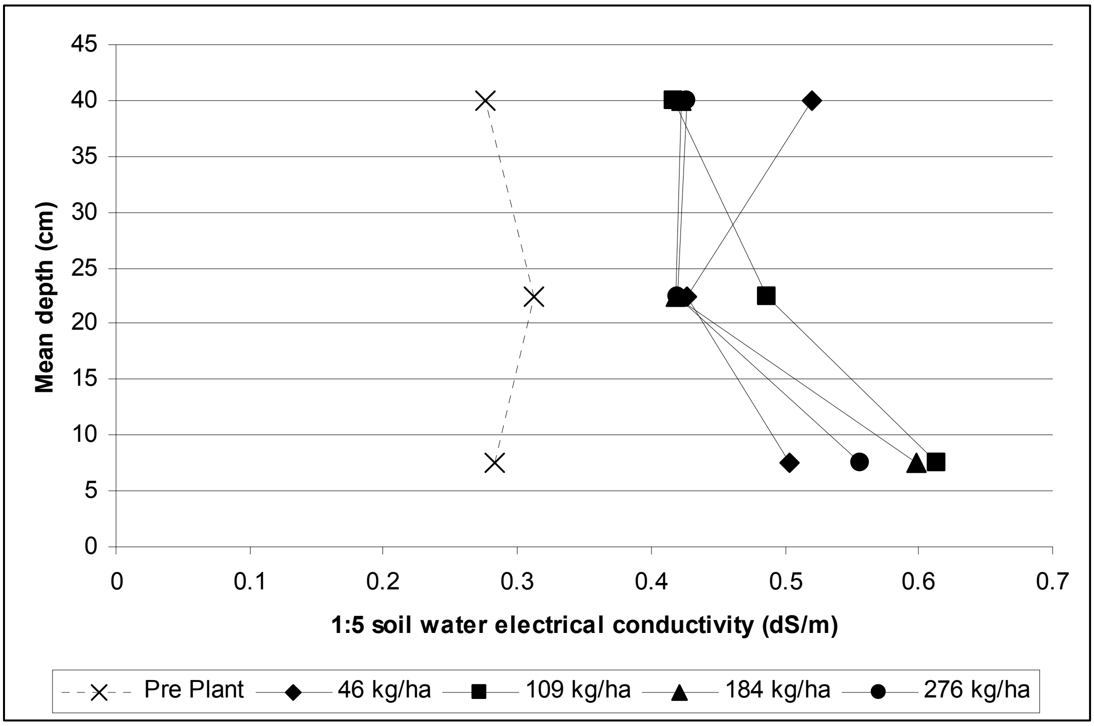

Figure 23. **Soil core sample 1:5 soil water electrical conductivity.**

Nitrates

Nitrate concentrations in the SSET samples from 15 cm showed some level of nitrate at 30 days after planting. From there on in, there was virtually no nitrate recorded, even after the second side dressing at 40 days after planting (Fig. 24). We can only think that the fertigation treatments pushed the nitrogen past the shallow SSET. The other puzzling result is how rapidly the nitrate levels dropped in a one-week period after the initial sampling. The deeper SSET results make more sense (Fig. 25), although we believe that the fall in nitrate from 50 days after planting until harvest may have been a combination of plant uptake, leaching, and increasingly wet soil conditions at that depth (diluting the solute concentration). Pre-plant and post-harvest soil sampling suggests significant uptake or leaching of nitrogen in the top 40 cm of the soil profile, particularly at 25-30 cm.

Given that there was no yield response from side dressing with nitrogen, we assume that the soil N plus the 46 kg/ha basal N was sufficient for this crop. Relatively high initial N levels pre-planting, presence of nitrates in the profile in hundreds of ppm, very high sap nitrates and leaf N contents early on could have confirmed we were in luxury levels. An important note is that to have confidence in a decision to withhold nitrogen side dressing, a range of measurements confirming good N status and supply are required. No one tool can provide all that information.

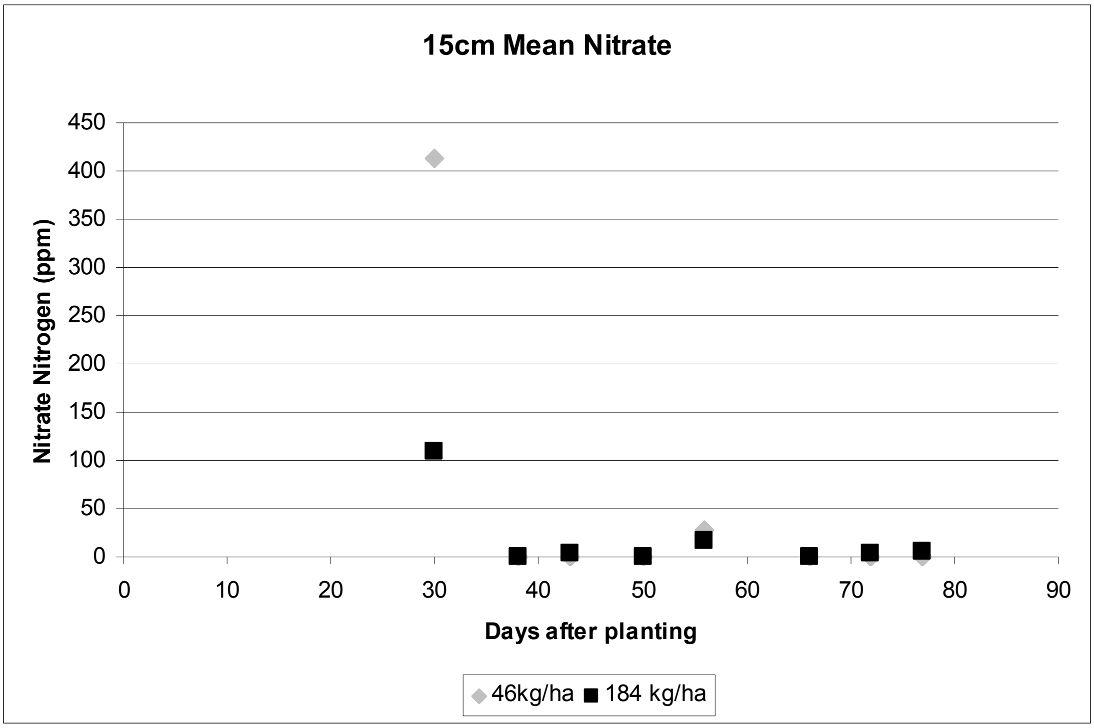

Figure 24. Nitrate nitrogen concentrations in SSET samples at 15 cm.

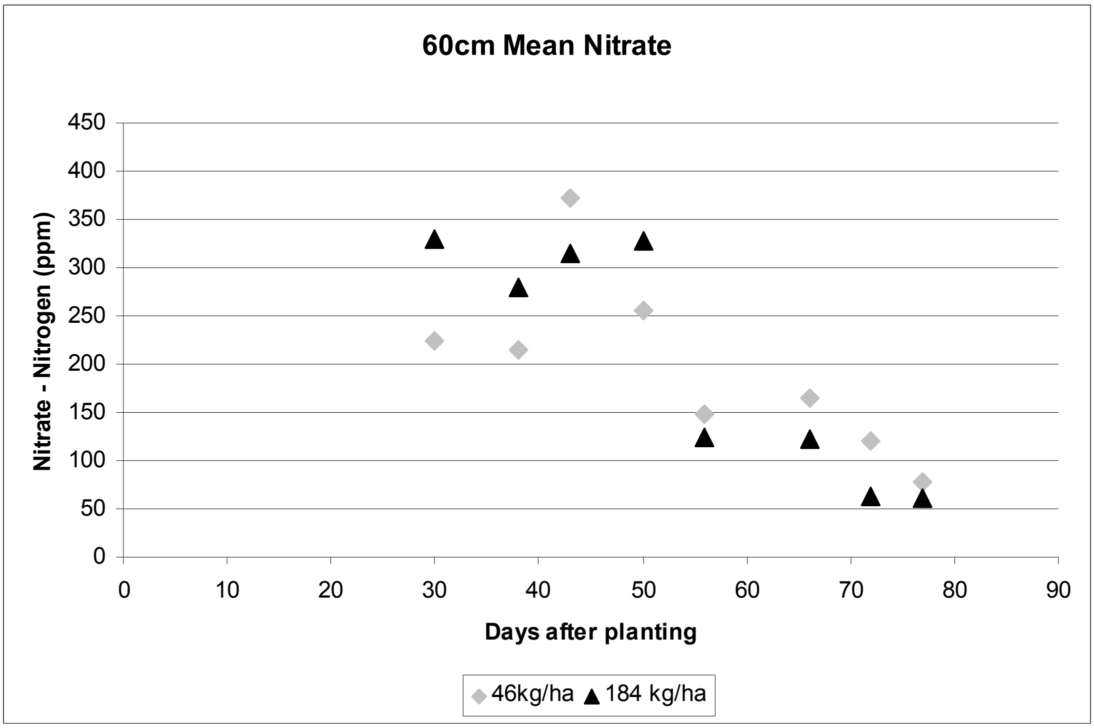

Figure 25. Nitrate nitrogen concentrations in SSET samples at 60 cm.

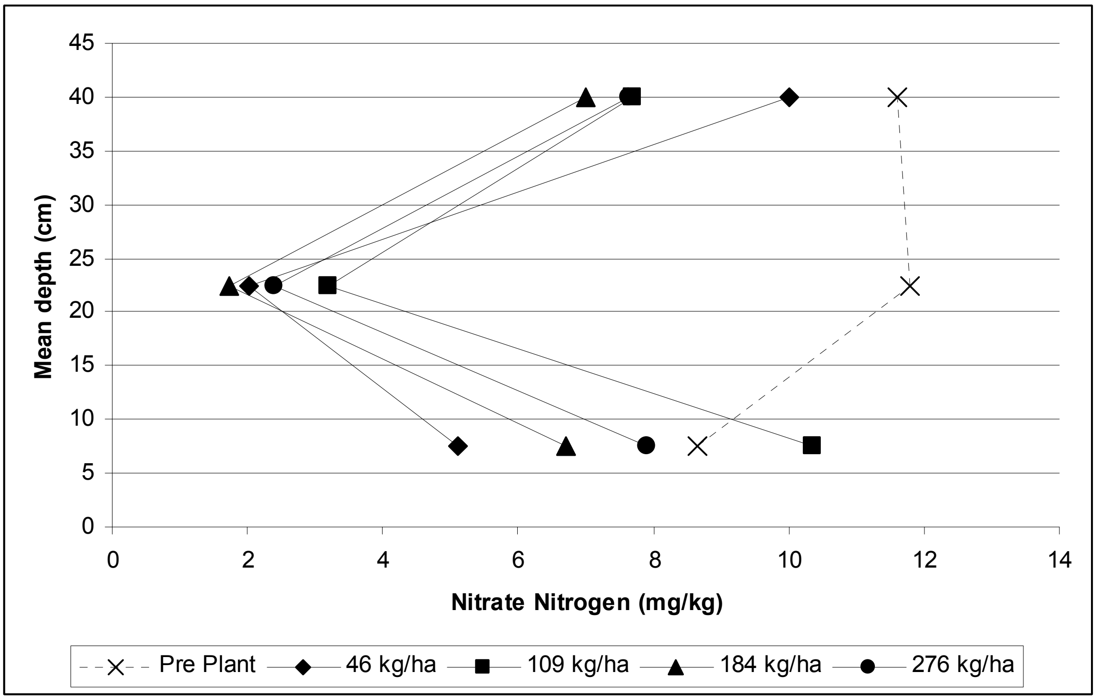

Figure 26. Pre-plant and post-harvest soil nitrate concentrations.

There was a very strong relationship between total amounts of nitrogen side dressings and sap nitrates (Fig. 27), suggesting that we were seeing luxury uptake and consumption of nitrate, soaking up some of additional nitrate from the side dressing treatments. It was also interesting to note the major differences between cultivars (Fig. 28), demonstrating how difficult it can be to derive absolute levels for determining fertiliser requirements. Another interesting observation is how large differences in sap nitrates are not reflected in large differences in nitrogen concentrations in dry tissues (Fig. 29), and how the changes over time are much greater than differences between treatments.

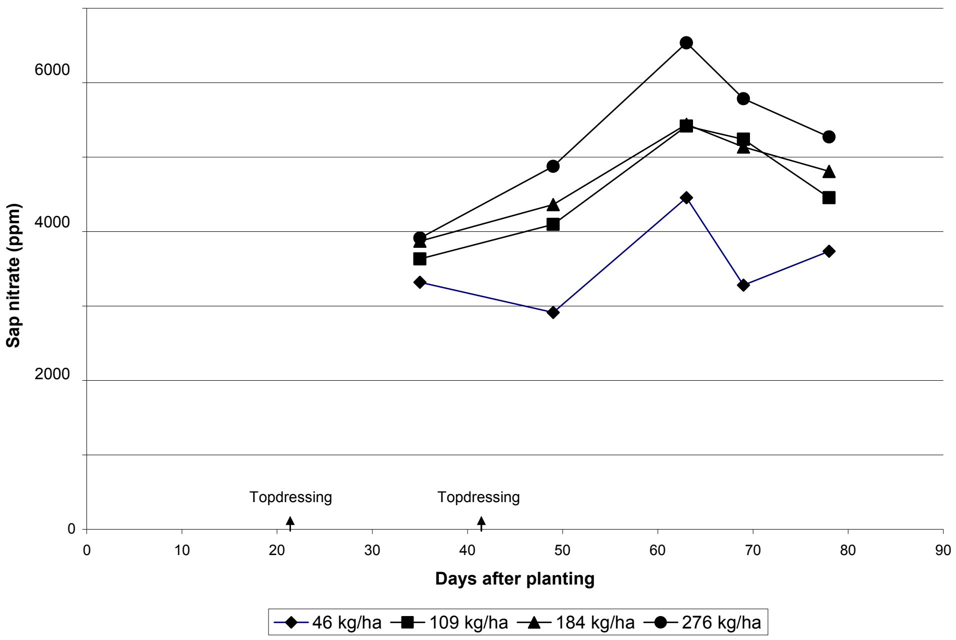

Figure 27. Sap nitrate concentrations compared between treatments over time.

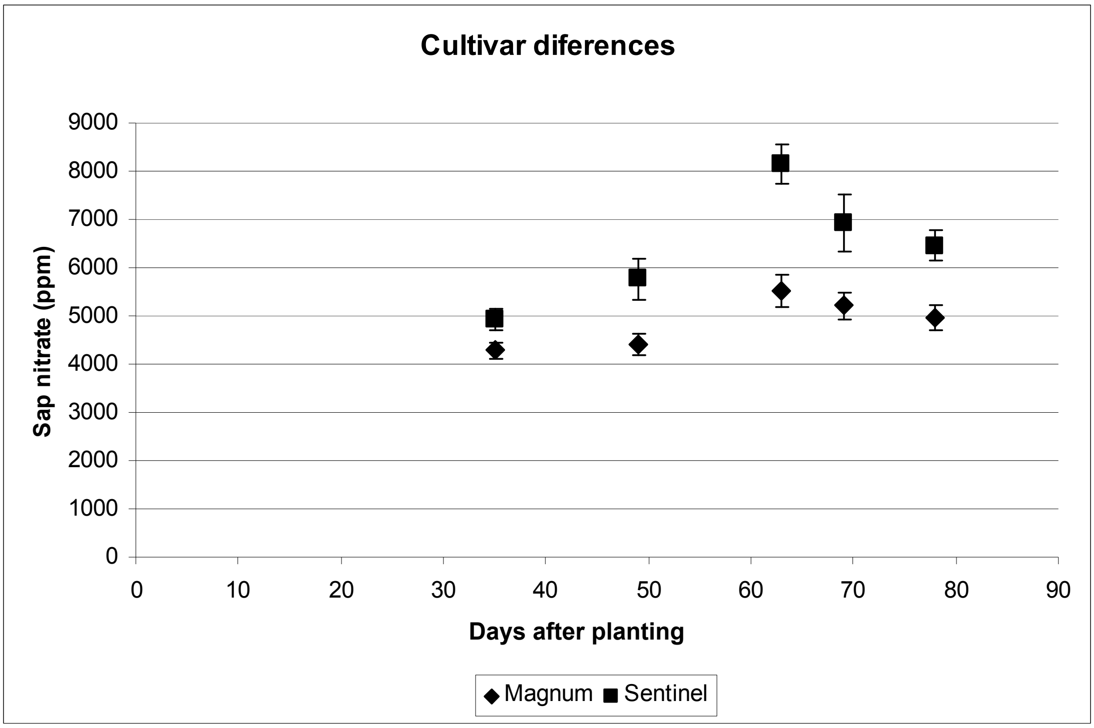

Figure 28. Sap nitrate concentration compared between cultivars over time.

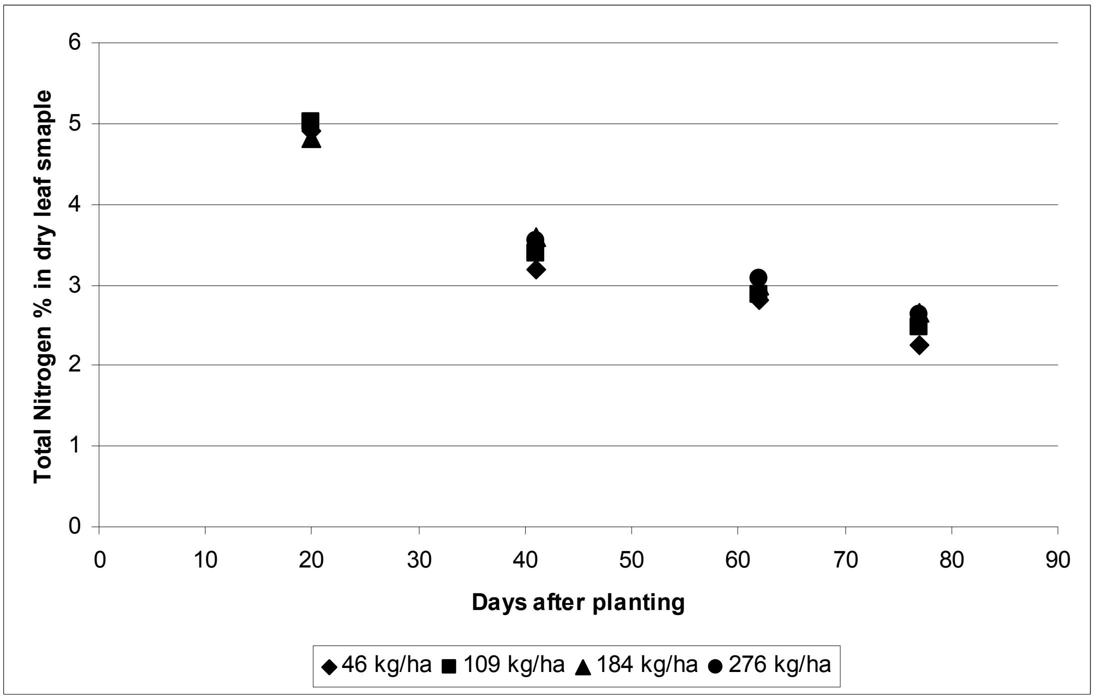

Figure 29. Total nitrogen percentage of dry leaf samples.

Irrigation and water balance

Looking at the irrigation and water balance data, it appears that irrigation volumes kicked up after about 40 days after planting (Fig. 30). This could explain why we started to see lower nitrate concentrations in the deeper SSET at that point, due to a combination of leaching and sample dilution. However, we would have expected EC to also decline in that instance, whilst the opposite actually occurred. A potential hypothesis is that the increased rain and irrigation mobilised some salts from higher up in the root zone, down into the deeper SSET extraction zone. At 4 ML/ha, the total amount of irrigation and rain applied is on the higher scale of what we would have expected for a drip irrigated sweet corn crop, hence it is likely that there was some deeper percolation of irrigation water.

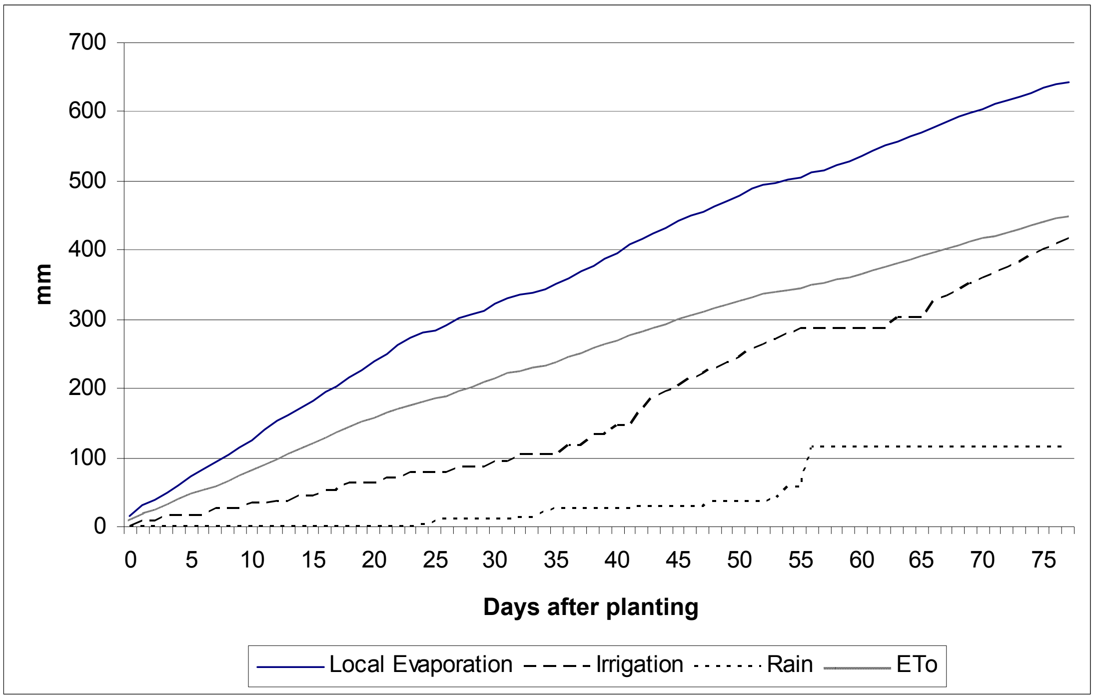

Figure 30. Cumulative water balance for the Yanco sweet corn crop.

References

Stirzaker, R., J. Stevens, et al. (2009). "Stages in the adoption of a wetting front detector." Irrigation and Drainage.

Successfully managing root zone nutrients and salts in a Granite Belt lettuce crop - A case study using FullStop™ wetting front detectors

(Experiment report prepared for circulation via online placement)

Adrian Hunt, David Carey, Craig Henderson and Greg Finlay

Gatton Research Station, Agri-Science Queensland

Key findings

- The FullStop™ wetting front detector showed potential as a feedback mechanism for irrigation and nutrient management in the sandy soils of Queensland's Granite Belt region.
- Nitrate concentrations and electrical conductivities in crop root zones were higher than we had anticipated; probably the result of large applications of manures and composts in previous cropping cycles.
- The grower and irrigation manager were able to use the information we gathered to improve understanding of their irrigation practices, including run times. They can also use this information to improve future crop management decisions, including fertiliser application rates and frequency in the cropping cycle.

Introduction

As part of a larger experiment investigating integrated pest management on a Granite Belt lettuce grower's property, we took the opportunity to install FullStop™ wetting front detectors in a lettuce crop. During this experiment, we demonstrated the wetting front detectors to the co-operating farm staff and property owner, as well as other local growers and resellers. Research staff and growers were interested to see how the FullStop™ performed on coarse textured soils, in comparison with heavier clay soils that we had investigated in earlier work. Sandy soils such as those in the Granite Belt region of Queensland are inherently susceptible to loss of nutrients through leaching. Their low water holding capacity means that efficient irrigation management requires diligent observation of the crop, and timely decision-making. The use of recycled water for vegetable and fruit production in this region has increased the importance of understanding movement of salts and applied fertilisers through crop root zones.

Demonstration method

We installed two pairs of FullStops™, one day after the collaborating grower transplanted the crop (7 February 2010). We located the pairs of FullStops™ at different depths, to better indicate irrigation water movement through the soil profile. We buried one FullStop™ from each pair at 15 cm; the second at 40 cm depth. We chose the 15 cm depth to sample from the lower section of the lettuce root zone. The 40 cm unit was below the main root zone, to catch irrigation water draining to depth. The FullStops™ were easily installed with a shovel in the coarse textured Granite Belt soil. This contrasts markedly with installation and retrieval of these devices in heavy clay soils, which requires significantly more effort.

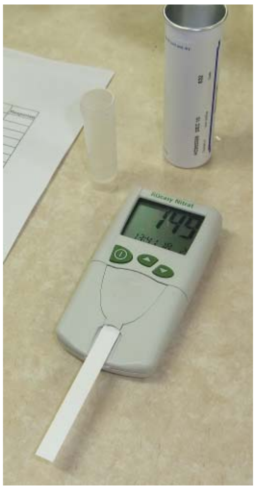

Figure 31. FullStop™ wetting front detectors installed in an healthy lettuce crop, and a Merck RQ Easy™ nitrate meter for laboratory analysis of nitrate concentrations.

The FullStops™ collect samples of soil solution as wetting fronts move through the profile, after rain or irrigation. For a detailed explanation of these devices, refer to the attached FullStop™ factsheet. We tested the water samples collected from the FullStops™ for electrical conductivity (EC) in the field, using a hand held conductivity meter. The electrical conductivity indicates the total concentration of salts in the soil solution, both useful plant nutrients and deleterious salts (mainly sodium chloride). The field testing with a simple conductivity meter was quick and easy, giving accurate results with minimal effort. We then froze the samples, and later tested them for nitrate content, using a Merck RQ Easy™ nitrate meter. Determining nitrate content took longer, involving a complicated process requiring accurate dilutions. We felt this was best done under controlled conditions, rather than in the field.

Observed results

General operations

The irrigation manager regularly carried out a series of small volume, frequent irrigations, which matched the limited water holding capacity of the soils. Our DEEDI research staff attending the demonstration site recorded that the shallow FullStops™ had triggered most times they visited. The farm's irrigation manager was encouraged to observe, check and reset the devices himself, as a means of fine-tuning his irrigation applications. Farm staff, being busy in the peak of summer production, did not keep detailed records of this device resetting, which led to some gaps in the data. Automated data logging would have been useful to overcome this issue. However, it would also have made it more complicated for irrigation staff to relate irrigation to the wetting front movement through the soil (as obviously indicated by these manually reset devices).

The deeper FullStops™, installed at 40 cm, only registered significant deep drainage twice throughout the cropping cycle (6 weeks). Once was because of local rainfall, while the second event resulted from a stand-in farm manager adjusting the irrigation schedule. This second event is likely to have leached some nutrients below the root zone. It highlights the learning curve associated with replacement of an experienced operator with another staff member. We also sometimes extracted small samples from the FullStops™, even when the flag was not triggered (due to insufficient drainage volume). We included analyses from these samples in the results.

Nitrate concentrations and movement

We measured trends in soil nitrate concentrations within the lettuce crop root zone for from the east and west zones of the paddock, at both 15 and 40 cm depths (Fig. 32). Nitrate levels were initially much greater nearer the surface in both replicates. The western replicate started 20% lower than the eastern replicate, and decreased to very low levels within two weeks. The decline in nitrate concentration was much slower in the eastern replicate, and only dropped to 300 ppm by the last sampling date (still very high soil levels of N). This may have been due to non-uniformity of application of fertilisers or irrigation. The 40 cm deep sample concentrations started lower, and decreased more gradually, than those at 15 cm depth.

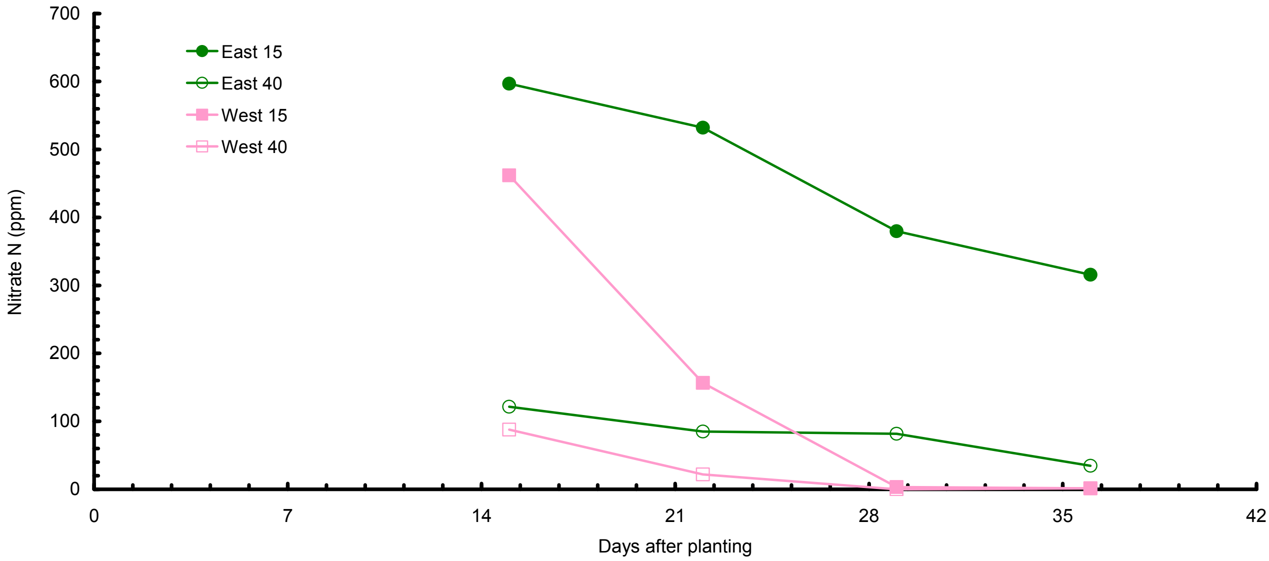

Figure 32. Nitrate nitrogen in the lettuce root zone declined during the growing period.

The nitrate measured in the 15 cm detector was within the active root zone of the developing lettuce crop. Most of the decrease in nitrate levels through the life of the crop was due to crop uptake, with the balance due to leaching, or transformation to another form of nitrogen. Importantly we did not observe large spikes in the nitrate concentration in the FullStops™ at 40 cm, which would have been the prime indication of a large leaching event.

The concentrations of nitrate nitrogen at the beginning of the cropping cycle appear to be quite high, particularly at the shallow depth (15 cm FullStops™). The grower reported using generous amounts (up to 5 tonnes/ha) of poultry and feedlot manure, as well as compost, before each crop, for the past several years. He is attempting to build up both soil structure and fertility in this relatively new cropping area. This soil amelioration program has produced results - soil sample analyses showed an organic carbon of 1.8%. This is high for these sandy soils. The soil within the plough layer in the upper soil profile was a much darker colour, with an improved organic matter appearance compared to the white sand observed at greater depths.

In addition to basal manure applications, the grower also applied relatively small amounts of fertiliser through the solid-set sprinkler system during the lifespan of the crop. Tests on run off water collected in a drainage dam found nitrate nitrogen concentrations that ranged from 10 to 30 ppm. Good design on this farm ensures that all paddock runoff (including that containing fertiliser) is captured in this drainage dam, and then pumped back on to the crop via the irrigation system, rather than leaving the property.

We collected whole lettuce plant samples at harvest, and analysed them to further investigate nitrogen movement within the system. The results indicated relatively low nitrogen percentages (averaged 2.3% dry weight) in comparison with previous experience in other growing districts. Though solution nitrate levels in the shallow FullStops™ were high at times, the soil tests at the end of the crop cycle showed only 12 mg/kg of residual nitrate nitrogen. There may be value in undertaking further testing during the course of the crop to improve our understanding of nitrogen uptake and removal by the crop, as well as changes in availability during the season on these sandy soil types.

Electrical conductivities

Electrical conductivities were highest in samples from the 15 cm FullStops™, with declines in EC in all devices during the cropping period (Fig. 33). As with the nitrate, the reductions in EC were much greater in the western zone of the lettuce paddock. The results indicate some leaching of total salt content occurred throughout the growing period, more substantial in the western zone. The electrical conductivities at the beginning of the growing period were higher than we had anticipated. It is likely that the high level of dissolved salts present in the soil was due to the large quantities of feedlot, poultry manure and compost added prior to planting, and historically in previous seasons. This highlights the diversity of the potential sources of dissolved salts in an agricultural production system. Dissolved salts at the high concentrations recorded in early stages of this demonstration may well have had a negative impact on the initial growth of the lettuce crop.

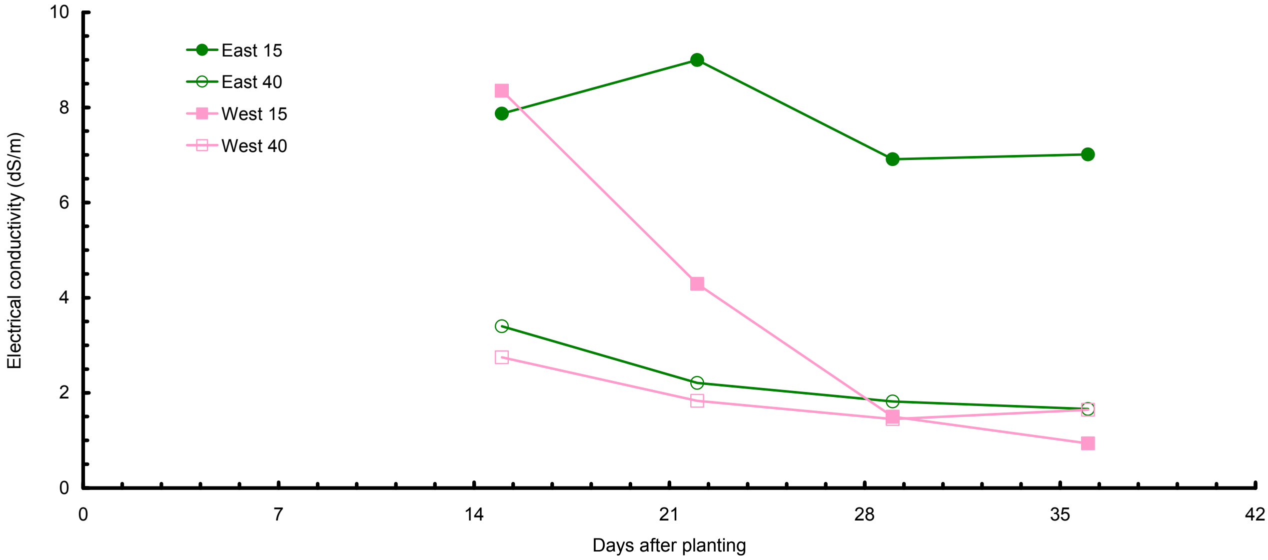

Figure 33. Electrical conductivities in the lettuce root zone declined during the growing period.

Using FullStops™ in Granite Belt lettuce production

The FullStops™ gave us an opportunity to sample and measure the quantities of solutes moving within the soil profile. The data provided an overview of solute concentration changes during the life of the lettuce crop.

Follow up discussions with the grower, based on these solute data, allowed us to identify areas of his fertiliser program that could be improved. The high initial levels of nitrate N meant there was less need for pre-plant applications, with more attention paid to irrigation management and supplementary fertiliser additions later in the crop. The idea is to better match available nutrient supply to plant requirements, through the life of the lettuce crop. The information gained from the FullStops™ was not pivotal to identifying these changes. However, they were useful in assisting the grower to better understand the levels and movement of dissolved solutes within his system. The grower is keen to build on his improved knowledge, and refine both the irrigation practices and soil solute management within his farming system.

The trial succeeded in raising the awareness of FullStops™ in the Stanthorpe area, with several growers and resellers who visited the site over the course of the demonstration commenting that they had not seen these devices before.

Growers who are managing irrigation of vegetable crops on sandy or sandy loam soils will likely find the FullStop™ wetting front detector a useful management tool, which will assist them to fine tune water applications. They can easily indicate when water has reached the desired depth in the plant root zone, as well as when major leaching events have occurred. These simple devices are easy to install on coarse textured soils, and can collect soil solution samples for rapid analysis, if there is a concern about salt or nutrient movements.

Successfully managing root zone nutrients and salts in a Laidley cabbage crop - A case study using Soil Solution Extraction Tubes

(Experiment report prepared for circulation via online placement

Adrian Hunt, Julie O'Halloran and Craig Henderson

Gatton Research Station, Agri-Science Queensland

Plate 4 Cabbage establishment in a field experiment, Laidley, August 2009.

Summary

We monitored nitrogen movement in a Lockyer Valley cabbage crop using soil solution extraction tubes (SSET), tensiometers and soil / plant analysis. The lateral separation between the drip tape through which fertigation was delivered and the plant row had led to concerns that nitrogen was not reaching the plant row. Tensiometers showed the plant rows drying out during the season, while soil under the drip tape remained near field capacity. Samples from SSET showed some spikes in nitrate concentrations below the root zone, but could not be used as a quantitative assessment. Nitrogen fertiliser use efficiency was extremely high at 200%, demonstrating good use of residual nitrogen from the previous crop. The grower gained a more complete understanding of the movement of nitrogen within his system, and will be able to use this in making management decisions in the future. We had reliability and ease of use issues with the SSET. This suggests they will not be practical for vegetable producers for continuous monitoring, but may still hold some merit for solute movement problem solving, when integrated with other measurements.

Introduction

A Lockyer Valley cabbage farmer invited Agri-Science Queensland staff on to his property, to undertake an experiment to better understand the nitrogen use efficiency within his system. Although the grower was not experiencing water shortage, he was interested to find out how his water application was affecting the movement of nitrogen within the soil profile.

The grower expressed concerns that the nitrogen he has been applying to the crop, using drip fertigation, may not be reaching the plant rows. This concern arose because of the separation between the plant rows and the drip tape through which fertigation is delivered. The grower also made a conscious effort not to over supply nitrogen, as he believed that this would lead to product quality issues such as tip burn. After an initial visit, a site was chosen to undertake the experiment.

Method

Soil samples were taken prior to transplanting, in order to asses the level of residual nitrogen carried over from the previous crop of green beans. This was found to be approximately 80 kg/h in the top 15 cm of soil. Basal fertiliser was then broadcast, which provided an additional 38 kg/h of nitrogen. The transplanted cabbage seedlings were irrigated by solid set sprinklers for the first three weeks. One line of drip tape was then laid on each bed with a row of plants on either side. This was carried out as part of scuffling weed control operations several weeks after transplanting. There were two applications of urea and one application of potassium nitrate applied through the drip tape as fertigation, contributing a further 42 kg/ha of nitrogen.

The seedlings were planted in two rows 75 cm apart on 1.5 m beds.

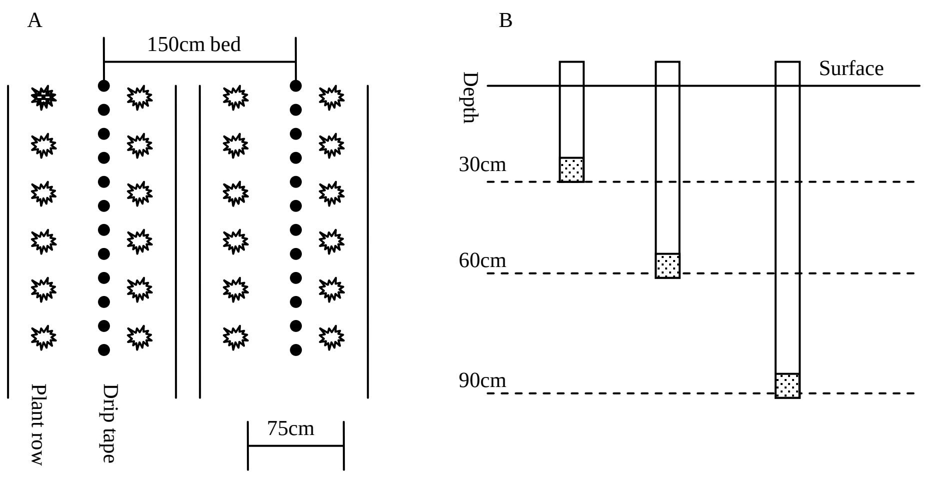

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Figure 34. Field layout. A; From above. B; soil profile showing SSET

Three replicates of soil solution extraction tubes (SSET) and tensiometers were then installed at 30 and 60 cm within the crop rows and 30, 60 and 90 cm between the crop rows, in line with the drip tape. The equipment was installed four weeks after transplanting. Although installations of these narrow tubes were not a complicated task, it did prove to be physically challenging in the moderately heavy clay soil. This was especially the case where tubes were installed to 90 cm depth or where rocks were encountered. Once installed we allowed two weeks for the SSET to settle in and drip tape to be installed.

We maintained a weekly sampling programme where practical. SSET were suctioned to -60 kPa and allowed to gather a sample for several days before collection. Samples were analysed for EC using a hand held conductivity meter and then frozen for later analysis of nitrate concentrations. We measured soil water tension using tensiometers whilst we were gathering samples from the SSET.

Figure 35. Hand operated suction pump.

Most of the SSET yielded a sample initially. After three weeks of sampling, most of the SSET in the plant row failed to yield a sample. This is likely be a result of drying out of the soil beyond a soil water tension at which the SSET could extract and some cracking of the soil which allowed air to flow into the SSET through the tip. SSET in line with the drip tape yielded samples more reliably, especially those at 60 and 90 cm, where soil water tension remained low throughout the assessment.

Results and discussion

The basic irrigation operating schedule used by the grower was to run the drip irrigation once every three days for 12 hours. This was then modified based on any rainfall events and other work scheduled. We calculated the applied volume of water based on measured emitter output. Approximately 31 mm was being applied every 3 days following the base schedule. Plant consumptive water use would rarely exceed 7mm per day even under hot, dry conditions. However, tensiometers placed in plant rows showed soil water tension increasing to above 50 kPa (Fig. 36). Given that this is in the upper range of soil suction before plant stress would be expected, and the low soil water tension measured under the drip tape, there is an indication that a large proportion of the applied water was not moving laterally into the plant row.

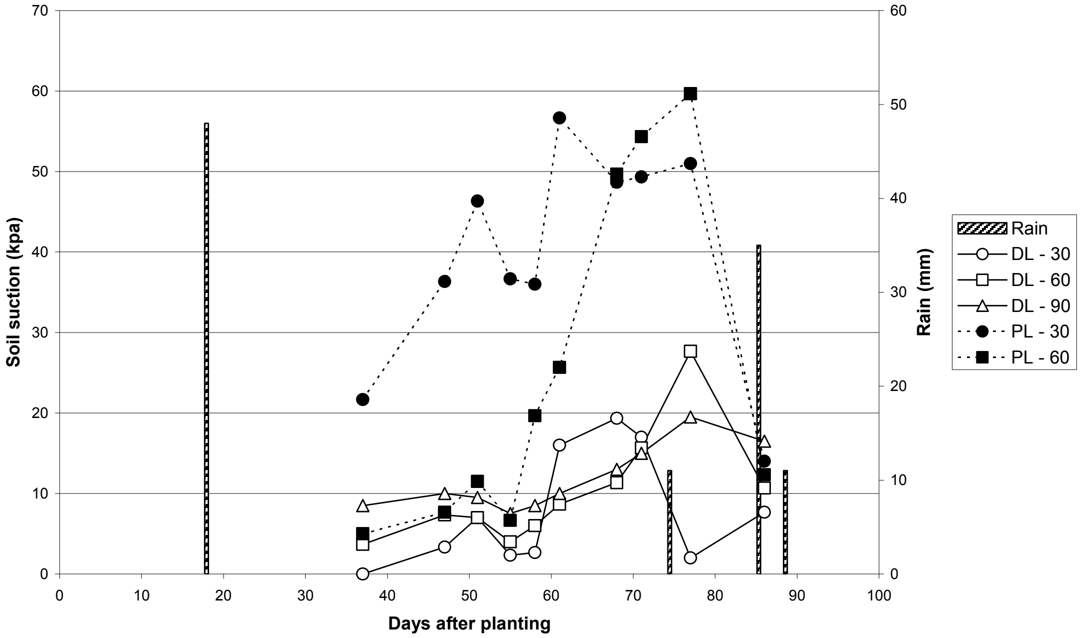

Figure 36. Soil water tension. PL plant line; DL drip line.

The failure of SSET in plant rows to collect samples after the first few weeks means that the evaluation of the lateral movement of applied nitrogen fertigation could not be carried out in the manner we originally intended. We did however find that there were spikes in nitrate concentration in samples taken from beneath the drip line (Fig. 37). Some of this is likely to have moved beyond the potential root zone of the cabbage crop. However, it should be noted that the spikes were relatively small, in contrast with those that have been seen in some other cropping situations.

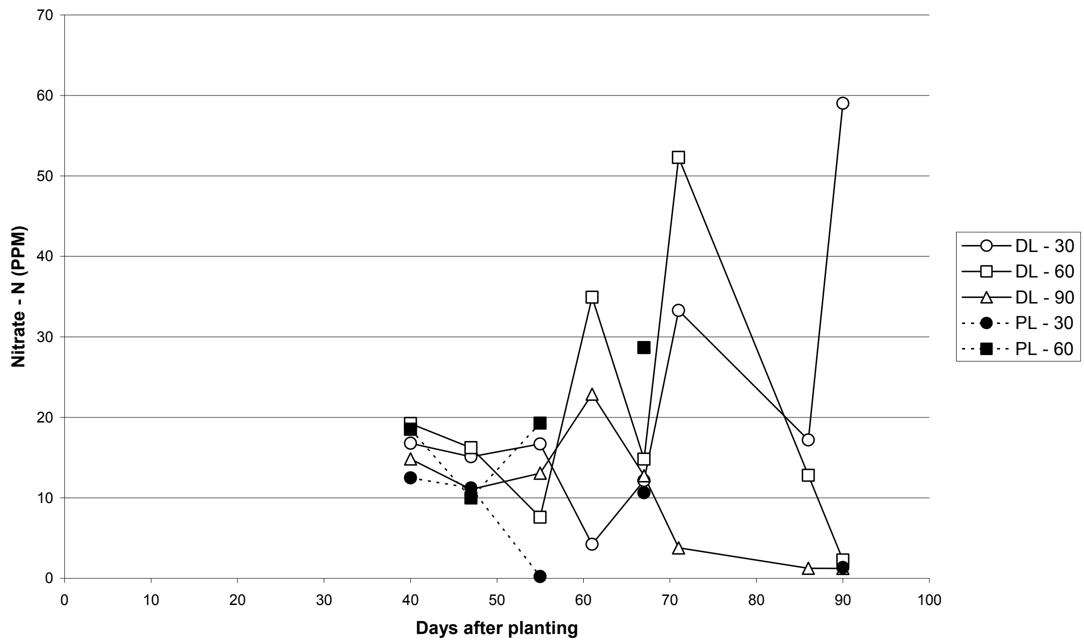

Figure 37. Nitrate N concentration of the soil solution extracted using SSET.

The electrical conductivity of the SSET samples was relatively low. There was a further reduction in EC, particularly in the samples taken at 30 cm. As would be expected, the leaching of total salt load would be greatest closest to the surface. It also confirmed that EC increased with depth. At no stage was the ECsw at a concentration that would be expected to have a major impact on the productivity of a cabbage crop.

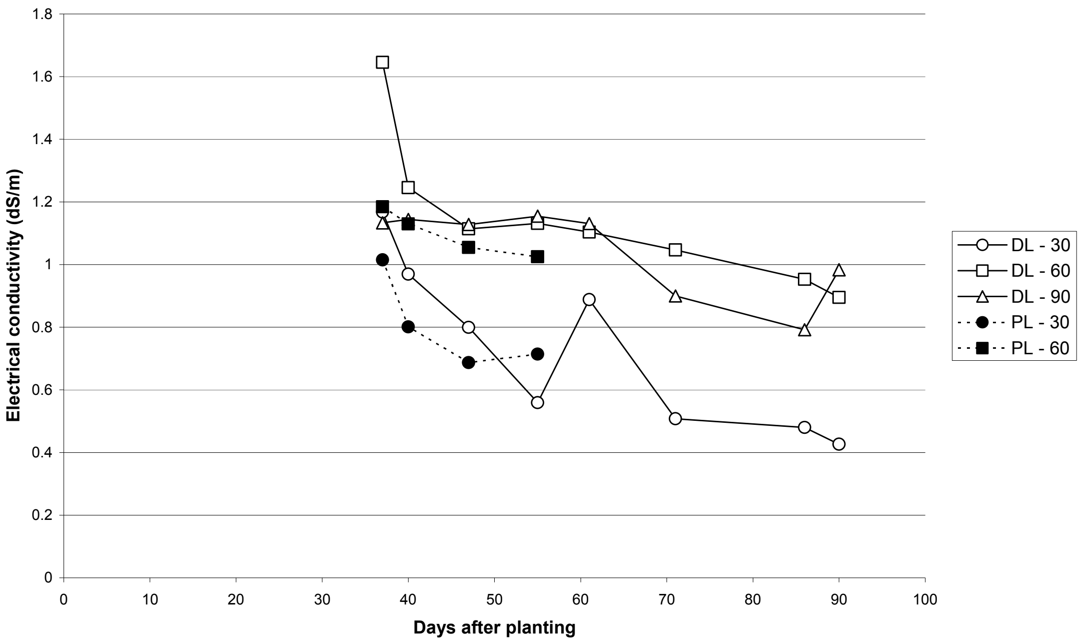

Figure 38. Electrical conductivity of the soil solution extracted using SSET.

At harvest, plant samples were taken, separated into marketable and residue components, dried and sent for nutrient analysis. This was then combined with the pre-planting soil test, basal fertiliser application and fertigation records, to give an indication of nitrogen use efficiency. The results indicated that the grower was operating at slightly over 110% efficiency in removing applied nitrogen in marketed product. The total nitrogen used by the crop would have been closer to 200% of the total applied nitrogen. This confirms the contribution made by the carryover of nitrogen from previous crops, through cropping residues and residual soil nitrogen. Any further reduction in applied nitrogen or diminishment in available residual nitrogen might risk crop nitrogen deficiency. This shows that the grower has already been applying good management practices by applying sensible levels of nitrogen fertilisers. This minimises the potential negative environmental outcomes without negatively affecting farm productivity.

In a follow up visit, the grower indicated that he had not grown cabbages on drip tape irrigation in the period since the experiment, due to favourable seasonal conditions. One change that he had made was to move the plant rows, which had previously been spaced uniformly, in closer to the centre of the bed. This means that when drip irrigation is used again in the future, both the water and nitrogen will not have to move as far from the drip tape to the plant row. Having had a look at the irrigation efficiency assessment, the grower will also be looking to move to an irrigation schedule that applies less water more frequently, whilst monitoring plant row soil water tension, to try to improve irrigation water use efficiency.

Although the trial did not provide the growers with definitive answers as to the movement of applied fertigation nitrogen, he was satisfied with the results overall. This is perhaps because they confirmed some of his own thinking and gave some indication as to where he could potentially adjust his system in the future.

Using SSET

The reliability of the SSET to recover a sample was a significant issue. In most instances, this appeared to be because soil water tension was above the range at which the SSET were capable of operating. This was in spite of timing sampling to coincide with irrigation events, when the soil was at its wettest. Options for overcoming this appear to be limited. Applying more water to make it easier to extract samples would distort the system that we were trying to evaluate. Placing them deeper, where the soil is slower to dry out, removes them from the most active part of the root zone, where the majority of the nitrogen uptake occurs.

The removal of sampling tubes proved to be a challenging exercise. Three separate visits were made to the site, before all of the equipment was successfully removed. Pulling upwards by hand on the tubes was sufficient where they were installed to 30 cm. However beyond this, other methods were used, including: excavating most of the soil from around the tube with a spade; griping the top of the tube with multi-grip pliers;, tying to the tubes using a clove hitch knot lifted vertically with a jack; and driving a deep soil corer over the top to the tube to the installation depth to remove both the tube and surrounding soil. Many of the tubes were damaged beyond repair in the process (Fig. 39). In some cases, this was because the tip broke away from the tube, and in others, the tube itself was damaged. Digging out all of the surrounding soil appeared to be the method that caused the least damage to the SSET, but also required the most physical effort.

Figure 39. SSET damaged during removal from the field

The time input required for the collection of each sample was not very long. However, the cumulative time required for installation, applying suction, collecting and analysing samples, as well as removing the equipment became substantial. It is unlikely that many vegetable producers would have the available time to do this on a regular basis. Outsourcing of these tasks would also likely prove costly. This is especially the case where SSET prove unreliable in extracting samples and the results are difficult to interpret, with no clear indication as to the extent of leaching or sufficiency of available nitrogen. The main opportunity to utilise this technology appears to be as a crosscheck / problem solving approach with irrigation and fertiliser management, in identifying when large-scale changes in soil solute concentrations within and below the root zone are occurring.

Outcomes

The grower now has an improved understanding of the nitrogen balance, movement of nitrogen and irrigation scheduling within his cropping system. He will be able to build on this knowledge in making sensible management decision in to the future. We gained experience and understanding of the challenges that need to be overcome to monitor solutes using SSET within a commercial cropping system.

In-situ monitoring of salt and nitrate-N in capsicum root zones irrigated with Class B water - A case study using Soil Solution Extraction Tubes

(Experiment report prepared for circulation via online placement

Sarah Limpus and Craig Henderson

Gatton Research Station, Agri-Science Queensland

Summary

Irrigating with recycled water has recently been bought back into focus as a viable practice for two main reasons. Firstly, to reduce nutrient loading in river catchments, for example the extensive Murray-Darling Basin. Secondly, recycled urban effluent can be a reliable water resource during times of drought, climatic variability and changing water allocation priorities.

The Stanthorpe Rural Recycled Water Reuse Scheme began supplying horticultural irrigators in 2005, in an effort to reduce nutrient loading in Quart Pot Creek. This was in response to requirements outlined by the Environmental Protection Agency in 1999. High salt and nutrient loads of recycled water can inhibit the sustainability of the farming system and cause soil degradation and yield reductions. These solutes can also lead to eutrophication of waterways and pollution of aquifers if not managed effectively.

In the summer of 2009/10, we examined the spatial and temporal fluctuations of salts and nitrates in the root zone of a capsicum crops irrigated with recycled water. We sought to understand how solute movements related to management practices on-farm. We used soil solution extraction tubes manufactured by JKG Tech.

Salt concentrations in the extracted solutions generally remained below 3 dS/m, but increased to higher levels for a short period. Monitoring indicated that drip irrigation on the coarse, shallow soils, with an impermeable underlying clay layer, was potentially generating a salt scald in a vulnerable section of the paddock.

Nitrate – N concentration remained below 125 mg/L. However, it is likely that some nitrates are being leached from the root zone, as concentrations did not decrease with depth in the soil profile.

Introduction

In the last decade or so, the push for recycled water as an irrigation source was mainly in response to environmental issues associated with nutrient loading in inland river systems. In average rainfall years, it is estimated that 25 % of the total nutrient load entering the Murray-Darling Basin through sewerage treatment plants (Bond 1998). This can cause major environmental damage. However, in times of climatic uncertainty, the focus on recycled water for irrigated cropping systems in the last few years has dramatically intensified. Recycled water is seen as a reliable source of irrigation water in a country under constant threat by drought and climatic variability. The ability of recycled water to succeed as a viable and sustainable option for irrigated cropping depends on the management of that system (Bond 1998). Therefore, there are some issues that need to be considered when irrigating crops with recycled water. These are principally related to:

- The salt concentration of the water, and
- The nitrate and nutrient concentrations of the water.

Recycled water (up to Class A) contains high levels of salts (particularly sodium), and nutrients (particularly nitrogen and phosphorus) and poses a potential for risk in horticultural cropping systems. Salts can affect the health of the crop and cause soil structural decline. While nutrients are a critical requirement of the crop, they can contaminate groundwater and cause eutrophication of waterways through leaching and runoff. However, by remediating one, it may have the opposite effect on the other. It is important to find the balance between the two, and this is individual to each site.

The purpose of the monitoring and analysis exercise discussed within this paper was to examine salts and nitrates within the root zone of a system that utilises recycled water as irrigation. Specialised equipment was used to monitor the solutes of a capsicum crop's root zone at three depths. This was used to develop an understanding of how their variations relate to the on-farm management practices.

Background information

<u>The Stanthorpe Rural Recycled Water Reuse Scheme</u>

Initiation of the scheme was a response to changes in environmental legislation regarding nutrient content of discharge into Quart Pot Creek. The Environmental Protection Agency in 1999 determined that discharge concentrations were not to exceed 0.75 mg / L of total nitrogen and 0.1 mg / L of total phosphorus. Actual levels of these nutrients in Quart Pot Creek were up to 48 times higher than specified prior to the scheme's commencement (Gray 2009). This prompted the Stanthorpe Shire Council (now Southern Downs Regional Council) to employ Sinclair Knight Merz, a consulting company, to develop a plan to reduce nutrient discharge into the creek (Sinclair Knight Merz 2006; Gray 2009). Sinclair Knight Merz found that a recycling scheme would be the most cost effective solution to achieve the new environmental conditions.

Expressions of interest for the recycled water scheme were advertised by the council in February 2001, these were primarily for commercial farms willing to access a reliable source of water for their businesses. The current scheme which supplies commercial vegetable farms and fruit orchards with Class B recycled water for irrigation was initiated in 2004 (Gray 2009).

The Stanthorpe Rural Recycled Water Reuse Scheme began supplying irrigators in 2005 and in 2006 / 2007 the scheme supplied 100% (up to 344.6 ML) of water delivered to the treatment plant back to urban and rural recycled water scheme participants (Gray 2009). Currently there are nine commercial fruit and vegetable businesses receiving recycled water as well as two sporting clubs, community sport ovals, the cemetery, high school and an agricultural society. All are supplied with Class B recycled water, with no plans to date to supply a higher class of water.

The property

Crop details

The property manager transplanted capsicums on the 7 November 2008 in block number 6R, Site 1, and on the 28 November 2008 in block number 9R, Site 2 (See Appendix 1 for block locations). Site 1 was irrigated with recycled water from the Stanthorpe Water Treatment Plant, while Site 2 was irrigated by water harvested from Quart Pot Creek.

Site details and soil type

The property, located near Stanthorpe, is situated in a land type known as 'Undulating Granite Plains' with a slope of 3 to 9 % exhibiting undulating lower slopes, occasional tors and rock outcrops (Maher 1996). See Fig. 40 for location of the property and the boundary lines of this land and soil type. According to Maher (1996), the major soil type of this country is 'Cottonvale' (Australian Soil Classification: Bleached – Sodic, Magnesic – Natric, Grey Kurosol). The soil profile; an example of which can be seen in Fig. 41, has a sharp textural contrast consisting of a sandy-loam top soil to 0.45 m deep and a layer of bleached sandy-clay above a grey, sandy-clay layer with orange mottling. The sandy-clay soil becomes grittier with depth, is acidic and the mottling suggests that drainage is poor (Maher 1996). These characteristics were observed during soil extraction with an auger. The grey-orange layer was saturated with water and very gritty. The soil depth on the property is often shallow, sometimes with little more than 0.9 m. In sections of the cropping area, there are visible granite rock outcroppings.

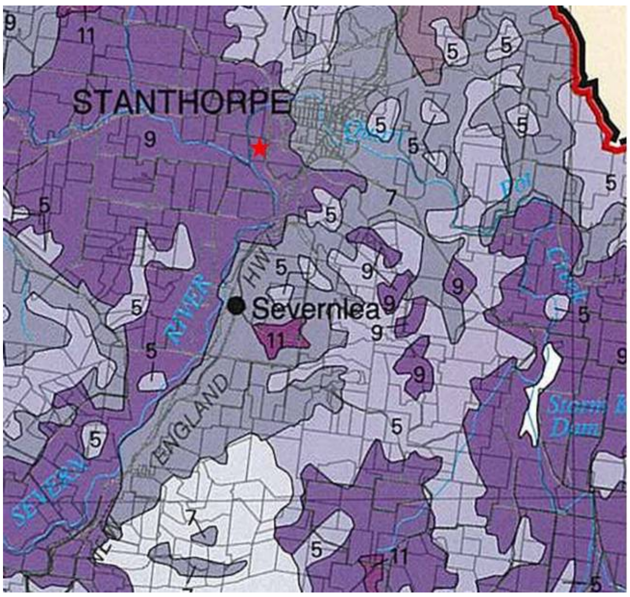

Figure 40. Map of Stanthorpe region, land / soil type boundaries. Property at red star, located in "Undulating Granite Plains" land type (dark purple area (Maher 1996).

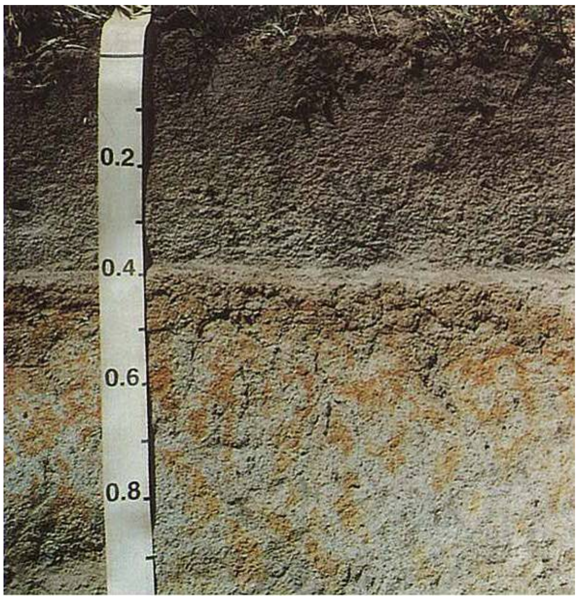

Figure 41. Example of the Grey Kurosol soil type of Wren's Valley showing the sandy-loam topsoil, (15-20% clay), the sandy-clay layer at 0.4 m, (45-50% clay) and mottled-grey, sandy-clay layer below, (30-35% clay). (Maher 1996) page 32.

The sandy-loam A horizons, with 10-20% clay content, generally has high water infiltration rates and low-moderate plant available water content. The bleached sandy-clay layer and underlying grey, mottled sandy-clay have lower infiltration rates. his results in water pooling in these sandier layers and above the textural boundaries of the B horizon (McLaren and Cameron 1996). This may cause problems with crop water logging and may even restrict root zones.

Traditionally these soils have not had problems with salinity, however during dry periods there is an increased risk of irrigated land becoming saline, especially when irrigated using trickle (Maher 1996). Drip irrigation concentrates water and salts within the root zone to reduce leaching, causing salinity to increase. These salinity problems may be short lived as seasonal rainfall is often enough to allow leaching of these built-up salts below the root zone (Maher 1996). An Electrical Conductivity (EC) of Site 1, from a soil test conducted before planting of the crop, was recorded as 0.20 dS/m (1:5 soil:water). For soils with 10-20 % clay content, according to Hazelton and Murphy (2007), this indicates the soil has a moderate salinity rating and moderately tolerant crops may be affected by salinity.

<u>Site 1 soil test</u>

The soil of Site 1 was tested for its chemical properties on the 25 May 2008, before transplanting of the crop. Due to the good organic matter content, pH and Cation Exchange Capacity (CEC) of the soil, these nutrients should be readily available. The property manager had concerns about iron deficiencies in high nitrogen water. The soil test does not suggest that there will be any micronutrient availability problems. However, when over-irrigating occurs, waterlogging of the plant can produce similar symptoms and can make iron, manganese and magnesium unavailable to the plant. Iron deficiencies can be a result of water logging above the clay layer, where drainage occurs much more slowly. Above this clay layer, we found the soil was saturated and water was pooling at the base of the slope of the field, indicating that water was not infiltrating past this layer and was instead running off to a seepage point.

<u>Irrigation water quality and schedule details</u>

Recycled water is pumped from the Stanthorpe Water Treatment Plant to on-farm storage. Creek water is pumped from Quart Pot Creek, which flows through the property. The recycled water irrigating Site 1 is stated as being Class B. According to Southern Downs Regional Council, this Class B recycled water should not contain more than 100 bacterial coliforms / 100 ml of water and 125 mg / L of total nitrogen, among other parameters. Salt concentration is not mentioned in the supply agreement, however this can range from 1 to 1.6 dS / m (WaterWise Queensland 2005). On 6 March 2009, we measured the EC of a water sample collected from the recycled water storage dam at 0.84 dS/m, with a nitrate concentration of 3 mg/L. The water sample collected from Quart Pot Creek was 0.19 dS/m, with a nitrate concentration of 0.7 mg/L.

According to the property manager, the irrigation for the capsicum crops is pulsed during the day. The irrigation is switched on three to four times a day, depending on evaporative demand, and run for approximately 15 to 30 minutes each time. This schedule was designed to reduce irrigation leaching and to allow the plants to have access to soil water during the day; essential in a soil with a low water holding capacity such as this.

In-situ monitoring devices

Soil solution extraction tubes (SSET) were used to collect soil solution samples from the root zone and below root zone. Produced by JKG Tech, the SSET consist of a tube with a porous ceramic tip glued securely to one end and a rubber bung in the other (Fig. 42). The tubes are available in a number of lengths including 0.3, 0.6 and 0.9 m; which we used in this monitoring exercise. The tubes are inserted into an augured hole in the soil the same diameter as the tube and firmed down to ensure good contact between the soil and the ceramic tip of the tube. Negative pressure is created within the tube by drawing air out with a syringe or pump to approximately – 60 kPa. When the negative pressure is applied, it will draw water from the soil the ceramic tip is in contact with and into the tube for collection.

Figure 42. Photograph of the SSET manufactured by JKG Tech with 0.3, 0.6 and 0.9 m lengths with the augers used to install them.

Comparing EC soil water to EC saturated extract measurements

Electrical conductivity measurements of soil water (EC_{sw}) samples collected with SSET are not directly comparable to measurements based on EC saturated extract (EC_{se}). This is because the samples collected by SSET are drawn from the soil-water solution under pressure and are therefore more concentrated than a measurement taken on a sample from say, a pool of water or from a drainage ditch (Raine 2009). To convert EC_{sw} to EC_{se} for the purpose of comparing data to crop thresholds, such as those presented in (Tanji and Kielen 2002), soil cores should be performed and EC_{se} taken for comparison. As we were unable to take soil cores to compare EC_{sw} and EC_{se}, we simply divided the EC_{se} by two, based on the pressure used to collect the sample (Raine 2009).

Note: EC_{sw} / 2 = EC_{se} formula was recommended to me by soil physicist Dr Steven Raine (University of Southern Queensland, Toowoomba) and is a factor of the tension by which the soil water sample is removed from the soil (-40 to -60 kPa).

Guideline nitrate values

The (ANZECC and ARMCANZ 2000), as part of the Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000, recommend that water used for short term irrigation have no more than 125 mg/L of nitrate – nitrogen (for irrigation up to 20 years, with a site specific evaluation). In a recycled water situation where fertigation is used, it is recommended that NO3 – N concentration of the water and fertigation combined be no more than this STV value. By applying irrigation water at this NO3 – N concentration, there should be adequate nutrition for crops. It also provides safety margins for volatilisation, denitrification and soil immobilisation. Water that has passed through the root zone and into potable water supplies would be of a suitable quality at the source for human consumption (potable water < 23 mg / L NO3 - N).

Note: To compare our nitrate – nitrogen (NO3 – N) results to nitrate values we used the following equation: NO3- = NO3 – N or N / 4.426 (value based on a calculation of the fraction of N that makes up NO3 – N)

Methods and materials

Installing the SSET

At Site 1, the SSET were installed on the 6 March 2009, in three positions, (A): at the top of the slope, (B): halfway down the field (3 to 9 % towards Quart Pot Creek) and (C): at the bottom of the slope, in Row 4 and 11 of the block. Three depths of SSET were installed at Position A and C, 0.3, 0.6 and 0.9 m. Only two sets of 0.3 and 0.6 m SSET were installed at Position B, due to a layer of shallow rock at a depth of <0.9 m. Their positions within the slope of the block were to determine any differences the slope may cause to salt and nitrate concentration data. The SSET were located in the centre of the bed, next to a drip tape emitter.

In Site 2, only a 0.3 and 0.6 m tube was installed (Quart Pot Creek irrigation water). An evaluation of this field was not initially planned and the two left over from Site 1, were installed at 0.3 and 0.6 m. This will provide us with a simple, but incomplete, comparison between salt and nitrate concentrations of the two sites, irrigated with different water sources.

Data collection

Data collection was initiated on the date of installation. A sample of both the creek water and the dam water was collected to provide base values of salt and nitrate concentration of the irrigation water, before addition of fertiliser and application to the field.

Sampling of soil water solution began on the 10 March 2009. The SSET were primed on the 9 March, between 6:30 and 7:30 am. The sample was collected the following day at the same time, and SSET were then primed for the next sample. This allowed us to collect data on a continuous cycle during the week. Samples were not collected on Saturdays and Sundays, due to the unavailability of staff to prime SSET and collect soil water samples. On the Friday, the solution was collected and the SSET remained un-primed until Monday morning. This prevented sample collection on Mondays too. This cycle continued until the 25 March, as the final harvest of the capsicum crop was performed on the 24 March, and thus irrigation events were terminated.

Soil water sample analysis

<u>Salt concentration</u>

The salt concentration of the soil water samples were analysed with an EC meter (Waterproof ECTestr®11+ Multi Range) manufactured by Eutech Instruments. Samples were tested for EC in the lab at the Applethorpe Research Station. At the beginning of each EC testing session, a calibration check was performed. If required, calibration was performed according to manufacturer's specifications. The cup of the meter was first rinsed with distilled water then again with a small amount of the sample to be tested. This ensured that the sample would not be diluted by any distilled water remaining in the cup. The cup was refilled with the sample and EC recorded. All the samples were tested for EC on the day of collection and then frozen for later nitrate testing.

Nitrate concentration

Freezing of the sample ensured that nitrate in the sample remained constant as at the time of sampling. If nitrate samples are left to sit at room temperature, the nitrate within the sample can change forms, which may not be detected by the nitrate testing procedure. Once sampling of the soil solution was completed, the samples were sent to the University of Queensland, Gatton Campus for nitrate testing after defrosting. NO3 – N was analysed colorimetrically on a Technicon Auto Analyser. This process involves reducing the NO3 – N present in the sample to Nitrite-N with hydrazine under alkaline conditions with copper as a catalyst and is measured at 520 nm (Raymont 2009). Then converted mathematically back into mg/L NO3 – N.

Results

Salt concentration

The average salt concentration present in the soil profile of both Site 1 and 2 crops (from 0.3 m to 0.9 m in depth) remained relatively stable over time (Fig. 43). These figures remained below 2 dS/m, well below the predicted 3 dS/m threshold corresponding to a decrease in yield for capsicum suggested by (Maas and Hoffman 1977).

A regression analysis (linear) performed with Genstat indicated that there was a correlation between position within Site 1 and salt concentration at 0.3 m, due to the slope of the field. The SSET positioned at the base of the slope indicated a trend in rising EC over time (Fig. 44). The 0.3 m EC values at the top and middle of the slope declined up to harvest.

Site 1 salt concentration at the 0.6 and 0.9 m depth did not significantly change over time (tests performed for significance: 0.9 m – standard deviation from the mean and 0.6 m – linear regression analysis – data not shown).

A regression analysis (linear) performed with Genstat found that Site 2 salt concentration varied significantly between the 0.3 and 0.6 m depths. Trends at 0.3 m decreased over time, while 0.6 m trends increased over time (Fig. 45).

Nitrate concentration

Averages of NO3 – N concentration at depths of Site 1 are shown in Fig. 46 (0.3 m), Fig. 47 (0.6 m) and Fig. 48 (0.9 m). During the sample collection period, there is a large degree of variation in sample concentration (as indicated by the standard error bars) but this did not correlate with a particular location in the field or depth sampled in the soil profile. However, on certain dates, all three average depths showed similar increasing and decreasing concentration trends.

At Site 1, there was a correlation between the rows the SSET were positioned. NO3 – N concentration at a depth of 0.3 m significantly increased over time in Row 11 but not in Row 4 (Fig. 49).

The NO3 – N concentration of Site 2 at the depth of 0.3 m decreased significantly over time (Fig. 50).

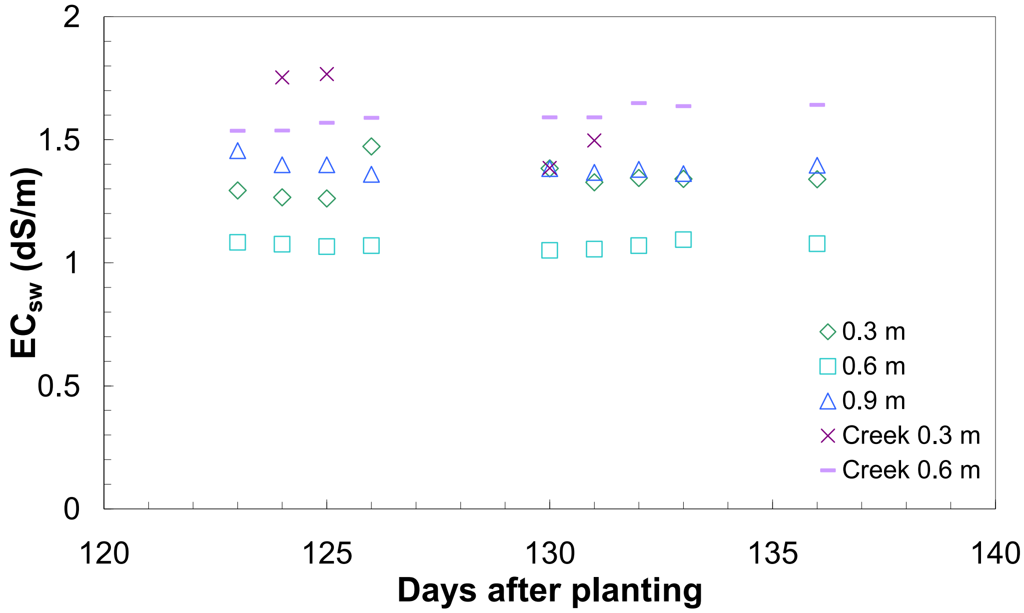

Figure 43. **The average salt concentration (EC) sampled from the soil profile at the three depths 0.3 m (n = 6); 0.6 m (n = 6) and 0.9 m (n = 4) at Site 1 – capsicum crop irrigated with recycled water; and Site 2 – capsicum crop irrigated with creek water, 0.3 m (n = 1) and 0.6 m (n = 1). Missing data points indicate that a sample was either not collected that day, due to an inability of the SSET to extract solution from the soil, or that the volume of the sample was too small to test.**

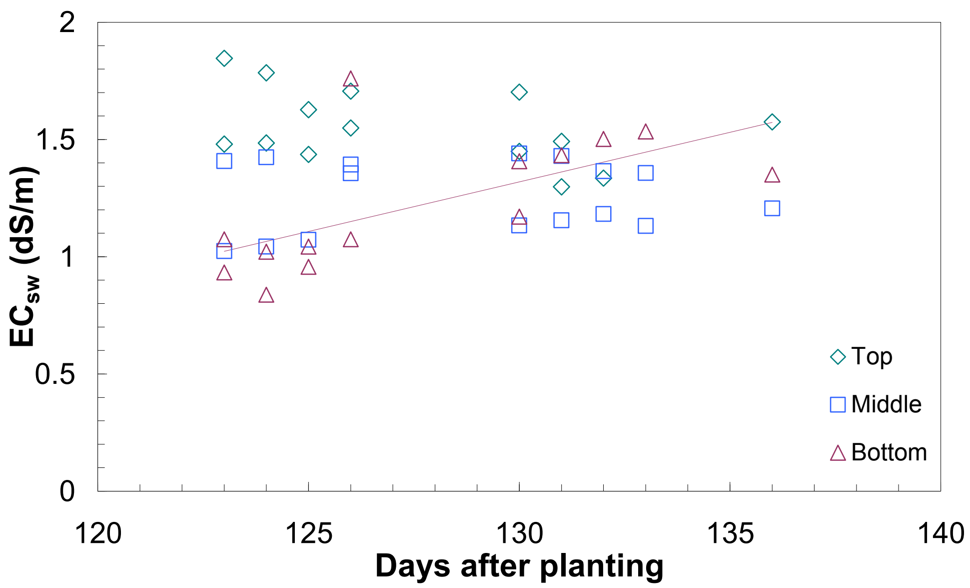

Figure 44. **Salt concentration sampled in the soil profile at 0.3 m according to position within the field of Site 1. "Top" is an average of all SSET located at the top of the sloping field, nearest the inlet (n = 6), "Middle" averages all SSET mid-slope (n = 4) and bottom, nearest the salt scald, averages all SSET located at the end of the field (n = 6); the lowest part of the crop at Site 1. Salt concentration at the "Bottom" location of Site 1 increases over time, shown by the solid line (R^2 = 0.37, significance = 0.013).**

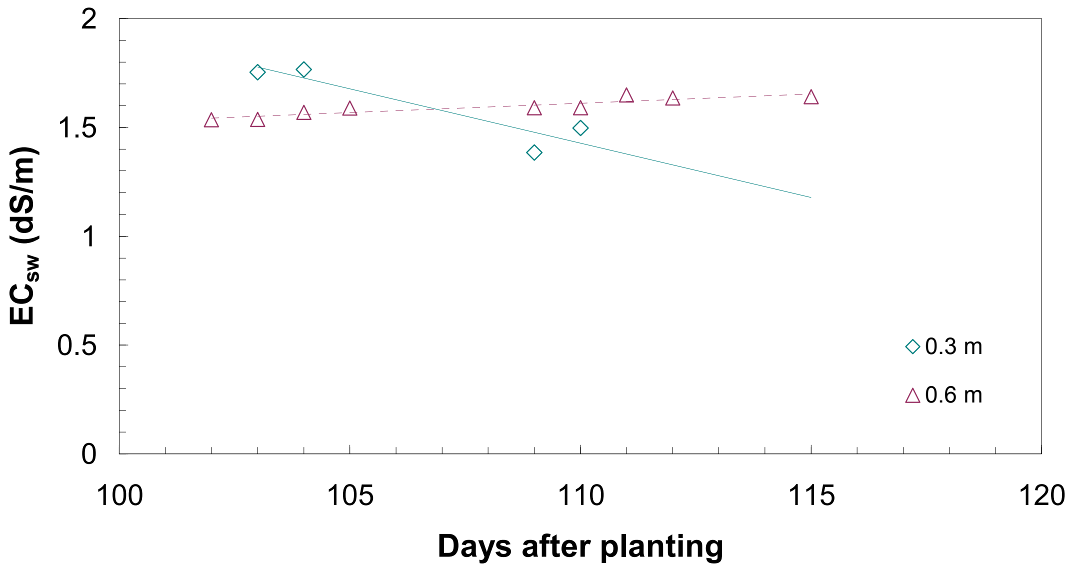

Figure 45. Salt concentration sampled in soil profile at Site 2 at two depths. The salt concentration at 0.3 m decreased significantly over time shown by the solid line (n = 1, R^2 = 0.78, significance = 0.075) while concentration at 0.6 m increased significantly over time; shown by the dotted line (n = 1, R^2 = 0.809, significance = <0.001).

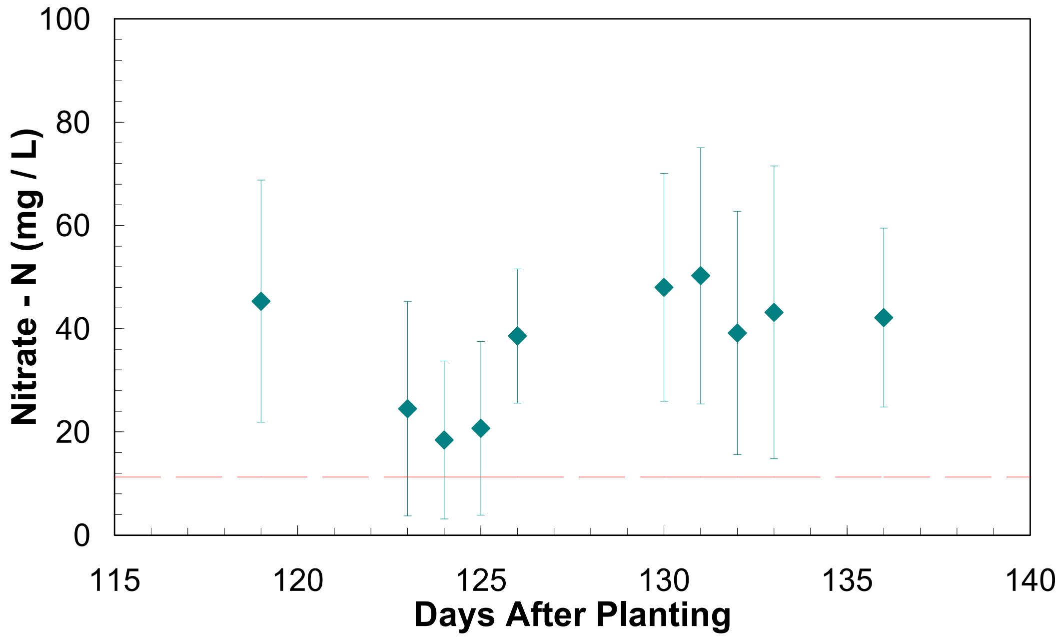

Figure 46. Site 1 Average NO3 – N concentration at 0.3 m depth in the soil profile (n = 6). The broken red line indicates the maximum NO3-N concentration of potable water for human consumption. The LTV is not represented on the following graphs as these levels are below it.

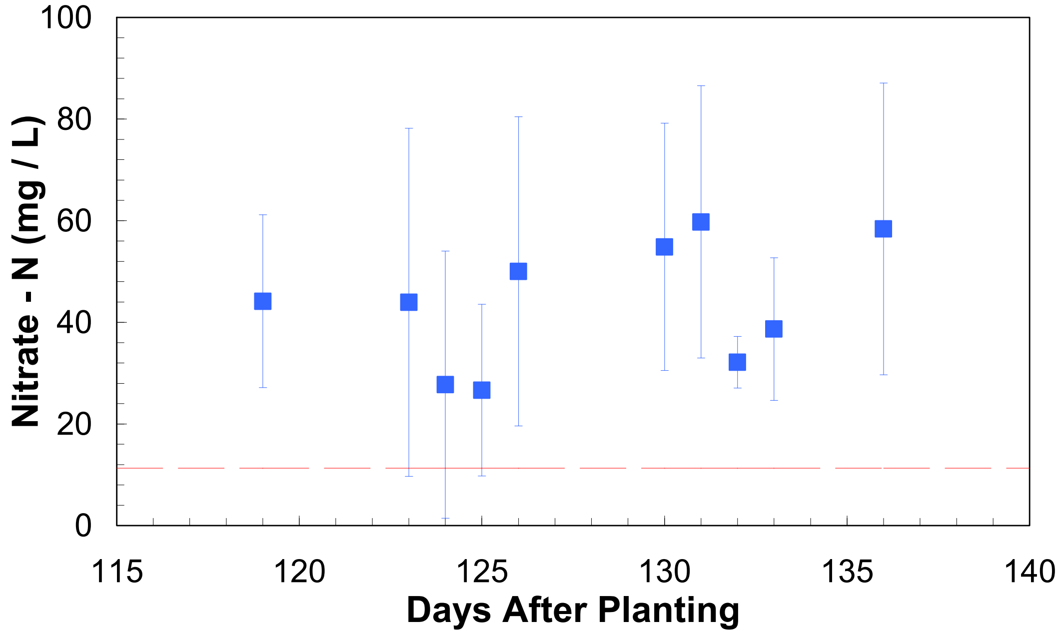

Figure 47. Site 1 Average NO_3 – N concentration at 0.6 m depth in the soil profile (n = 6).

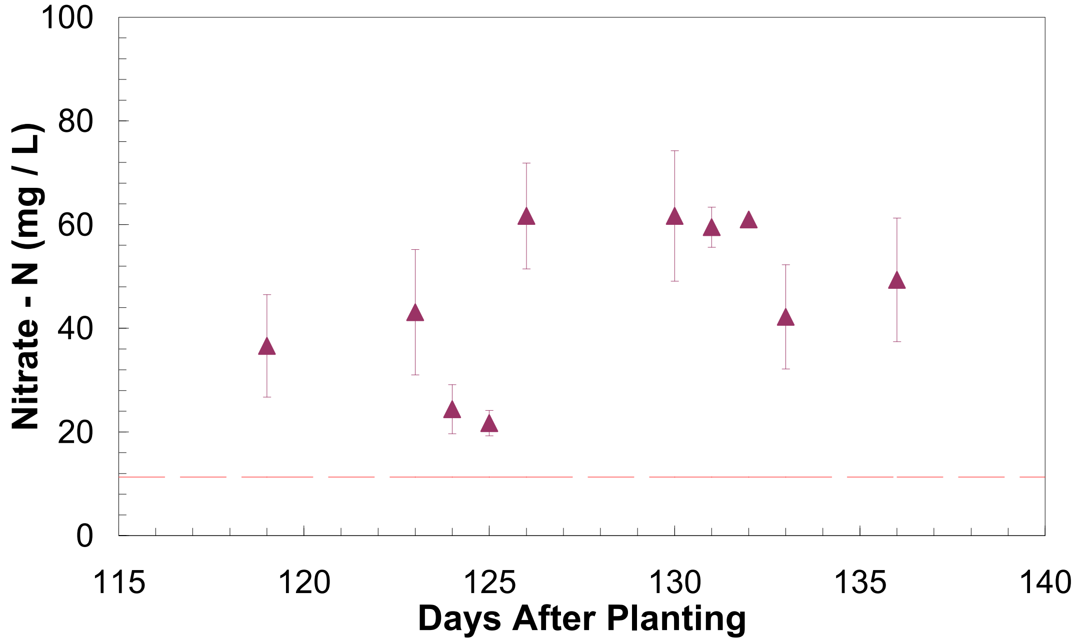

Figure 48. Site 1 Average NO_3 – N concentration at 0.9 m depth in the soil profile (n = 4).

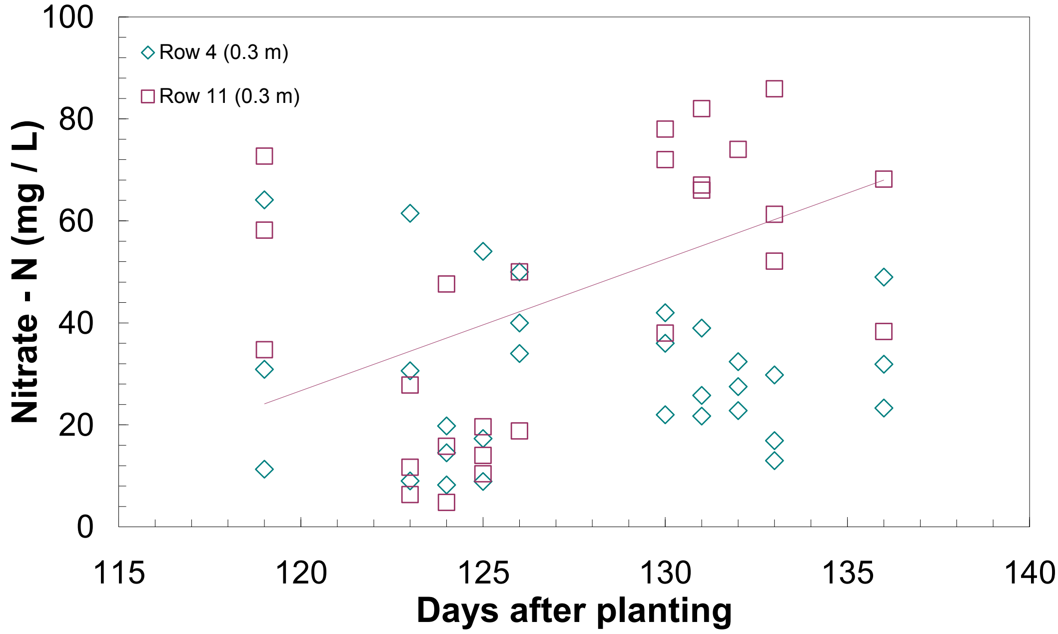

Figure 49. **Site 1 NO_3 – N concentration sampled from the soil profile of Site 1 at 0.3 m (Row 4 n = 3, Row 11 n = 3) of Site 1 according to row number SSET are located in. NO_3 – N concentration of samples from SSET located in Row 11 significantly increased over time shown by the solid line (R^2 = 0.215, significance = 0.01)**

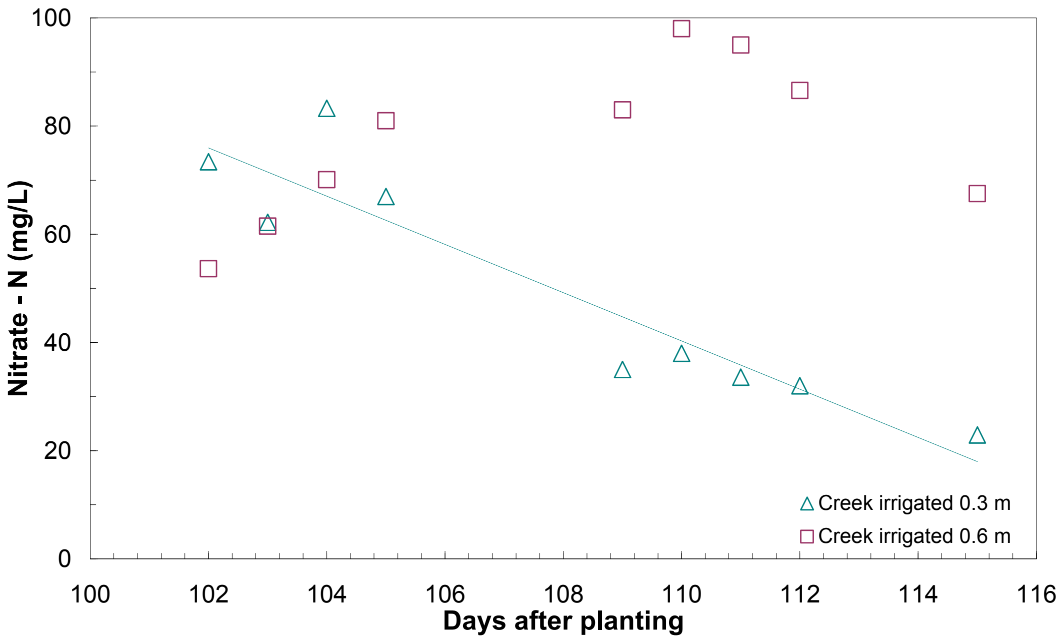

Figure 50. **Site 2 NO_3 – N concentration sampled from a depth of 0.3 m (*n* = 1) and 0.6 m (*n* = 1) in depth shows NO_3 – N concentration at 0.3 m decreasing over time, shown by the solid line (R^2 = 0.847, significance = <0.001)**

Discussion and conclusions

Salt concentration

Salt concentrations were generally below 3 dS/m, below the threshold for yield decline as outlined by (Maas and Hoffman 1977) for a capsicum crop. There was little risk that yield will be significantly affected by salt here. The highest EC recorded was 1.62 dS/m (equates to 3.24 dS/m EC saturated extract or EC_{se}) at a depth of 0.6 m. At this concentration, it is predicted that the capsicum crop may experience a yield loss of 30% based on work done by (Ayers and Westcott 1994). However, this work assumes a uniform concentration of salinity over the plants lifecycle in a controlled environment. In reality, the environment and concentration gradients within the soil may mean that these types of yield reductions are avoided.

An important observation is that the highest EC recorded in the root zone were at 0.3 and 0.6 m; this is also where the majority of the roots will be concentrated. The (Food and Agriculture Organization of the United Nations 2002) state that the roots of a capsicum plant will be most concentrated in the top 0.3 m of the soil; however, they can go as deep as 1 m. This means that if the high EC zone is located within this top 0.3 m of the crops root zone, a leaching requirement may have to be implemented to ensure the minimisation of yield loss due to salinity. In this situation we monitored there is some evidence of leaching and runoff under the current irrigation regime.

The results displayed in Fig. 44 indicated rising soil EC at 0.3 m, correlated to decreasing slope of the field. Here it is hypothesised that irrigation water moves quickly through the sandy loam top soil. When it reaches the high clay content sub-layer, it percolates down slope before penetrating further. This has lead to an increase in EC at the base of the slope and a seepage area. An ideal example, from a salinity management perspective, of this leaching balance can be seen in the non-recycled water irrigated site. Here, the 0.3 m root zone consistently decreases in salinity concentration over time while the 0.6 m zone increases. This means that salts are leached from the top layers and accumulate in lower layers, indicating there is little leaching at 0.6 m.

Nitrate concentration

Although there is a high variability in the data, NO3 – N concentration consistently remains below 125 mg/L. This means that in the top 0.6 m, NO3 – N is readily available for plant nutrition. It is concerning that these levels do not significantly decrease at the 0.9 m section of the root zone. Here it is unlikely that much of this nutrient is captured by the crop. At these depths, NO3 – N is at risk of moving in the environment and possibly into Quart Pot Creek (a tributary). However, between this site and the creek there is approximately 300 m of cropland that is much more gently sloped and this may tie up some of this runoff before entering the creek.

This increase of NO3 – N concentration at depth can be seen in Fig. 50 graphically displays the difficulty in maintaining the balance between reducing salts in the root zone, while preventing nutrient loss from the active root zone. As mentioned previously, EC levels were decreasing in the top 0.3 m of the root zone and accumulating at 0.6 m, this is an ideal situation in terms of salinity – crop management as it keeps the active root zone free of damaging salts. However, it also means that nutrients are leached along with salts and we can clearly see a decrease of NO3 – N in the active root zone. Accumulation of NO3 – N at 0.6 m, means it is no longer available in the high root density portion of the root zone.

Through this process of monitoring solutes of this crop, we found some issues with the fertigation uniformity. The NO3 – N concentration collected by the SSET located in Row 11 significantly increased over the monitoring period, indicating that irrigation uniformity is affecting the delivery of nutrients added through the fertigation system. This uniformity issue may be related to the irrigation configuration, operating pressure or the solubility of the nutrient solution.

Recommendations

The management practices performed on-farm aim to promote organic matter to reduce the loss of nutrients from leaching and help improve soil structure. The manager has installed tail-water collection systems as specified by the supply agreement with the Southern Downs Regional Council and the Irrigation Management Plan. This prevents high nutrient water and sediment from being transported off-site into environmentally sensitive areas. These practices should significantly prevent or counteract any environmental risks that are associated with using recycled water as irrigation.

Preventing percolation caused by the clay sub-layer and the slope of the field may not be possible without intensive drainage and soil structure improvement works, or extensive adjustments to the irrigation system and / or scheduling regime. However, the following points can help improve the management of crops irrigated with recycled water, to prevent the loss of crop inputs and any potential environmental effects from the use of high salt and nutrient waters in the landscape:

- Install soil moisture monitoring equipment to fine tune irrigation to the crops requirements. For example, a device that can be automatically logged since irrigation is pulsed during the day and the soil is a rapidly draining sandy-loam a logger will ensure all data is captured.

- Perform an irrigation and fertigation uniformity assessment to identify problem areas or the causes of these uniformity issues and to help to rectify them.

The use of soil solution monitoring tools can provide an effective way of monitoring the salt - nitrogen balance. If used to their advantage, growers could identify high salt levels and flush these before applying the next fertigation, reducing salt and increasing the effectiveness of irrigation. This eliminates nutrient losses from the crop, which can be detrimental to yield. This can also prevent eutrophication of waterways. Nitrogen or nitrate concentration can be tested with stand-alone, hand-held devices that are easy to use for quick field monitoring. However the SSET can be problematic to install and remove in higher-clay content soils, and once installed need to be monitored regularly and re-set each day (in pulsed irrigation situations) or immediately after an irrigation event to capture the relevant information.

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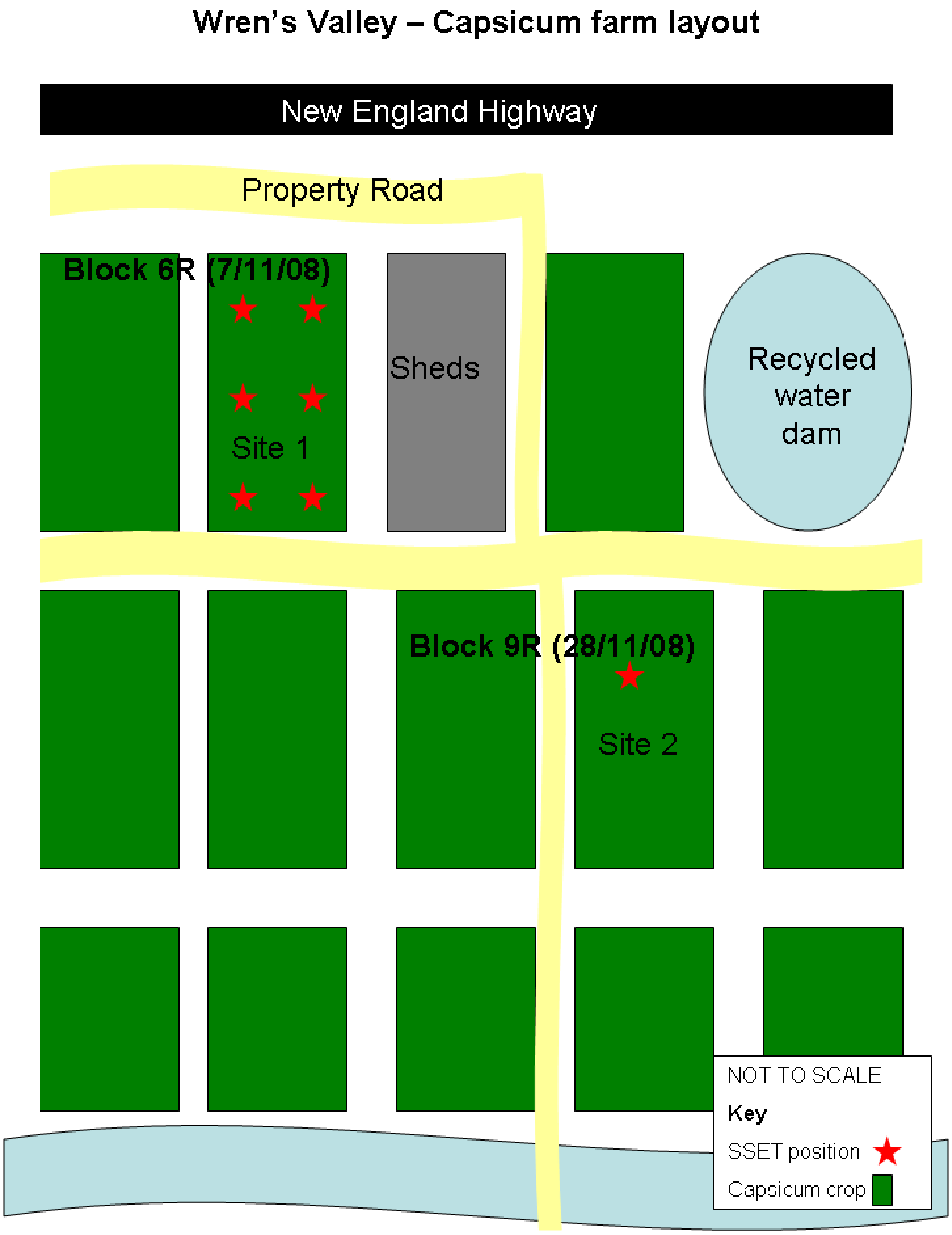
Appendix 1

Map of part of the property showing the general location of Site 1 (capsicum crop irrigated with recycled water drawn from the storage dam) and Site 2 (capsicum irrigated with water drawn from Quart Pot Creek). Red stars indicate the location of the soil water sampling devices.



Optimising drip irrigation infrastructure, fertigation technologies and planting arrangements

Key findings

- Proximate drip irrigation systems, where there is a row of drip tube within 5-8 cm of the vegetable crop row, make management of irrigation easier. They improve nitrogen uptake, water use efficiency, and reduce the risk of poor crop performance through moisture stress, particularly in the early crop establishment phases. Close proximity of the drip tube to the crop row gives the producer more options for managing salty water, and more flexibility in taking risks with forecast rain. Correct installation and interpretation of root zone solute tools is easier in these proximate systems.

- In many vegetable crops, proximate drip systems may not be cost-effective. The next best alternative is to push crop rows closer to the drip tube (leading to an asymmetric row structure).

- Drip irrigation may be beneficial in providing nutrition to a vegetable crop following adverse wet weather. The extra investment in the irrigation system could be considered a risk management strategy.

- Pulse irrigation did not prove beneficial for vegetable production on clay loam soils.

- Investing in improving irrigation uniformity was shown to improve marketable yield of vegetable crops.

- Optimising plant population can have a surprising impact on irrigation water use efficiency. In one experiment, we found increasing sweet corn plant population could stop plants wasting resources on unmarketable secondary cobs. This improved conversion of irrigation water to profitable yield by 15 to 20 per cent.

- In field fertigation-chemigation units can give more timely and accurate distribution of fertilisers and soil-applied chemicals than remote units. They are particularly suited to operations on leased land, or where only one or two applications are required per crop. They are also excellent tools for experimental operations.

Activity focus

Apart from the root zone monitoring tools, we also investigated a range of other technologies and techniques to drive profitable irrigation practices. Agronomic irrigation efficiency is about improving tonnes of marketable product per ML of irrigation. It is obviously also important to maintain or improve profit whilst doing so.

Apart from the irrigation monitoring and diagnostic tools developed by the SEQIF team (detailed in a later section), we evaluated a range of options for improving irrigation in vegetable cropping. The strategies described in the following reports cover issues such as pulse irrigation, improving irrigation uniformity, arrangement of drip systems, and manipulating plant density. In discussions with individual growers and consultants, there was most interest in the in-field fertigation chemigation units, and placement of drip lines in relation to beds and crop rows. Techniques such as increasing plant density, changing row spacing, or even the in-field fertigation units, are relatively inexpensive, and easy for producers to trial, evaluate, adapt and adopt. Major changes in irrigation infrastructure would require more evaluation and confirmation of benefits.

Customising drip irrigation for profitable vegetable production

(Experiment report prepared for Irrigation Australia Limited Conference, Melbourne 2008.)

Craig Henderson, Megan Yeo and Greg Finlay

Gatton Research Station, Agri-Science Queensland

Abstract

Ongoing drought throughout irrigated vegetable growing areas of Australia has seen a substantial shift to drip irrigation. With reduced bore flow rates and accessible water volumes, growers have invested significant capital and labour switching from sprinkler systems. A primary focus is maintaining capacity to fulfil their vegetable supply contracts.

Optimising economic returns from drip irrigation in vegetables requires customisation of drip/crop configurations, irrigation frequency and soil water management. In an experiment investigating these issues (August 2007), we transplanted broccoli into clay-loam alluvial soils at the DPI&F Gatton Research Station in southeast Queensland. We planted 2 broccoli rows per 1.5 m wide bed, and applied standard agronomic practices across the experiment, except for irrigation management.

We compared a single, central row of drip tape, with 2 rows of drip tape per bed (adjacent to each row of crop). In both cases the pressure-compensated, no-drain drip tube was pegged at the soil surface. We also compared pulse irrigation (4 times per day) with irrigation every day, or every second day. We measured soil water status using tensiometers, irrigation volumes, as well as broccoli yields and head quality.

In our experiment, we achieved excellent broccoli yields (nearly 12,000 kg/ha of fresh heads) with both the central drip line for every 2 rows of broccoli, or with drip lines adjacent to every broccoli row. Similarly, there were no differences in broccoli yields or quality from pulse irrigating, irrigating once a day, or irrigating every second day.

Managing soil water conditions in the crop root zone was much easier with a drip line adjacent to every broccoli row, compared to the single, central drip line. With 2 drip lines per bed, we generally kept tensiometer values in the main crop root zone less than 40 kPa, whilst encouraging use of deeper soil water reserves. In contrast, with the single, central drip line, it was difficult to move water laterally into the main broccoli root zone. In this latter treatment, there was also greater propensity for wetter soil conditions at 60 cm, a precursor to deep drainage.

The bed configurations with drip lines adjacent to every broccoli row reduced irrigation requirement by 25%, compared to the configurations with a single, central drip line.

Additional investment installing and maintaining two drip lines per bed, compared to a single, central line, will probably only be cost effective in situations where availability of irrigation water is limiting the grower's production area.

On clay loam soils, there appears to be little current benefit investing in infrastructure to pulse irrigate vegetable crops (such as broccoli) several times per day. We could not observe any benefit from pulsing in improving lateral spread, nor any reduction in water use, when compared with the single daily irrigation.

Introduction

Ongoing drought throughout irrigated vegetable growing areas of Australia has seen a substantial shift to drip irrigation (Hickey *et al.* 2006). With reduced bore flow rates and accessible water volumes, growers have invested significant capital and labour switching from sprinkler systems. A primary focus is maintaining capacity to fulfil their vegetable supply contracts.

Optimising economic returns from drip irrigation in vegetables requires customisation of drip/crop configurations, irrigation frequency and soil water management. Lockyer Valley vegetable growers are still experimenting with various arrangements of bed size, crop rows per bed and rows of drip tape per bed (Henderson 2007). Issues include investment costs in reconfiguring bed forming and planting machinery, metres of drip tape per ha (including fittings), and agronomic impacts of different crop row / drip tape configurations.

Once a configuration is installed, the next management decision faced by vegetable growers is irrigation scheduling. Many producers (recently switching over from overhead systems) irrigate every 2-3 days, analogous to the way they operated their solid-set sprinklers. Other growers irrigate daily, and a few growers pulse irrigate every few hours, using automated systems.

There is still extensive debate in the literature, and in practice, about the value of high frequency pulse irrigation in field vegetable production (Cote *et al.* 2003; Elmaloglou and Diamantopoulos 2007; Mostaghimi *et al.* 1981). The current rationale for most growers attempting pulse irrigation is to achieve maximum lateral spread from the drip tape, and thus reduce the amount of drip tape they require in their crop.

Using broccoli as an example crop, we report here on an experiment investigating these issues.

Materials and Methods

This experiment was conducted at the Department of Primary Industries and Fisheries Gatton Research Station, Queensland. The soil was a moderately self-mulching Black Vertisol. In August 2007, we transplanted broccoli (cv. Babylon) into beds 1.2 m wide and separated by 0.3 m furrows. Broccoli rows were 0.35 m off the centreline of each bed, with intra-row spacing of broccoli plants of 0.33 m. Each experimental plot consisted of 3 beds (a central measurement bed, with a buffer bed either side), and was 10 m in length. We conducted all our measurements on broccoli plants in the central 8 m of the measurement bed (generally 22-23 plants in each of the 2 rows). Standard agronomic practices for nutrition, weed and pest management (Heisswolf et al. 2004) were imposed across the experimental area.

We used Plastro Hydro PCND drip tube (pressure compensating, no drain), with12 mm external tube diameter and 0.15 m emitter spacing. Emitter output at a pressure compensated 200 kPa was 1.15 L/hr, giving a linear drip tube output of 7.67 L/m/hr. We used no-drain emitters to enable us to accurately measure water volumes applied to the plots, without having to adjust for differential drainage after each irrigation. The drip tube was laid on the soil surface, and held in place by an inverted v-shaped wire inserted into the soil.

Our experimental design was a factorial with 2 drip configuration treatments * 3 irrigation scheduling treatments. Our 2 drip configurations were: (i) a single line of drip tube down the centre of the bed and (ii) 2 lines of drip tube per bed, adjacent to the broccoli rows. Our irrigation schedules were (i) every two days; (ii) daily and (iii) pulse irrigated 4 times per day (8 am, 11 am, 1 pm and 3 pm). Thus, we had a total of 6 treatments in our experiment.

Apart from irrigation, side dressings of N and K fertilisers were applied by the drip system 4, 5 and 6 weeks after transplanting. The same total amounts of nutrient were applied to each treatment on each occasion.

We measured total water volumes applied to each treatment at each irrigation, as well as daily rainfall and pan evaporation from an adjacent weather station. At 8-9 am each day, we manually measured soil water potential at 0.15 m and 0.6 m below the surface, using tensiometers adjacent to the northern broccoli row of each bed.

The amount of irrigation we applied was determined using crop factors and net pan evaporation (accounting for rain) since the previous irrigation. For the pulse irrigation treatment, the 8 am irrigation was standardised at 0.5 mm, with the remaining 3 irrigations allocated to provide the same water volume as the daily irrigation. Occasionally, the pulse irrigation treatment received the initial 8 am irrigation; however, no further irrigation was applied after reviewing the tensiometer values. The crop factors for each treatment were regularly adjusted based on tensiometer values. If the shallow tensiometer values were rising (i.e. the soil was drying out), the crop factors were increased (increasing the irrigation applied) for the next event, whilst the converse was also true. The deep tensiometer values were monitored to look for excessive irrigation past the root zone, in which case crop factors (and thus irrigation) were generally reduced.

We made general notes on the health of the broccoli plants during the growing period, and took aerial photos of the crop to assess growth and canopy cover on a weekly basis (not reported here). We harvested the broccoli heads as they matured on 3 sequential dates; 16/10/2007, 19/10/2007 and 23/10/2007. We selected the appropriate harvest dates for each head to maximise the match with industry product specifications. We assessed each head against those specifications, measuring fresh head weight, head diameter, and the presence of major and minor defects. The main defects that occurred in our experiment were: no head (due to early insect damage or genetic deformity), undersize (less than 90 mm diameter), grossly immature, small leaves growing through the head, or uneven head shape.

Results and Discussion

Agronomic performance

There were no significant differences ($p \leq 0.05$) in broccoli yields or quality due to either the drip tape configuration or irrigation timing. All treatments had an average harvest date of 63 days after transplanting, with a standard deviation 2.1 days either side. Across the experiment, 96 ± 3% (± standard error of the mean) of plants produced marketable heads, with an average head weight of 336 ± 20 g, and head diameter of 133 ± 3 mm. On an area basis, this provided 11,900 ± 900 kg/ha of broccoli heads, equivalent to nearly 1,500 icepacks per hectare. This was an exceptionally high yield; industry statistics refer to yields of 1,100 icepacks/ha as high (Heisswolf et al. 2004).

However, there were 2 quality issues that may have impacted on price received for these heads, particularly if the market was oversupplied and buyers could afford to be choosy. A substantial proportion of heads had small leaves growing through the florets; 54 ± 7% in the single drip tube treatments, compared to 48 ± 7% in the double drip tube treatments; a statistically non-significant ($p=0.054$) and agronomically unimportant difference. Around ¼ of the marketable heads had an uneven shape (note that some heads were both uneven and had internal leaves), a common outcome when harvesting extends into a warm Spring. Only 39 ± 6% of heads were considered prime and unblemished product.

Because there were no significant differences in broccoli performance, any impacts of the irrigation treatments on profitability (or otherwise) of the systems under evaluation will depend on how they affect input efficiency, particularly water requirement.

Irrigation performance

For the first 4 weeks after transplanting, plant water requirements were mainly supplied by rain (Fig. 51a) and stored soil moisture. There was no substantial difference in irrigation supplied to any of the treatments (Fig. 51b), reflected in both shallow (Fig. 52a) and deep (Fig. 52b) tensiometer values.

Between 4 and 6 weeks after transplanting, shallow tensiometer values in the root zone of the beds with only a single drip line down the centre continued to increase (solid lines in Fig. 52a). This observation was particularly noticeable in the treatment watered every 2 days. In contrast, the beds with two lines had relatively consistent root zone soil moisture tension values, despite receiving substantially less irrigation than their single line companions. Deep soil zones beneath the crop rows were also consistently wetter in the single line treatments (Fig. 52b).

In the period 6-8 weeks after transplanting, shallow tensiometers values in all treatments reached 40-60 kPa on occasions; generally greater values in the single tube beds. The other point to note is that in the treatments with drip lines adjacent to the crop rows, it was much easier to reduce tensiometer values back below 40 kPa, using lower volumes of irrigation. Note that it was also easier to encourage slight drying of the deeper subsoil in these treatments (Fig. 52b), whereas deep soil in the single line treatments stayed wet. The 20 mm rain event 8 weeks after transplanting rewet most of the crop root zones, with the exception of the driest treatment (watered every 2 days).

Hot dry weather in Week 9, with consequent high plant water use, (and exacerbated by a Sunday with no irrigation applied), caused dramatic increases in tensiometer values across all treatments (Fig. 52). Catch-up irrigations in the ensuing 10 days managed to reduce tensiometer readings to desirable values during the harvest period.

Across the growing period, in the treatments with 2 drip lines per bed, there were only 4-5 days with tensiometer values in the root zone greater than 40 kPa. Of the single line treatments, the one irrigated every second day had 26 days with shallow readings >40 kPa, whilst both daily and pulse treatments had 14 days >40 kPa.

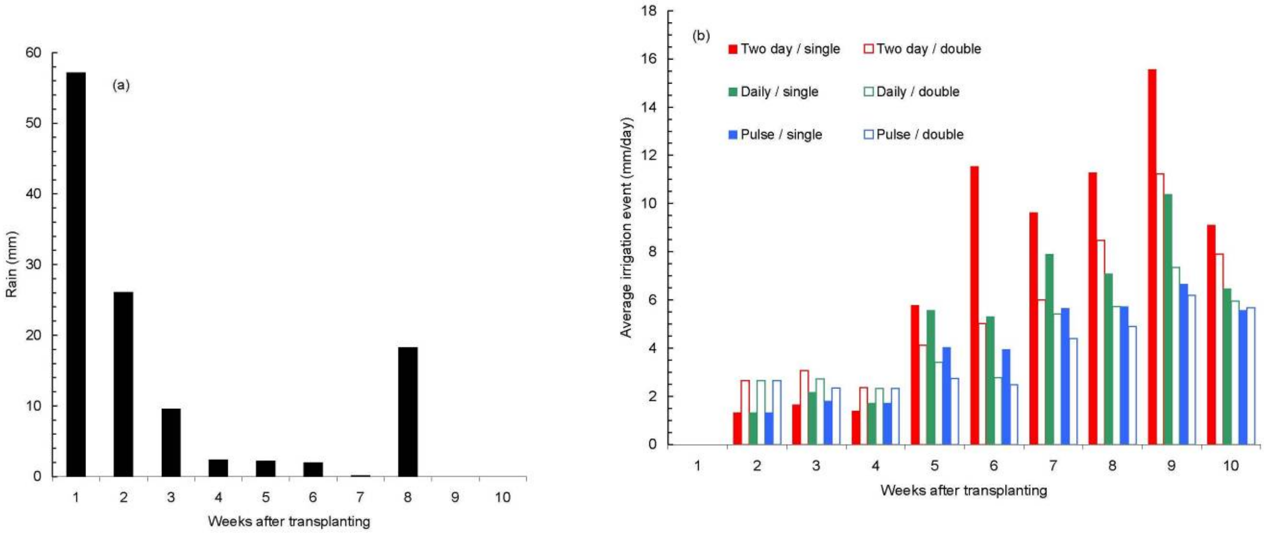


Figure 51. Water applied by (a) rain and (b) irrigation on broccoli beds with single or double drip lines per bed, and irrigated every second day, every day, or pulse irrigated 4 times per day.

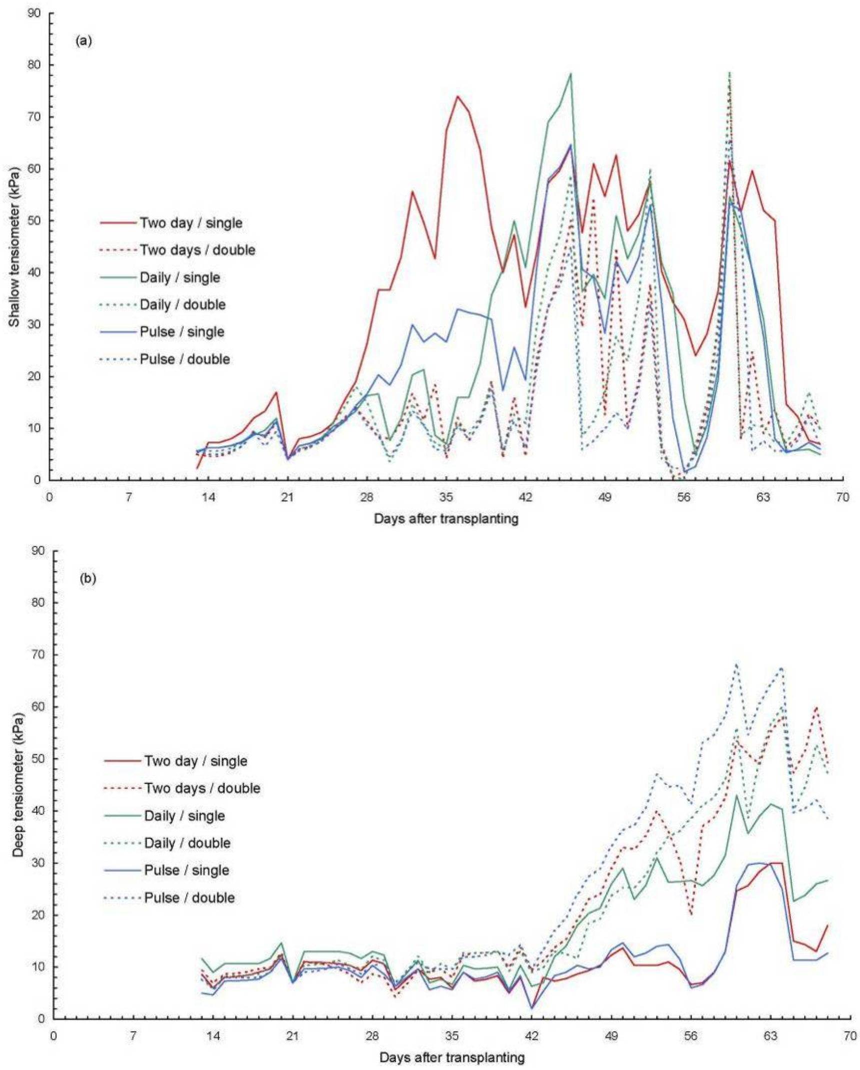


Figure 52. Daily soil water tensions from tensiometers installed (a) 15 cm and (b) 60 cm below the surface, adjacent to broccoli crop rows. Treatments are from broccoli beds with single or double drip lines per bed, and irrigated every second day, every day, or pulse irrigated 4 times per day.

From 4 weeks after transplanting until harvest, the single line treatments received appreciably more irrigation per application, than their double line counterparts. As previously mentioned, this was to try and supply sufficient water laterally to the crop root zone. In order to test the benefit of pulsing, we reduced this irrigation supply difference between single and double drip lines in the pulsing treatments (Fig. 51b).

Viewing the cumulative water (irrigation plus rain) inputs for each of the treatments compared to cumulative pan evaporation (Fig. 53), there was obviously very little difference between any of the treatments with a single, central drip line. In this experiment, we applied 2.1-2.2 ML/ha for each of these single line treatments, whether irrigated every second day, daily, or pulsed 4 times per day.

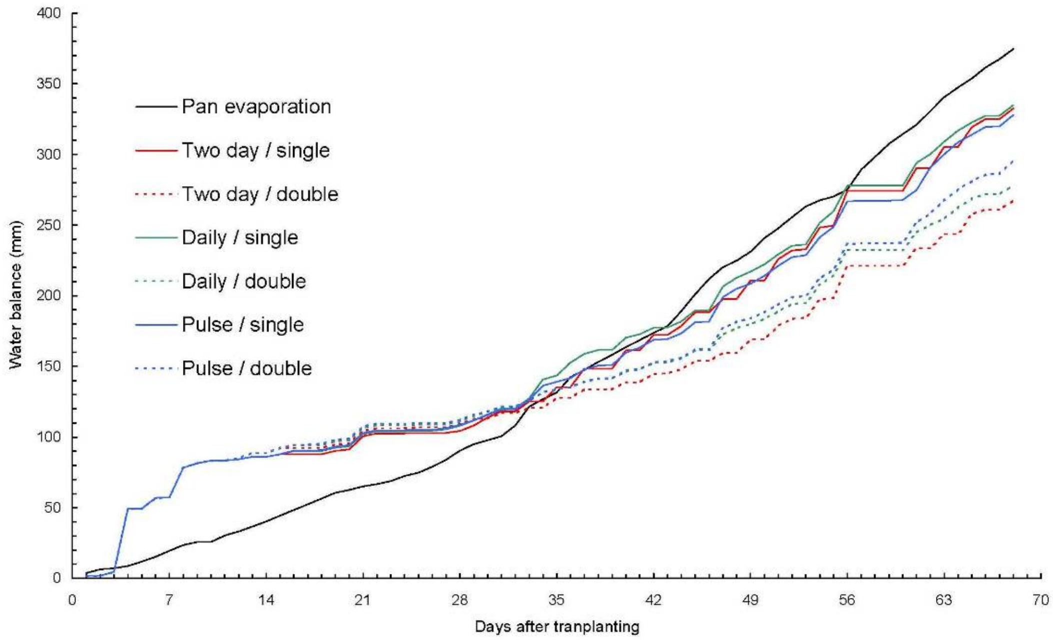


Figure 53. Cumulative water applied (rain plus irrigation) under 6 different broccoli irrigation treatments, with single or double drip lines per bed, and irrigated every second day, every day, or pulse irrigated 4 times per day. Cumulative water applied is compared with pan evaporation for the same period.

We applied considerably less water where there were irrigation lines adjacent to each crop row (dotted lines in Fig. 3). In these double line treatments, the pulsing treatment received 1.8 ML/ha of irrigation, the daily treatment 1.6 ML/ha, and the beds watered every second day the least irrigation (at 1.5 ML/ha). Because deep tensiometers in the pulsing treatment were reaching values exceeding 70 kPa late in the growing period, we increased irrigation on those plots to try to reduce that value slightly.

Economic considerations

In this experiment, there were no broccoli outturn differences between the treatments, therefore all economic evaluations are based on the efficiency of input use; in this case irrigation water.

Compared to daily irrigation, pulsing several times per day did not seem to provide better lateral spread of irrigation water to the crop root zones (based on shallow tensiometer values in the single drip line treatments). Pulsing is a relatively complex irrigation procedure, requiring an automated irrigation system to avoid excessive labour. On our soils, it is unlikely that additional investment in pulsing-friendly drip tube and irrigation automation equipment could be justified solely based on improved irrigation efficiency.

In a single line system, the biggest difficulty was rewetting the remote root zone once the beds had started to dry out. Delays in irrigation may exacerbate this problem, therefore the capacity to water every day, or at least every second day is probably required. Based on our experiment, if using a single line drip line per bed configuration, the lowest cost system that can manage regular irrigation would be most economic.

There could be substantial opportunities for using less irrigation water where drip lines are located close to crop rows. In our experiment, we found we could reduce irrigations in anticipation of rain, because we knew we could easily rewet the root zone with irrigation if required. We could also effectively encourage use of deeper soil water by applying less irrigation, yet still maintain low surface soil water tension values. Although not measured in our experiment, salt pushed to the margins of the wetted area would be displaced from the crop root zone, rather than toward it. In our experiment, we used on average 0.5 ML/ha less irrigation water in the treatments with 2 drip lines per bed, compared to those with one drip line per bed. This was a water saving of 25%.

However, there are significantly increased material, installation, maintenance and disposal costs associated with double the number of drip lines per hectare! In our experiment, the only material benefit from this marked increase in irrigation investment was the reduced water use, as there was no crop performance benefit. At this time, we are uncertain how to cost the ‘ease of management’ benefit. In a situation where availability of irrigation water is not limiting production, it is highly unlikely that the savings in water cost (even at $300-400/ML) would justify the increased investment in drip infrastructure required by two drip lines per bed. However, the situation changes when water IS a limiting resource (Henderson 2003; Hickey et al. 2006). In that situation, water saved can be used to grow additional hectares of profitable crop, so although the $/ha return may be lower, the increased production area more than compensates. The authors envisage a more comprehensive economic analysis of this experiment will be presented at a later date.

Conclusions

- Excellent broccoli yields are achievable with either a central drip line for every 2 rows of broccoli, or with a drip line adjacent to every broccoli row.
- Managing soil water conditions in the crop root zone is much easier with a drip line adjacent to every broccoli row, compared to a single, central drip line.
- A bed configuration with a drip line adjacent to every broccoli row may reduce irrigation requirement by 25%, compared to a configuration with a single, central drip line.
- Additional investment installing and maintaining two drip lines per bed, compared to a single, central line, will probably only be cost effective in situations where availability of irrigation water is limiting the grower’s production area.
- On clay loam soils, there appears to be little current benefit investing in infrastructure to pulse irrigate vegetable crops (such as broccoli) several times per day.

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Preliminary evaluation of relationships between irrigation non-uniformity and crop responses in lettuce.

(Experiment report prepared for Irrigation Australia Limited Conference, Melbourne 2008.)

Amjed Hussain[1], Steve Raine[1] and Craig Henderson[2]

[1] NCEA, University of Southern Queensland

[2] Gatton Research Station, Agri-Science Queensland

Abstract

Optimisation of irrigation management should aim to increase crop responses (yield and quality) to water application and reduce input (e.g. water and nutrients) losses. A key limitation to improving water use efficiency is the uniformity of irrigation application. To evaluate the impact of water application uniformity a trial was conducted using lettuce under a solid set irrigation system. Three weeks after transplanting, the sprinkler pressure was deliberately and asymmetrically reduced in one sprinkler grid (termed the Poor-1grid) producing an average water distribution uniformity (DU) of 53%. In a second grid (termed the Poor-2 grid) the uniformity was reduced by nozzle and sprinkler head changes to an average DU of 63% while in the Control grid the average DU was 75%. A significant variation in soil moisture tension (4 to 93 kPa) was observed between the high, medium and low water application areas of the Poor-1 grid while comparatively less variation (maximum 41 kPa) in soil tension was observed across the Control grid. No relationship was found between water application and lettuce canopy width. However, significantly lower harvest fresh weight, head size and head weight were found in the low and medium application areas compared to the high water application area of the Poor-1 grid. There were also substantial reductions in the number of marketable heads found in the Poor-1 (42% of total heads) and Poor-2 (58%) grids compared to the Control (71%). There was no indication that the marketability and/or production benefits of improving uniformity of application reached a plateau at the industry accepted levels for irrigation uniformity (i.e. DU ≥75%, CU ≥80%). This work has quantified the relationships between irrigation uniformity, water application and production in lettuce. However, further work is required to incorporate the effect of environmental conditions (i.e. probability of in-season rainfall), crop production responses, water availability and price, as well as the cost of application system changes into a framework for the identification of optimal levels of application system uniformity.

Introduction

Soil-water availability is a major determinant of crop yield and is often highly correlated with the uniformity of irrigation application. Uneven watering has been found to affect crop growth for a range of crops including cauliflower and lettuce (Barber and Raine 2002), sugar beet (Ucan and Gencoglan 2004), citrus (Dagan 2002), corn and soybean (Kravchenko and Bullock 2000) and cotton (Elms et al. 2001). Improved water control using precision management (Sadler et al. 2005) has been found to significantly increase crop water use efficiency (Jin et al 1999).

Low uniformities of water application under sprinkler irrigation systems may be caused by a range of problems but most commonly are due to inappropriate sprinklers selection, sprinkler and lateral spacing, pressure differences along the laterals or operating the system under inappropriate conditions (e.g. high wind) (Raine 1999). However, optimal irrigation management not only requires the appropriate knowledge of the irrigation system but also needs environmental knowledge. For example, crop water requirements may be fulfilled during certain periods by rainfall.

Vegetables are a major contributor to irrigated agriculture production in Australia (ABS 2004) and the annual value of the lettuce industry is approximately $174 million (AUSVEG 2007). Solid set sprinkler irrigation systems are commonly used by lettuce growers in Australia (Barraclough and Co 1999). However, very little information is available on the spatial variability of irrigation application and its impact on lettuce growth. The main focus of this research was to evaluate the effect of non-uniform irrigation application on lettuce crop growth and yield.

Materials and Methods

This experiment was conducted at the Department of Primary Industries and Fisheries Gatton Research Station, Queensland. The soil was a moderately self-mulching Black Vertisol. The total area planted with lettuce was 92 × 11 m. The trial area was cultivated into seven longitudinal beds, each 1.3 m wide and separated by 0.3 m furrows. A solid set irrigation system consisting of ISS Rainsprays (1.98 mm nozzles) mounted on 0.6 m risers and operating at 335-380 kPa was used to irrigate the trial. The sprinklers were arranged in a square pattern with 9 m spacings along the laterals and 11 m between laterals. Five week old Iceberg (cv. Titanic) lettuces were transplanted on the 12/4/07, with three lettuce rows on each bed and an intra-row spacing of 0.33 m.

One pre-plant (5/4/07) and ten in-crop irrigations were applied during the growing period. A total of 7.4 mm of rainfall was received from six rainfall events during the main growing period. Three measurement grids were established within the trial area: a Poor-1 grid (9 x 11 m in size; 9-18 m from the sub-main), a Control grid (36-45 m from the sub-main) and a Poor-2 grid (63-72 m from sub-main). Since water pressure in sprinkler systems has a significant role in the uniformity of water application (Hanke et al. 2004, Mateous 1998) the uniformity of sprinkler application in the Poor-1 grid was reduced after the fourth (26/4/07) in-crop irrigation by asymmetrically fitting pressure reducers (nominal pressure at sprinklers of 362, 137, 172 and 137 kPa) to the risers in each corner of the grid. The uniformity of application in the Poor-2 grid was altered by changing the sprinklers nozzles after the fifth (2/5/07) in-crop irrigation and then replacing each sprinkler head with Nelson R2000 rotators (K2 9° plate, #10 2TN nozzle) after the seventh (14/5/07) in-crop irrigation. Water application within each sprinkler grid was measured using 42 plastic catch cans arranged on a grid (1.5 $\times$ 1.56 m spacing). Irrigations were conducted late in the afternoon with catch can data collected the following morning. Irrigation performance was calculated using Christiansen's (1942) Uniformity Coefficient (CU) and Distribution Uniformity (DU) as described by Walker and Skogerboe (1987). Soilspec tensiometers were installed at 0.15 m depth next to each catch can in the Poor-1 grid and next to every second catch can in the Poor-2 and Control grids. Soil tension measurements were recorded at 9 am each day. Irrigation was applied to all grids when the average tensiometer values in the Control grid approached 25 kPa (Heisswolf et al 1997).

The lettuce canopy cover and head size of two tagged plants either side of each catch can were measured using a measuring tape after implementation of the sprinkler changes. Six lettuces were harvested for evaluation around each catch can in the Poor-1 grid and every second catch can in the Poor-2 and Control grids. Serial harvesting of the crop was conducted from the 29/5/07 to 8/6/07 using the Harvesters' Tactile Assessment of Head Maturity (Heisswolf et al. 1997) test. After harvesting, each lettuce head was individually assessed for total plant fresh weight, head fresh weight and diameter, and a range of lettuce quality characteristics.

Results and Discussion

Irrigation system performance

There was no significant (P<0.05) difference in the average depth of irrigation water applied in each grid prior to implementing the sprinkler and pressure modifications (Table 5). In general, there was also difference in the uniformity parameters for each irrigation prior to sprinkler modification. However, the Poor-1 grid did have a lower uniformity compared to the other treatments for the two irrigations (20/4/07 & 26/4/07) immediately prior to treatment implementation. Following sprinkler modification, there was no significant difference in average water applied in the Poor-2 and Control grids but the average depth applied in the Poor-1 grid was approximately 23% lower than in the other grids. As expected, the variability in the applied depths was higher in the Poor grids after sprinkler modification compared to the Control grid. The average CU of the Poor-1 grid after modification was 64.1% compared with 75.6 and 83.2% for the Poor-2 and Control grids, respectively. Similarly, the average DU decreased from 74.8% in the Control to 63.4 and 53.0% in the Poor-2 and Poor-1 grids, respectively.

Soil moisture tension

Soil moisture tension was generally maintained at less than 30 kPa across the majority of areas in each grid before modifying the sprinklers. However, after introducing the pressure reducers, significant differences in the soil tension were observed (Fig. 54) across the Poor-1 grid in response to differences in the depth of water applied. Towards the end of the season, the low water application areas reached a maximum soil tension of 93 kPa while in the medium and high application areas the maximum value was only 55 and 22 kPa, respectively. After irrigation, soils in the high and medium water application zones within the Poor-1 grid generally re-wet to field capacity, whilst the low water application zones stayed drier. In the Control grid, soil tensions peaked at 21, 29 and 41 kPa for the high, medium and low water application areas, respectively.

Table 5. Water applied and uniformity for each irrigation event.

Date of irrigation applied	Av. water applied (± std dev) (mm)			Uniformity Coefficient (%)			Distribution uniformity (%)		
	Poor-1 grid	Poor-2 grid	Control grid	Poor-1 grid	Poor-2 grid	Control grid	Poor-1 grid	Poor-2 grid	Control grid
5/4/07	20 ±5	19 ±4	19 ±4	77.7	82.2	81.6	69.6	75.9	74.7
13/4/07	31 ±7	33 ±6	29 ±5	81.5	86.2	86.1	76.6	82.0	79.8
15/4/07	25 ±4	25 ±4	23 ±4	86.1	85.8	87.4	80.8	77.6	80.8
20/4/07	17 ±6	17 ±3	16 ±5	73.5	84.4	78.2	60.5	77.3	71.3
26/4/07	19 ±6	19 ±4	17 ±3	73.1	84.9	79.2	64.6	79.2	73.6
2/5/07	16 ±6	21 ±5	21 ±4	66.5	81.7	84.1	56.0	75.8	74.1
8/5/07	16 ±7	25 ±6	22 ±5	63.4	78.8	80.9	53.1	68.6	71.0
14/5/07	17 ±7	26 ±5	22 ±3	66.6	84.1	88.9	50.1	76.1	82.9
18/5/07	8 ±3	10 ±4	10 ±3	64.6	66.9	76.0	51.6	51.2	64.9
25/5/07	14 ±5	17 ±4	17 ±3	70.3	82.0	88.9	63.1	74.0	84.7
30/5/07	7 ±4	11 ±5	11 ±3	53.4	66.0	80.4	44.3	47.1	70.9

Note: Shading indicates modified irrigation performance

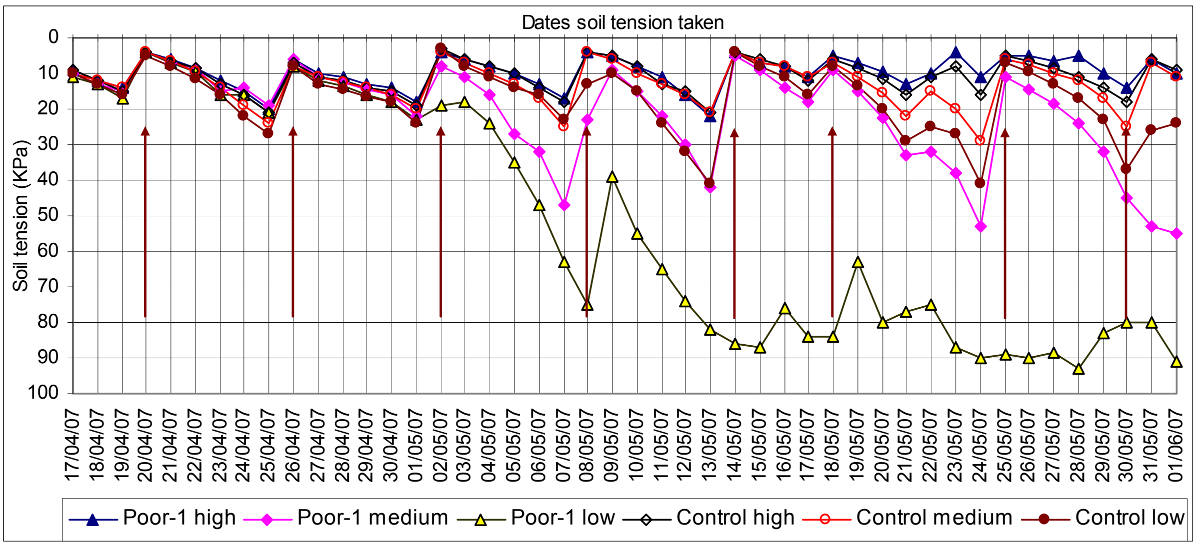

Figure 54. Representative soil tension in the low, medium and high water application areas of the Poor-1 and Control grids (arrows indicate irrigation events).

Relationships between water application and lettuce growth

After introducing the pressure reducers in the Poor-1 grid, the irrigation system generally applied more water near the sprinklers, compared to other parts of the grid (Figure 55a). This pattern was observed to be similar through the remaining irrigations. Visual inspection of the spatial patterns in lettuce canopy size, head size and the number of marketable heads suggest that there is a relationship between water application and plant response (Figures 55b-d). However, the plant canopy width data from the Poor-1 grid showed only a small non-significant trend towards smaller plants and greater variability as the season progressed (Table 6). The canopy width was also poorly correlated (R2 < 0.1) with cumulative water application.

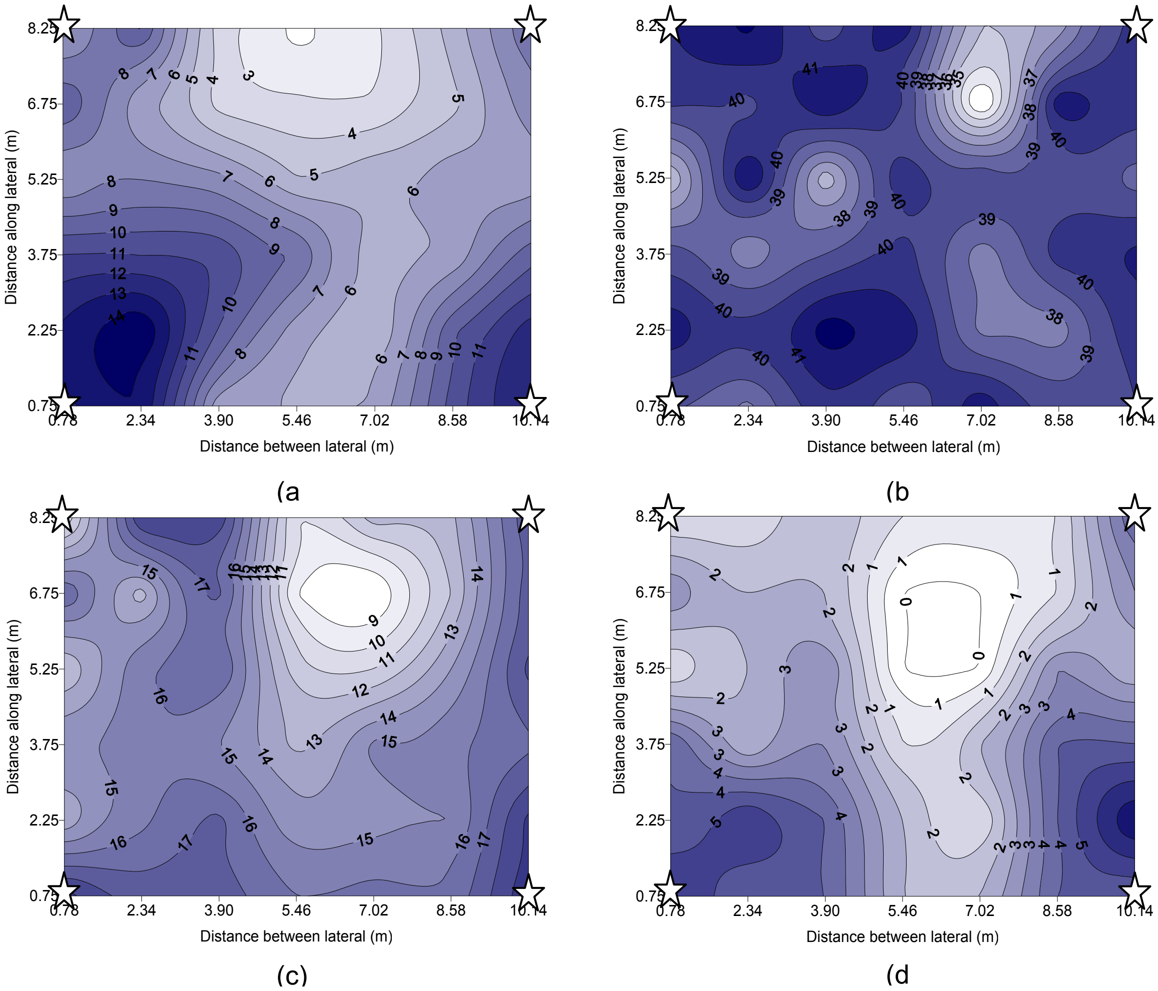

Figure 55. Poor-1 grid (a) water distribution applied on the 18/5/07 (in mm), (b) lettuce canopy size measured 24/5/07 (in cm), (c) lettuce head size measured 28/5/07 (in cm) and (d) total marketable lettuce heads (per 6 head sample)

Table 6. Effect of water application on lettuce canopy width in the Poor-1 grid

Application area	1//5/07	7/5/07	13/5/07	16/5/07	18/5/07	22/5/07	24/5/07
Low	20.7±1.3	27.8±2.3	32.0±1.0	35.8±2.0	36.7±2.7	38.0±2.6	39.0±3.6
Medium	21.6±1.1	28.4±1.1	33.0±1.5	36.9±1.8	38.9±1.5	39.3±2.0	40.6±2.3
High	21.6±2.2	28.7±1.6	33.8±1.2	36.7±2.3	37.9±1.6	40.1±2.2	40.2±1.8

Variations in water application across the Poor-1 grid were found to produce significant differences in lettuce fresh weight, head diameter and head weight at harvesting (Table 7). The average head diameter was 14% smaller and fresh weight was 18% lighter in the low water application area compared to the high water application area. These differences translated into a large reduction in the marketable heads in the low (18% marketable) and medium (24% marketable) water application areas compared to the high (73% marketable) area (Table 8; Fig. 55d). Similar, but smaller, trends were found in the Poor-2 and Control grids with the low water application area in the Control grid producing 54% marketable heads compared with 87% marketable heads in the high water application area. These differences across the grids produced substantially higher total marketable heads in the Control (71%) than in the Poor-2 (58%) and Poor-1 (42%) grids (Fig. 56). The number of marketable heads increased for each of the first three harvest dates but did not change substantially after the 5/6/07. There was no difference in the total marketable heads between the Poor-2 and Control grids for the first two harvest dates (29/5/07 & 1/6/07) but there were substantial differences at the third harvest date (5/6/07).

Table 7. Effect of irrigation application on harvested lettuce in the Poor-1 grid

Application area	Lettuce fresh wt. (g)	Lettuce head diameter (cm)	Lettuce head wt. (g)
Low	741 ±140	16.6 ±1.7	443 ± 96
Medium	827 ±152	16.8 ±1.8	473 ±103
High	899 ±141	19.2 ±2.1	571 ±121

Table 8. Marketable heads in the low, medium and high water application areas of each grid

Application area	Poor-1	Poor-2	Control
Low	18 %	43 %	54 %
Medium	24 %	57 %	62 %
High	73 %	82 %	87 %

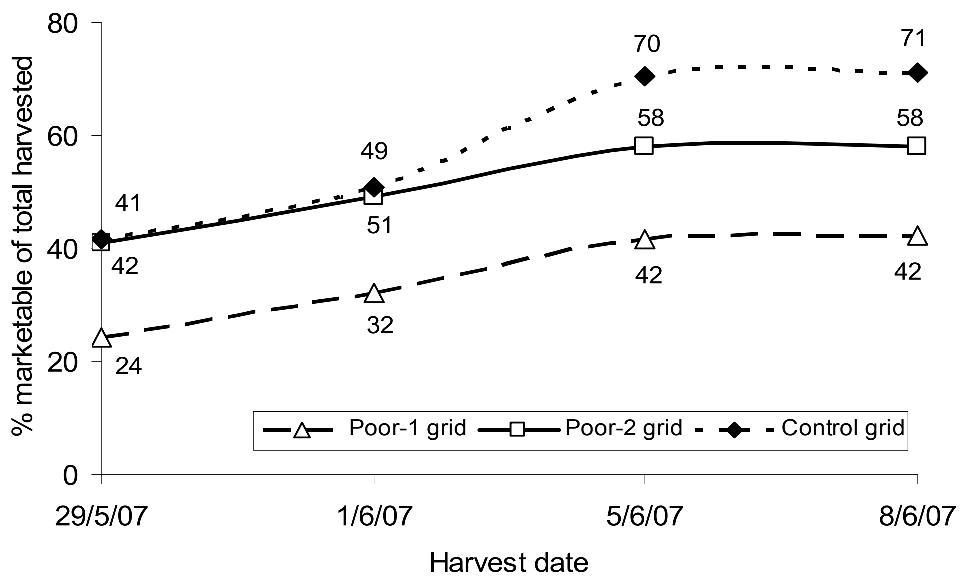

Figure 56. Effect of irrigation uniformity on cumulative marketable lettuce heads with harvest date

The catch can and marketability data was used to develop a water production function (Fig. 57) which showed there is a strong positive linear relationship between the water applied and lettuce head marketability. This confirms that increasing water application increases lettuce marketability, at least under the environmental conditions encountered and the range of water application depths applied in this trial. Only three levels of irrigation uniformity were evaluated in this study. However, the results obtained at these levels suggest that there is also a strong linear relationship between overall system uniformity and marketability.

It should be noted that there was a 30% loss in marketable yield when the application system was operating at the industry accepted benchmark level for uniformity (i.e. DU ≥75%, CU ≥80%). While this may have been due to non-irrigation issues (e.g. pest or nutrition), the nature of the relationships shown in Figure 4 suggest that improving the irrigation uniformity above these levels should further increase marketability. However, local lettuce irrigators anecdotally report that they have much lower levels of non-marketability despite their application systems often having measured uniformities well below the benchmark level. This suggests that these irrigators may be compensating for low irrigation uniformity by applying higher irrigation volumes at lower application efficiencies and raises concerns over losses to deep drainage, nutrient leaching and waterlogging on high clay soils. The relative economic merits of either improving system uniformity or suffering a reduced water use efficiency due to higher application rates is the subject of on-going research but is likely to be a function of the environmental conditions (i.e. probability of in-season rainfall, sol drainage properties), crop production responses, water availability and price, as well as the cost of application system changes.

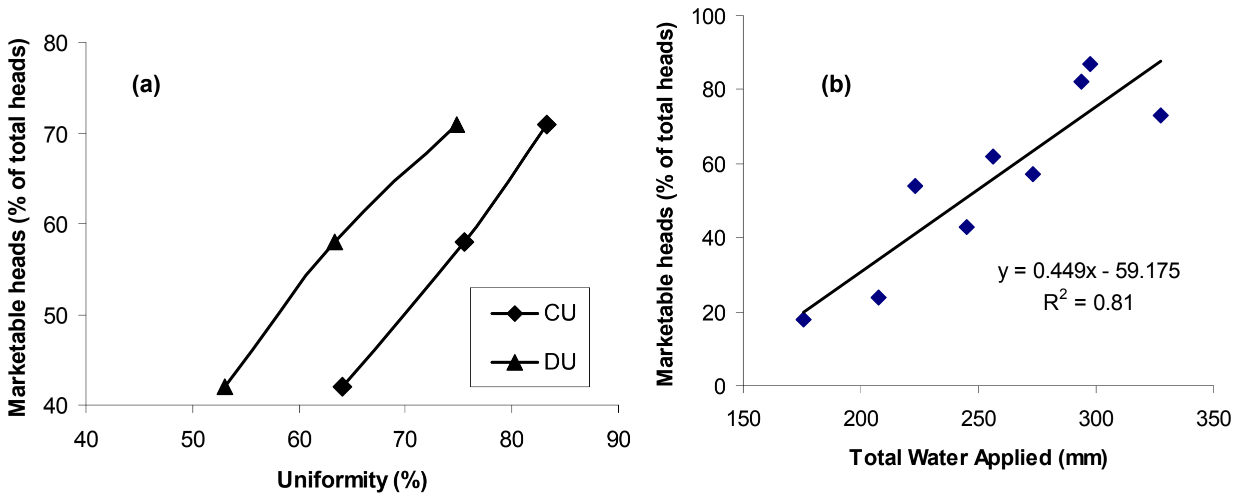

Figure 57. Effect of (a) total water applied on the marketable lettuce heads within grids and (b) irrigation uniformity on the total marketable lettuce heads in each grid

Conclusions

The uniformity of the irrigation application system has been shown to significantly affect the uniformity of soil moisture availability and the resultant lettuce production. While there was little impact of water application variations on the growth of the lettuce canopy, significant impacts were observed in terms of lettuce head marketability. The relationships between irrigation uniformity and lettuce marketability under the soil and rainfall conditions experienced in this trial have been demonstrated and a response function between water application and marketability developed. However, further research is required to assess the relative economic merits of either improving system uniformity or suffering a reduced water use efficiency due to higher application rates under a range of environmental conditions, crop returns and application system conversion options.

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Optimising profitability of sweet corn by understanding high plant density effects on water use, phenology and yield.

(Experiment report prepared for Irrigation Australia Limited Conference, Sydney 2010.)

Sarah Limpus, Craig Henderson, Greg Finlay, Dhananjay Singh, José Payero

Agri-Science Queensland

Introduction

Many years of drought in southeast Queensland have put pressure on groundwater levels in the Lockyer Valley (Bleakley 2010). Here groundwater is the primary source of irrigation water for vegetable producers. Lockyer Valley growers have to deal with both low water availability and reduced flow rates, while still filling production contracts. Although many growers are addressing these issues through investment in irrigation infrastructure, other simple crop management options may also improve the ability of growers to meet market demands.

We investigated the effects of increasing standard plant densities of sweet corn crops from 65,000 plants per hectare (p/ha) to 95,000 p/ha on yields, phenology and water use. Increasing planting density of sweet corn, with slight increases in start-up expenditure to cover extra seed and fertiliser, could significantly enhance yields of sweet corn, with little effect on irrigation volumes. We investigated the actual evapotranspiration of the crop with weighing lysimeters, to compare the water use of the high density with standard density crops. We hypothesise that an increase in plant density may contribute to higher yield and faster development of the canopy, with only a small difference in total water use at the season's end, compared to low density crops.

Methods and Materials

In January 2010, sweet corn cultivar Pacific Hybrix 5 (Pacific Seeds Pty. Ltd.) was sown into the medium-clay alluvial soils at the Gatton Research Station in southeast Queensland.

Three planting densities were sown in a complete randomised block design. These were 65,000 p/ha (low density), 80,000 p/ha (medium density) and 95,000 p/ha (high density).

Weighing lysimeters, to monitor water use by the crops, had previously been installed in 2009.

Standard agronomic practices were applied to all plant densities except fertiliser. A higher rate of nitrogen (185 kg/ha of N) was added to the 50 kg/ha of N (based on soil test of the field) already present as nitrate in soils to all treatments, meeting the highest plant density's requirements.

Tensiometers were installed into the lysimeters, and the surrounding field, at 0.3 and 0.6 m deep in the plant row, to monitor soil moisture tension on a daily basis.

Measurements during the season and at harvest concentrated on water use, canopy development, cob development and yield. Other data was collected on crop phenology, leaf area index and interception of photosynthetically active radiation.

Results and Discussion

Water use

We found that increasing the density of sweet corn from 65,000 to 95,000 plants / hectare, increased dry biomass by 20%, total water use by 17%, and irrigation water use efficiency (IWUE) by 22% based on marketable yield, (Table 9). Due to having only one lysimeter working in the medium density crops, that data cannot be confidently be relied upon. Water use for the medium density has been estimated from biomass and leaf area data. Low and high density water use are significantly different from each other (p = 0.03) and this 17% increase in water use, (not in water application) is contrary to previous experimental work (Downey 1971b and Downey (1971c) in maize plant density.

Table 9. Water use data of sweet corn treatments measured by weighing lysimeters and calibrated by biomass data

	Low Density 65,000 p/ha	Medium Density (80,000 p/ha)	High Density 95,000 p/ha	FAO 56 / SILO prediction*	*CropWaterUse* tool prediction
Water use† (mm)	280[a]	304	340[b]	350	347
WUE‡ (g/kg water)	6.1	7.2	7.5		

* Crop water use prediction by FAO / SILO based on crop factors from *CropWaterUse* tool

† Water use has been based on lysimeter data and lysimeter plant biomass and then calibrated with harvest biomass data of field plants, which grew under more normal conditions compared to lysimeter plants.

‡Water use efficiency is based on irrigation and marketable yield of cobs

The increase in water use almost entirely reflects the increase in biomass the high density crop experienced. Even though biomass seemed to increase at the same rate of water use, we still saw an increase of 22% in IWUE of the high density crop based on irrigation applied and marketable yield. This means that by increasing plant density of sweet corn crop, the plant becomes a more efficient user of water in relation to marketable yield.

We compared tools that aim to facilitate the decision making process for irrigation and irrigation planning, such as CropWaterUse (DEEDI, 2009) and SILO (BOM, 2009), which uses the FAO 56 method described by Allen, Pereira et al. (1998). We found that the crop model CropWaterUse and SILO, were able to accurately predict crop water use for 95,000 p/ha with biomass production of 19 t/ha and leaf area index of 4.5. However these tools overestimated crop water use, based on biomass, for 65,000 p/ha, by up to 25%. According to sap test results, it is likely that the crops in this experiment were nutrient stressed, particularly nitrogen, during the late vegetative and tasseling stages. This would have had an impact on the amount of biomass produced and therefore water use may have been reduced. Here it seems likely that the high density crop grew as well as the crop these coefficients are based on but not as well as it would have as a high density crop in a non-limiting environment. Given that crop water use is directly proportional to biomass produced by the crop (Singh 2010); this indicates that crop coefficients may need to be tailored to the health of the crop when using these estimation methods. This may prevent over-irrigating of a crop that is grown in an environment that limits its development.

Soil moisture tension data, which can be an indicator of water stress and extraction by the plant, from field locations indicated differences in water extraction late in the season between the three densities (Fig. 58). This relationship between extraction zones in relation to root depth and concentration between treatments became quite evident nearing the end of the season, when soil tensions became quite high. At this stage, low density soil tension was up to 40% higher than high density at 0.3 m deep. This indicated that the low density crop tended to concentrate water extraction in shallow soil depths, where the highest concentration of roots may have been located.

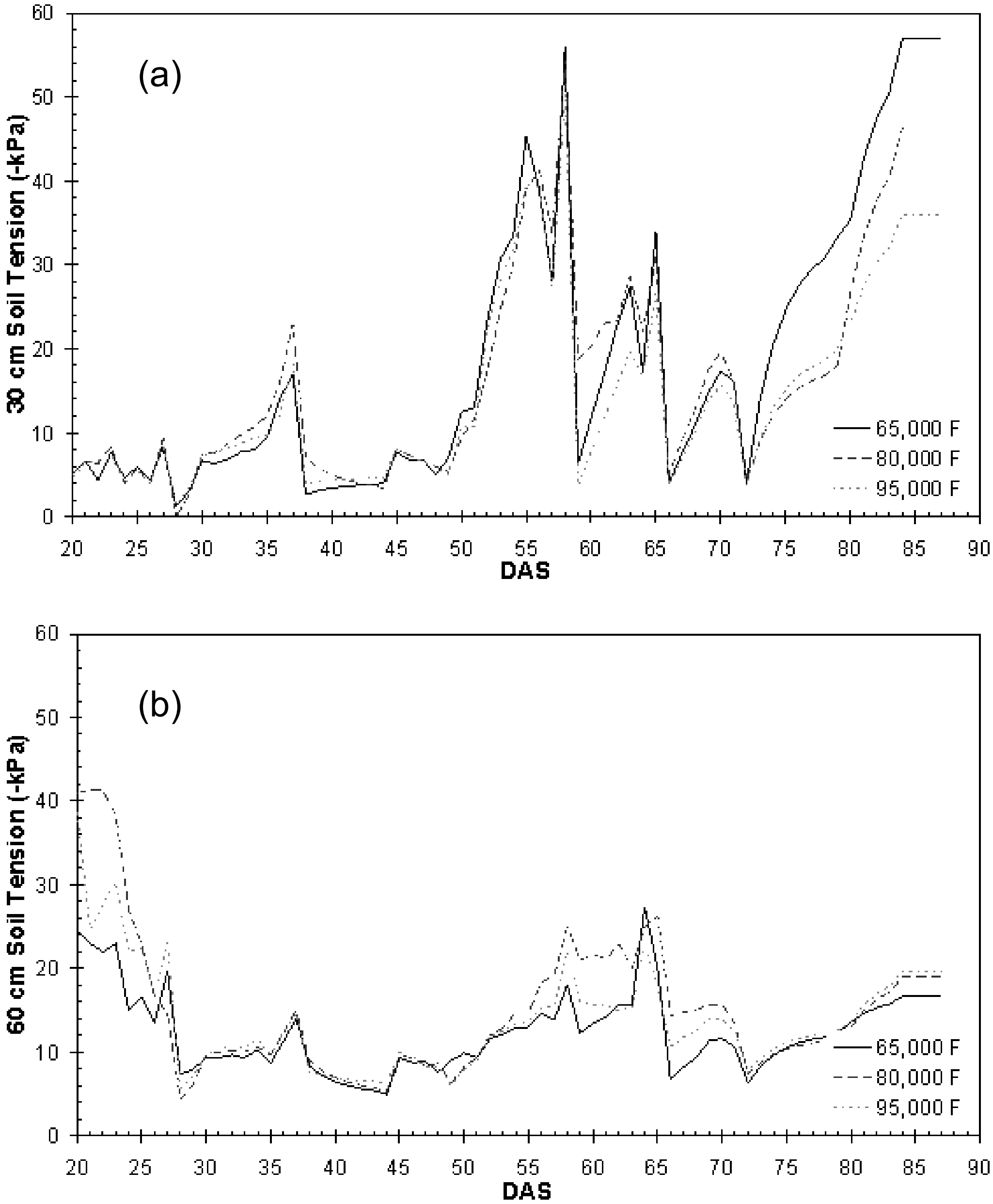

Figure 58. Soil moisture tension at (a) 0.3 and (b) 0.6 m below the soil surface of low (solid line), medium (broken line) and high (dotted line) density treatments of the sweet corn experiment.

This pattern of the low density crop's soil tension being higher than both medium and high density is reversed beyond 0.3 m. At 0.6 m, high density soil tension was up to 15% higher than low density. Here, high density seemed to extract higher quantities of water at around 0.6 m. This may be because the high density crops developed a deeper and more extensive root zone at depth than the low density crop, in response to competition from the increased plant and root density at 0.3 m for water. This may have contributed to the increase IWUE due to the plants access to deep water from irrigation and rainfall penetration. This may help in planning to prevent water stress risk, as high density plants developed an extensive root zone to capture deep soil water after high rainfall, or irrigation drainage if present.

Phenology and Physiology

Previous studies in maize phenology indicate that high density plantings could delay the vegetative, tasseling, and silking stages as well as maturation (Habib-Akbar, Muhammad et al. 2002, Lang, Pendelton et al. 1956, Du Plessis and Dijkhuis 1967).However we found no significant delays between sweet corn stages once initiated. We did find a cob maturation delay of two days by increasing density to 95,000 p/ha.

Increasing plant density can increase the risk of the crop lodging during adverse weather conditions. This is because plant height is greater, stem diameter decreases, and ear height from the ground increases (Downey 1971a). Results of our experiment confirmed that by increasing population density, the risk of crop failure due to lodging also increases.

Yield

Here, we saw a slight increase of 0.9 t/ha in total yield of the high density crop from 17.9 t/ha for low density. Many researchers have found increased yields can be obtained by increasing density of sweet corn (Mack 1972; Stone, Sorensen et al. 1998; Oktem and Oktem 2005) and maize (Amanullah, Khattak et al. 2009). However, these authors state that any increases in total yield are accompanied by decreases in the marketability of a portion of the produce in the form of decreased ear numbers (Oktem and Oktem 2005), weight (Stone, Sorensen et al. 1998; Oktem and Oktem 2005) and tip fill (Stone, Sorensen et al. 1998). Our results of marketable yield contradicted these authors' reports of the loss of marketability of high density cobs. Here we found an increase of 36% in cob quality in high density; that is fewer cobs were rejected based on tip and body fill as density increased (Fig. 59).

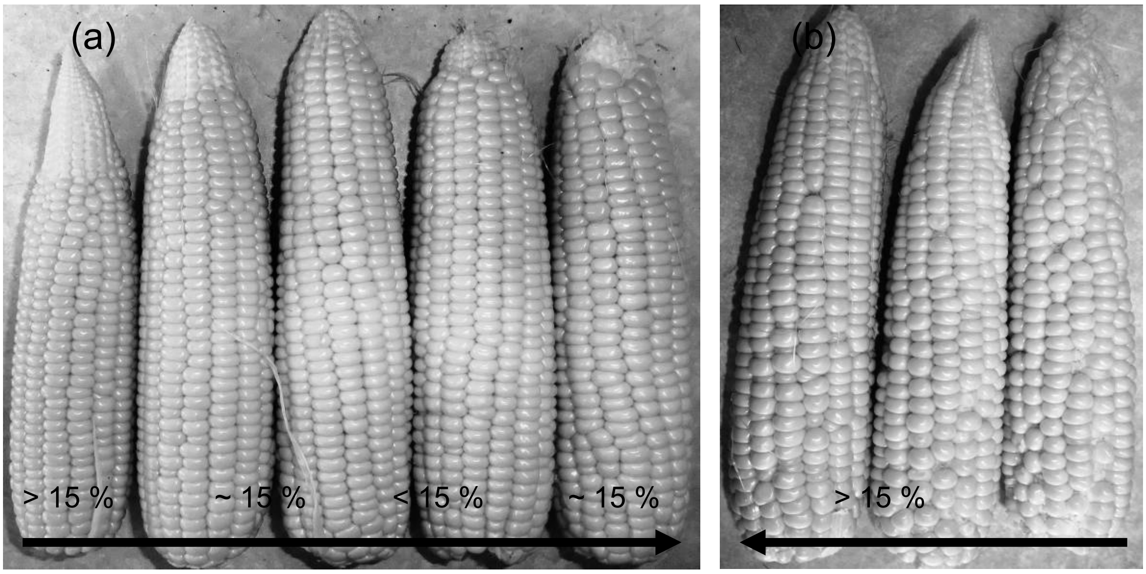

Figure 59. Sweet corn cob quality. Cob quality specifications state no less than 15 % of the kernels may be missing at the (a) tip of the cob or (b) within the body of the cob. Arrows indicate the direction of increasing marketability of sweet corn cobs based on percentage of kernels missing.

Our experimental results showed no decreases in primary cob size compared to the low density crops but did show decreases in secondary cob size. Experimental results reported by Falivene (1996) state that increasing density of a sweet corn crop from 55,000 to 77,000 plants per hectare improved marketable yields by 10%, with no significant difference in primary cob size and weight. Falivene (1996) also states that the development of a secondary cob may be prevented or delayed, to increase the diversion of resources towards the primary cob, reducing losses in marketable yield. In our sweet corn experiment, we observed that no second cobs in any treatments matured properly, or met market specifications.

Conclusion

Increasing the plant density of a Hybrix 5 sweet corn crop by 30,000 p/ha increased water use of the crop but also improved conversion of irrigation into marketable yield. In situations where water is scarce, this may be an economic strategy for maintaining productivity.

Acknowledgements

We would like to acknowledge Dave Schofield, Steve Soderquist, Vince Schiewe, Ken Quade and Chris McManus at the Gatton Research Station for taking care of the experiment. Thank you Laura Barnes and the team at the CSIRO Cooper Station Research Lab at Gatton for letting me take up space and the leaf area machine. Thanks also to Steven Harper, Tim O'Hare, Lung Wong, Neil Huth and Allan Peake for allowing us to access your expertise for this experiment.

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Impacts of drip tape arrangement and nitrogen fertiliser applications on performance of a sweet corn crop

(Experiment report prepared for circulation via online placement)

Adrian Hunt, Craig Henderson and Greg Finlay

Gatton Research Station, Agri-Science Queensland

Key findings

- Implementing a drip arrangement with one row of drip tube for every row of sweet corn (1:1), was more forgiving, less risky, and more intuitive to manage than a system with one row of drip tube for every two rows of sweet corn (1:2). It may be possible to improve the performance of the 1:2 system by closer row spacing, greater early irrigation applications to insure against poor lateral spread, or use of overhead irrigation for a longer period at crop establishment.

- The 1:1 system yielded 2.4 t/ha more marketable cobs than the 1:2 system (a 15% increase), due to the ability to maintain plant population immediately after establishment. The 1:1 system used 25% less irrigation to produce this result.

- Although there was no effect on N fertiliser strategy on yield, sweet corn in the 1:1 treatment captured more applied N, and lost less through leaching, than the 1:2 treatment.

- A combination of FullStops™, tensiometers and sap testing gave a very good portfolio of information for managing salt, nitrogen and water inputs. SSET were more difficult to interpret.

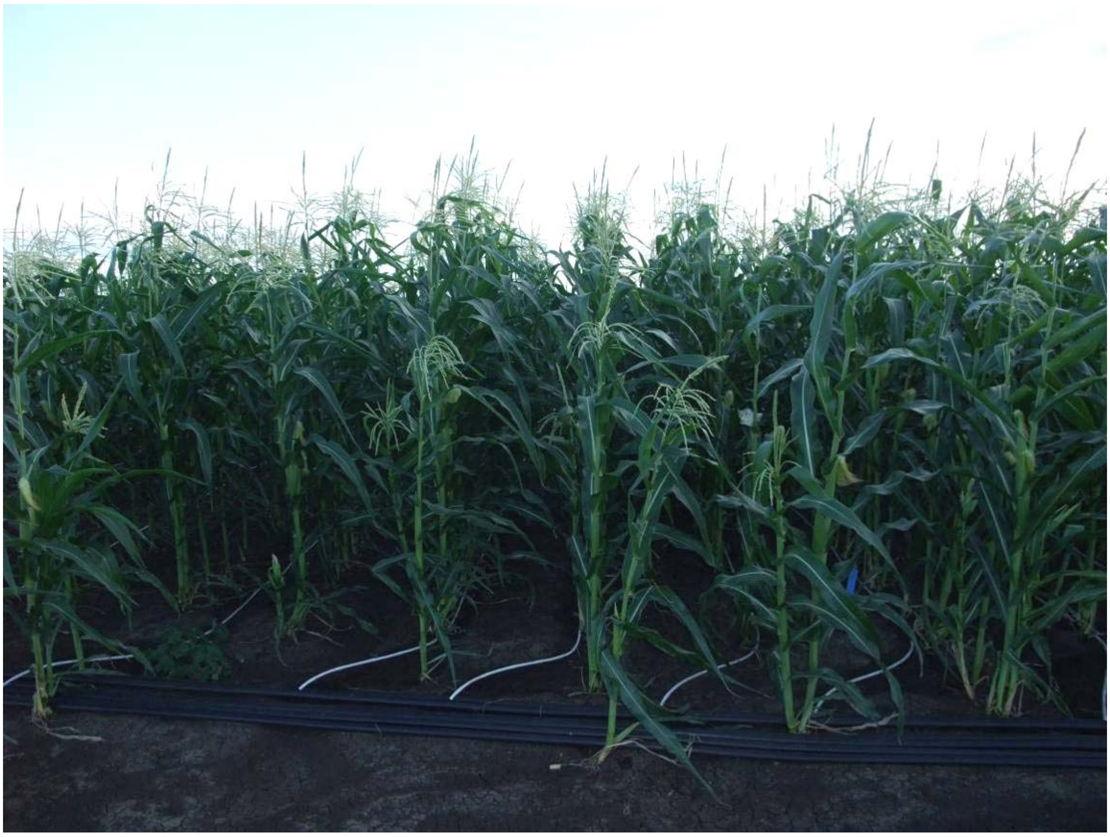

Plate 5 Sweet corn silking in a field experiment, Gatton, May 2009.

Introduction

Sweet corn is a major irrigated crop in Australia grown for both fresh and processed markets. Production in the year 2005/06 is reported to have been worth $74.7 million with over two thirds of the value of production coming from Queensland (ABS 2007).

Sweet corn growers in some regions have moved to drip irrigation due to a lack of available quantity and quality water for irrigation. In the Lockyer valley, this has generally involved the use of one drip line positioned mid-bed for every two plant rows (1:2). This configuration relies significantly on the lateral movement of water from the drip line to the developing plant root system. An alternative is to have one drip line for every plant row (1:1). However, this increases the cost by doubling the amount of drip tape required. Producers therefore need an understanding of the impacts of choosing either of these configurations, in order to make the best decision.

The objective of the experiment was to examine the following hypotheses:

- 1:1 improves crop performance
- 1:1 improves water use efficiency
- 1:1 improves nutrient use efficiency
- 1:1 makes management easier/simpler
- 1:1 improves root zone salinity

The measurement of root zone solutes is not a new field. However, it has been receiving increased attention recently, as people have become increasingly concerned about efficiently using crop inputs such as fertilisers and water. Making best use of poor quality water sources for irrigation has also been receiving more interest. Much of the research so far has focused on root zone solute management in perennial production systems, with less attention on intensive irrigated annual vegetable production systems. The development of monitoring practices that are practical and meaningful for the management of root zone solutes within these systems would be of benefit to both the vegetable industry and the environment.

Materials and methods

The experiment was carried out on the Queensland Primary Industries and Fisheries Gatton Research Station. The soil was a brown, moderately to strongly self-mulching heavy clay topsoil with slightly alkaline pH. A soil test that was undertaken pre planting. These tests indicated that nitrate-nitrogen was present at concentrations of 26-28 mg/kg, Colwell phosphorus 110-130 mg/kg, potassium 0.71 meq/100g and an EC 1:5 of 0.15 - 0.16 dS/m.

The sweet corn crop was planted on the 17 February 2009. Beds were 1.5 m centre to centre and 10 m long. Six treatment combinations were evaluated in a full factorial design, with three blocked reps. Two drip tape configuration treatments were used; one drip tape per plant row (1:1), and one drip tape per two plant rows (1:2), i.e. per bed. Three nitrogen fertiliser treatments were also assessed across both drip irrigation setups. Each experimental plot bed had a buffer bed on either side that received the same treatment. Every seventh bed was set aside to allow for spray machinery access, with a total of 62 beds planted. The cultivar Hybrix 5 (Pacific Seeds) was used, with rows planted 37.5 cm from the bed centre. Intra-row seed spacing was 20 cm, and the sweet corn was sown using an air seed drill.

Irrigation was supplied using Plastro Hydro PCND (pressure compensated, no drain) tube with 150 mm emitter spacing. The emitter output specification was 1.15 l/hr, for an equivalent linear output of 7.67 l/m/h. Two tools were used to evaluate the effects that the irrigation system and applied fertiliser had on root zone soil solutes. FullStop™ wetting front detectors were placed in line with drip tape at depths of 30 and 60 cm in the normal nitrogen treatment. JKG Tech Soil Solution Extraction Tubes (SSET) were placed at depths of 30 cm, 60 cm and 90 cm in line with the drip tape in all of the plots. In addition, 30 and 60 cm SSET samplers were installed in the crop rows in the normal nitrogen treatment. We extracted solute samples from the FullStop™ wetting front detectors each time they were triggered. SSET were suctioned to >60 kPa and allowed to gather a sample for 2-3 days before collection in most weeks. Solution samples were tested for electrical conductivity (EC).

Irrigation scheduling was carried out using tensiometers installed inline with the plant row, at depths of 15 and 60 cm. Scheduling aimed to keep the shallow tensiometers at <50 kPa, with deep tensiometers steady or slowly rising to 40 kPa. Irrigation volumes were fine tuned using observed rainfall and calculated ETo (FAO56) from the Australian Bureau of Meteorology Irrigation SILO website patch point data (http://www.longpaddock.qld.gov.au/silo/), with crop factors adjusted based on tensiometer response patterns. Irrigation run times, pressures and volumes were recorded each time a plot was irrigated. Nitrogen fertigation treatments in the form of urea were added, based on recommendations from Wright *et al.* 2005. We provided an initial basal application of 45 kg of nitrogen per hectare, followed by two applications of 30 kg nitrogen/ha for the normal treatment at four leaf and tasseling stages of development, using a proportional inline injection system (Netafim, Dosatron, D 45 RE 3). The low N treatment received 10 kg/ha at each side dressing, whilst the double N treatment received 60 kg/ha at each side dressing.

The crop was treated for weed control with 1.5 L/ha of Dual Gold (S-metolachlor) one day after planting, immediately watered in by overhead irrigation. The volume of overhead irrigation applied was not included in crop water usage calculations as it is assumed to have brought the soil to field capacity as a uniform starting point. One spray was applied at the 4-5 leaf stage of the crop, and comprised Success2® (400 ml/ha), as well as zinc and boron micronutrients.

Six whole plant samples from the normal nitrogen treatment rows were used for sap sampling of nitrate, magnesium and zinc at the four leaf stage. Four whole plant samples were also harvested from the same plots for dry sample assessment. At tasseling and at harvest, four stem segment samples were taken from each plot for sap sampling, and leaf samples were taken for dry nutrient analysis.

The final harvest was carried out on 18 May 2009, 91 days after planting. Cobs were harvested from eight metres of both rows from the experimental beds. The number of plants within the harvested area were counted, cobs were graded into marketable and unmarketable according to specifications from Woolworths (Woolworths Supermarkets 2007). Cobs were segregated into primary (initial cob) and secondary cobs. The number and mass of marketable and unmarketable cobs was recorded. A one metre section from each row in each experimental bed was harvested separately, with plants also removed. The total fresh weight of the plants and cobs from these sections was recorded, and then a subsample used for assessment of dry weight. Cobs that were undersized, or had obvious external defects or damage, were designated as unmarketable, with the rest considered marketable. A sub-sample of ten marketable cobs was graded for tip fill.

Statistical analysis was carried out using GenStat™ software 11th edition via two way ANOVA and summary statistic functions.

Results

General Observations

Crop establishment did not achieve the plant density that was expected. This may have been caused by a combination of poor seed germination and misses by the planter. The crop only received one overhead irrigation after which it relied on rainfall and drip irrigation. There was some lodging noted particularly in the 1:2 drip line per plant row treatment at around 20 days after planting (Fig. 60). On close inspection, the lodged plants lacked secondary roots in comparison with those that had not lodged, and was most prevalent where the distance from the drip line was greatest. On the 16 March, a storm hit the Gatton Research Station with wind gusts recorded of up to 85 km/h. This had a noticeable effect on the crop with most plants bent sideways away from the prevailing wind. Plants in rows that were irrigated by the 1:2 irrigation treatment appeared to be the most damaged, and suffered a greater decline in plant density (Fig. 60).

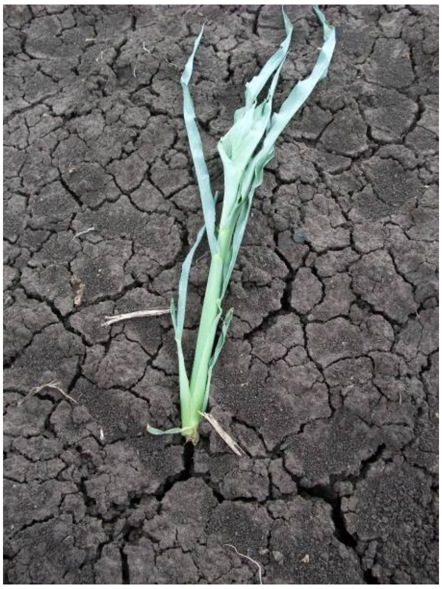

Figure 60. Water stressed developing seedling and lodging crop damaged by storm

Yield

The 1:1 treatment yielded 54,000 cobs/ha, which was 5000 cobs/ha more than the 1:2 treatment. Yield on a weight/ha basis was also higher in the 1:1 treatment, at 18.7 t/ha compared to 16.3 t/ha in the 1:2 treatment. The number of marketable cobs per plant was not significantly different between treatments. However, the population density was significantly higher in the 1:1 treatment at 52,000 plants/ha, compared to 47,000 plants/ha in the 1:2 treatment. This shows that the final yield was highly dependent on the plant population density. The nitrogen application treatments did not effect yield (P=0.05). The proportions of cobs deemed unmarketable were not significantly different between irrigation or N application treatments.

Sap analysis

Differences in NO_3^- P, Mg, Zn and Ca concentration at the four leaf stage were not significantly different (P=.05). There were slight differences in sap K concentrations between the irrigation treatments, but both were within the sufficiency range suggested by the sap-testing laboratory. Concentrations of boron were however well below the optimum sufficiency range.

Both irrigation configuration and N application had a significant effect on sap nitrate concentrations at tasseling and harvest, however all levels were in the high or above normal concentration based on the sufficiency range suggested by the sap testing laboratory (Table 10).

At the tasseling and harvest maturity stages, the sap concentration of nitrates was higher in the 1:1 irrigation treatment. The double nitrogen treatment significantly increased the sap nitrate concentrations at the tasseling and harvest stage above that of the normal and one-third nitrogen treatments. The sap nitrates were only found to be significantly higher in the normal nitrate treatment then the one-third treatment at the final harvest. Nitrogen treatments did not have any significant effects on sap concentrations of the nutrients tested for, other than nitrate. Note that there was no treatment effect on N contents of dry tissue.

Table 10. Mean sap concentrations at tasseling.

Treatment	NO_3 ppm
1:1	7650.± 160
1:2	7200 ± 130
One third N	7220 ± 170
Normal N	7270 ± 220
Double N	7780 ± 140

FullStop™ wetting front detectors

The variation between replicated measurements of the same treatment demonstrates the variability in salt accumulation and leaching within the site. This variation complicates the interpretation of any effect from applied treatments on total salt movement. The variability between FullStop™ samples can be characterised as:

- Variability in the number of FullStops triggered.
- Variability in the EC at single point in time
- Variability in the change in EC between two consecutive samples

FullStops™ at 30 cm in the 1:2 treatments were triggered most often, followed by the 60 cm units in the 1:2 treatments, the 30 cm units in the 1:1 treatments and the 60 cm units in the 1:1 treatments. On 14 occasions, the FullStops™ triggered at both depths in the 1:2 treatments, but neither depth triggered in the 1:1 treatments. Only two events triggered all of the FullStops™. One was due to an overhead irrigation and the other a rain event after harvest.

EC of solutions collected in triggered FullStops™ installed at the 30 cm depth started at 2-2.5 dS/m in both drip installation treatments. The FullStop™ wetting front detectors in the 1:1 drip irrigation treatment was not triggered for the following 40 days and when it did had increased to 5.5 dS/m. This indicates that by regularly applying small amounts of irrigation directly around the sweet corn plant, salt was accumulating in the soil above the FullStop™, until a sufficiently strong event occurred to trigger the wetting front detectors. This pattern recurred throughout the growing period – salt accumulation, followed by a flushing event every few weeks. In contrast, where there was only one line of drip tube per bed, the FullStops™ were regularly triggered, and EC of solute samples remained around 2.5-3 dS/m. The mean EC of solutes collected from the 60 cm FullStop™ wetting front detectors were initially high, at 6.5-7.5 dS/m. This was probably due to salt accumulation from previous cropping cycles and irrigating with moderately poor water. The EC of these deeper solutes decreased during the first 30 days after planting in the 1:2 treatments, reflecting the greater amounts of irrigation applied to move the water laterally. The EC in the 60 cm FullStop™ wetting front detectors in the 1:1 treatments also decreased, but did so over a longer time period, due to lesser irrigation amounts, and therefore less leaching. In both instances, the solutes collected toward harvest were in the range of 2-2.5 dS/m.

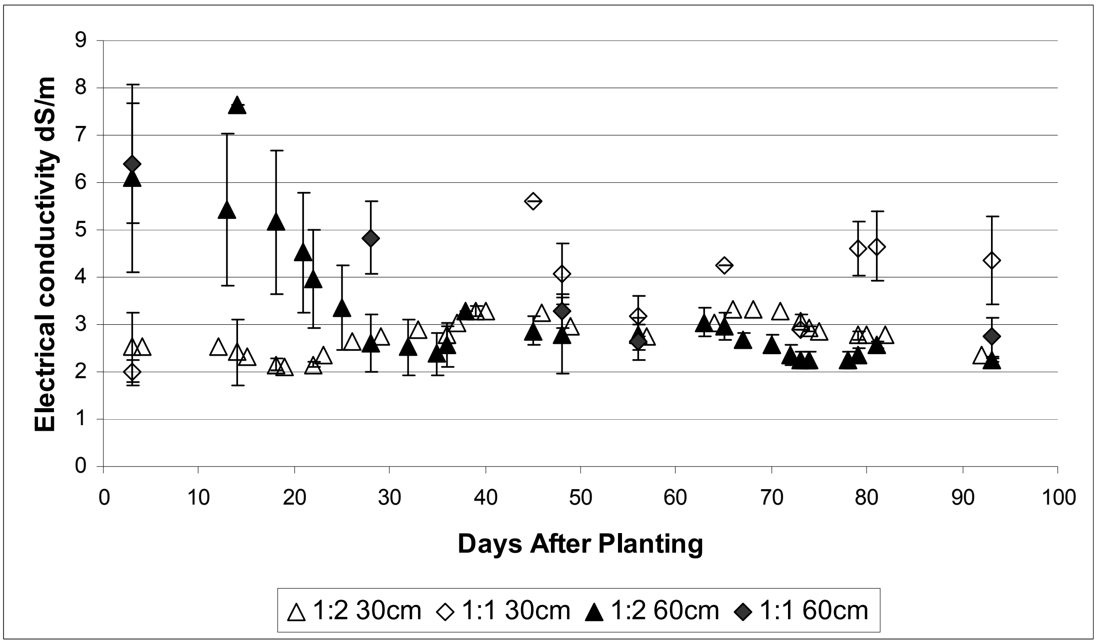

Figure 61. FullStop™ wetting front detector electrical conductivity. Error bars indicate SEM.

As previously mentioned, shallow FullStops™ in those treatments with a line of drip tube for every row of sweet corn (1:1), triggered much less often than where there was only one row of drip tube per bed (1:2). In both treatments, solutes collected from the shallow FullStops™ started off with high nitrate concentrations (around 700 ppm). In the 1:1 treatments, nitrate concentrations gradually declined during the cropping period, to close to zero by 65 days after planting (Fig. 62). We believe this indicated effective uptake by the crop. The 1:2 treatments followed a similar pattern, although there were spikes in concentration around 40 and 70 days after planting, following the side dressings.

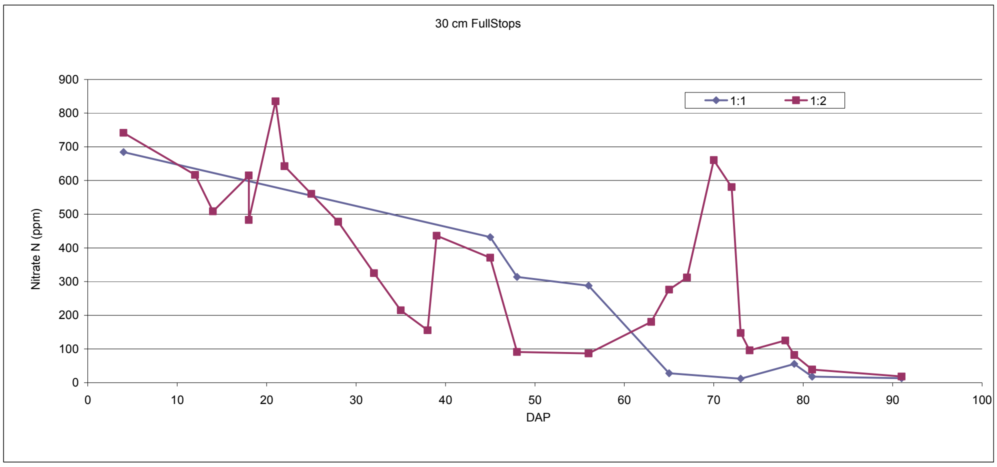

Figure 62. Nitrate concentrations in solutes from FullStop™ wetting front detectors installed at 30 cm below the drip tubes in two drip arrangements.

The deep FullStops™ in the 1:1 treatments triggered infrequently. Although they started with nitrate concentrations around 600 ppm, there was a spike of 700 ppm around 30 days after planting. This indicated a significant leaching event, probably associated with the heavy early rainfall. After this, there were only a few more occasions where the deep FullStops™ in this treatment were triggered, and the nitrate concentrations in these solutions were <200 ppm. In contrast, the deep FullStops™ in the 1:2 treatment were regularly triggered, and the concentrations of nitrate in the extracted solutions were regularly higher than the 1:1 treatments. This indicates much greater nitrogen movement deeper into the soil profile was occurring under the 1:2 treatments.

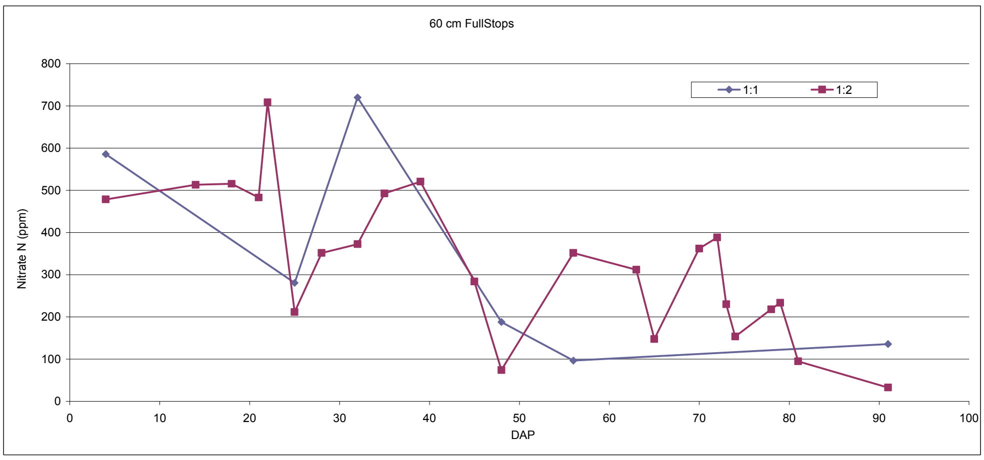

Figure 63. Nitrate concentrations in solutes from FullStop™ wetting front detectors installed at 60 cm below the drip tubes in two drip arrangements.

SSET

The EC of solute samples collected from the SSET were relatively consistent during the growing period (Fig. 64). The jump in EC at 90 cm that occurred 40 days after planting is an artefact primarily of 2 out of 3 of the SSET failing to provide a sample. The sample EC at 30 cm in both drip treatments were similar; starting at 2.8-3 dS/m and finishing at 3.5 dS/m. Mean EC increased with depth as did the variability.

Mean EC values from the SSET did not show as dramatic a change over the course of the experiment compared with mean EC values for samples collected from the FullStop™ wetting front detectors. This reflects the pores that the instruments are sampling from, and the influence water status has on the measurements. The SSET values probably reflect the underlying salinity status of the soil profile at that depth. We see a gradual increase in EC under both drip arrangements at 30 cm. However, the levels are not concerning to crop health. In the 1:2 drip tube arrangements, we see a slight decline in EC at 60 cm, indicating some long-term leaching, whereas we see a slight increase in the 1:1 treatments, suggesting a slight salt build up. At 90 cm, the salinity is both high and static, indicating a long-term impact of irrigated cropping systems in a period of low rainfall over many years.

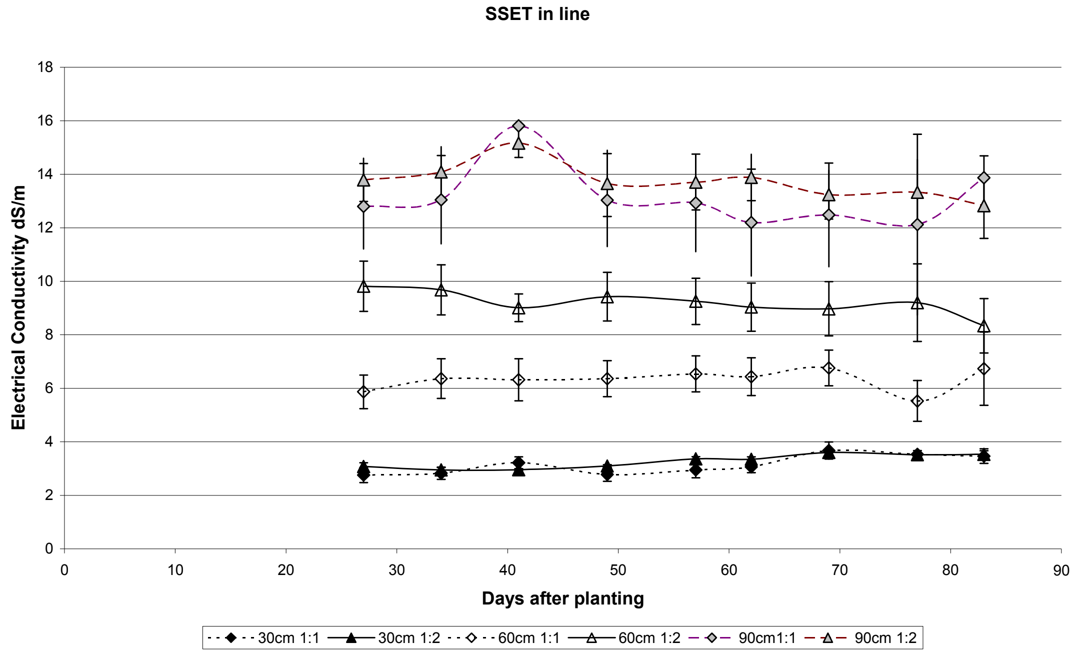

Figure 64. Electrical conductivity of SSET samples over time. Error bars indicate SEM

The solute solutions extracted from the SSET reflected the quantities of nitrogen added in the side dressings. For the least N additions, we can see a relatively steady decline in solute nitrates at 30 cm as the growing period progressed, with slight increases after each top dressing. The peaks were higher for the normal N treatments, and much higher for the Double N treatments (Fig. 65). We can see much higher nitrate levels in solutes from the Double N treatment at 60 cm for the first 60 days after planting, although for the weeks before harvest, there was basically no difference between any of the treatments at this depth (Fig. 66).

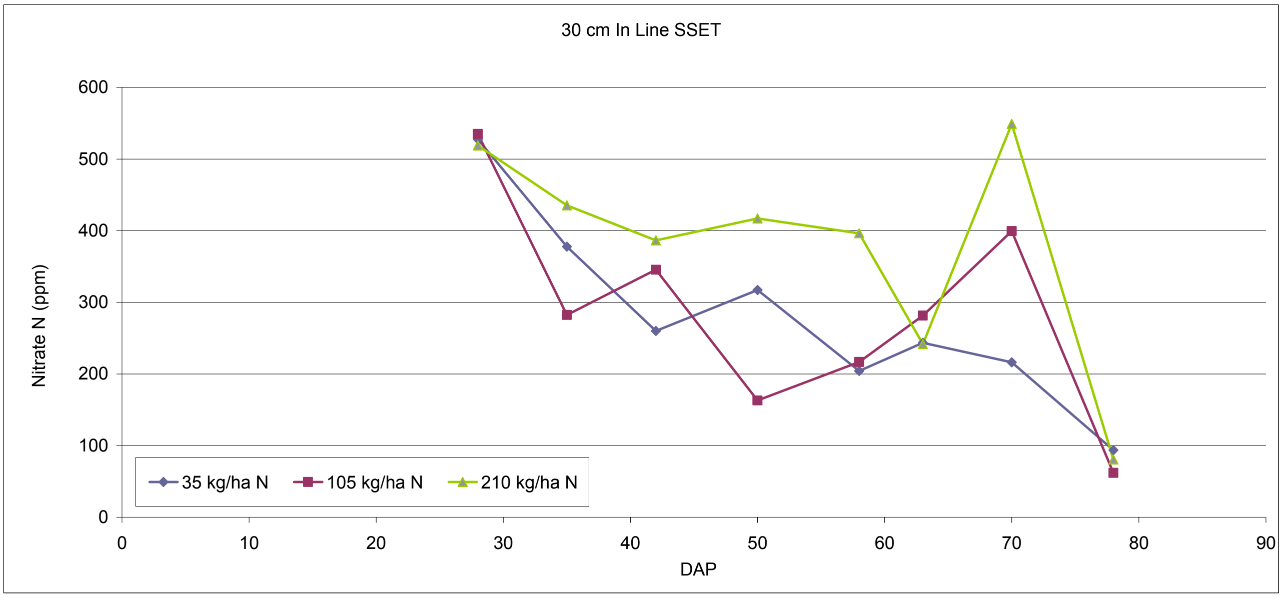

Figure 65. Nitrate concentrations in solutes from SSET installed at 30 cm below the drip tubes under three nitrogen treatments.

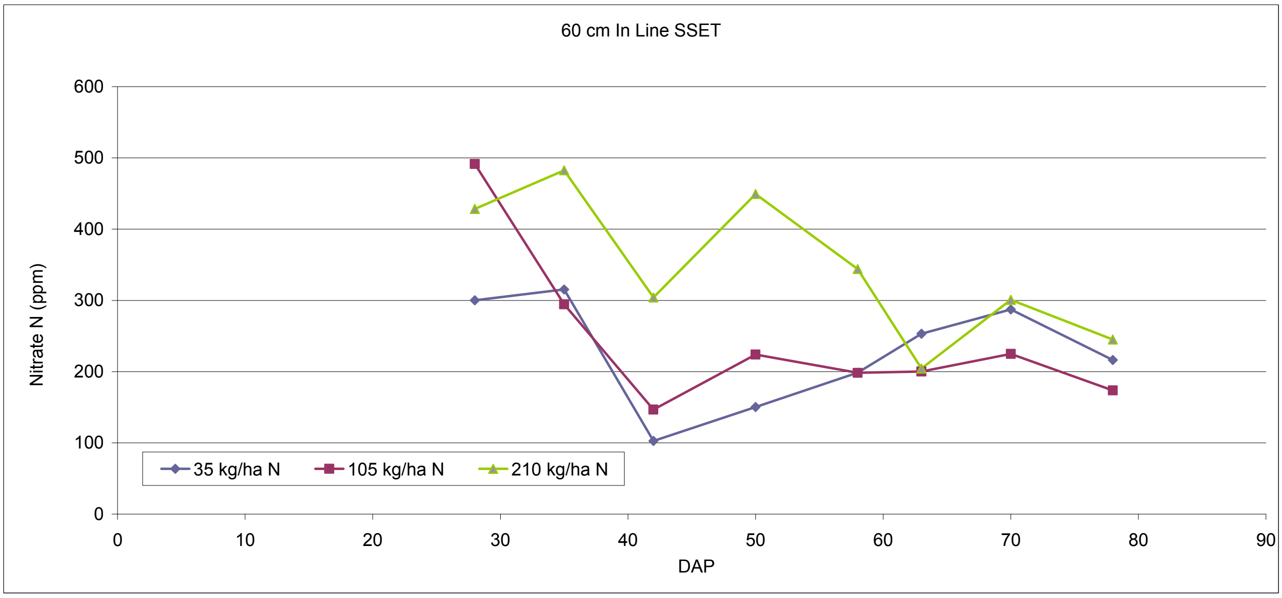

Figure 66. Nitrate concentrations in solutes from SSET installed at 60 cm below the drip tubes under three nitrogen treatments.

Nitrate levels in the solutes extracted at 30 cm from the 1:1 treatments declined rapidly during the growing period, with substantial spikes following each side dressing, while the decline in nitrates in the 1:2 treatments were slower, and the spikes less proportionally obvious (Fig. 67). This reflects the situation where the sweet corn roots were closer to the drip tube and SSET during the initial growing period in the 1:1 treatments. Nitrates at 60 cm were relatively similar, although the nitrogen use by the plant from this zone was probably also slower in the 1:2 treatments (Fig. 68).

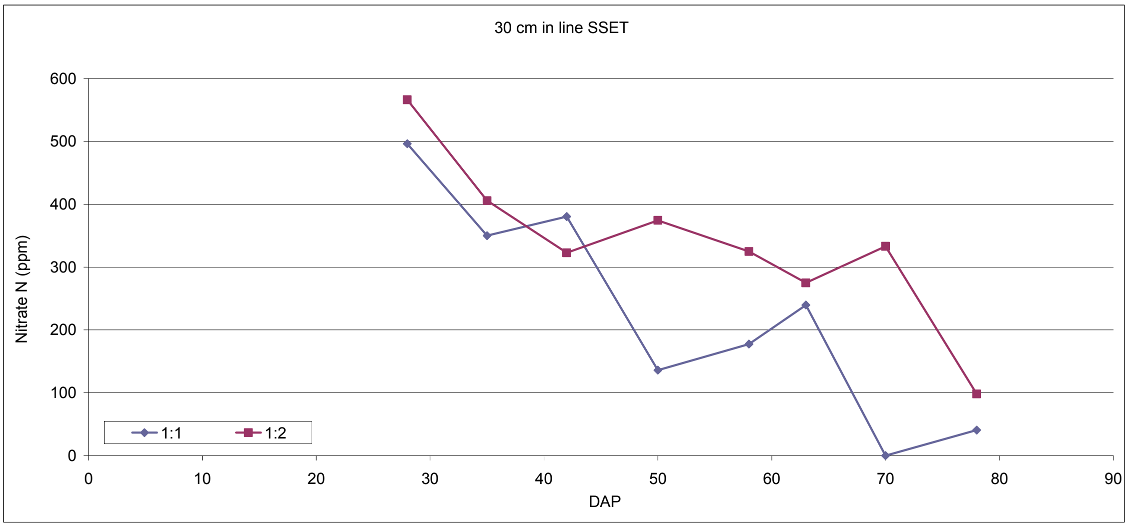

Figure 67. Nitrate concentrations in solutes from SSET installed at 30 cm below the drip tubes in two drip arrangements.

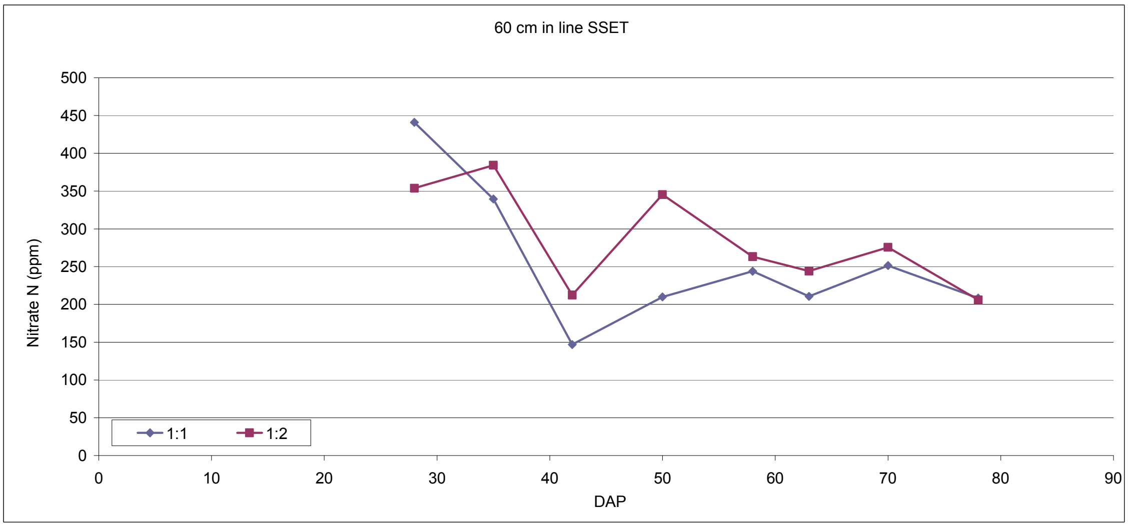

Figure 68. Nitrate concentrations in solutes from SSET installed at 60 cm below the drip tubes in two drip arrangements.

Nitrate levels at 90 cm also declined during the growing period (Fig. 69). Interestingly, there were more substantial spikes after side dressing in the 1:1 treatments, compared to the 1:2 treatments, which was unexpected. Perhaps there was some preferential water movement down the root channels of the sweet corn?

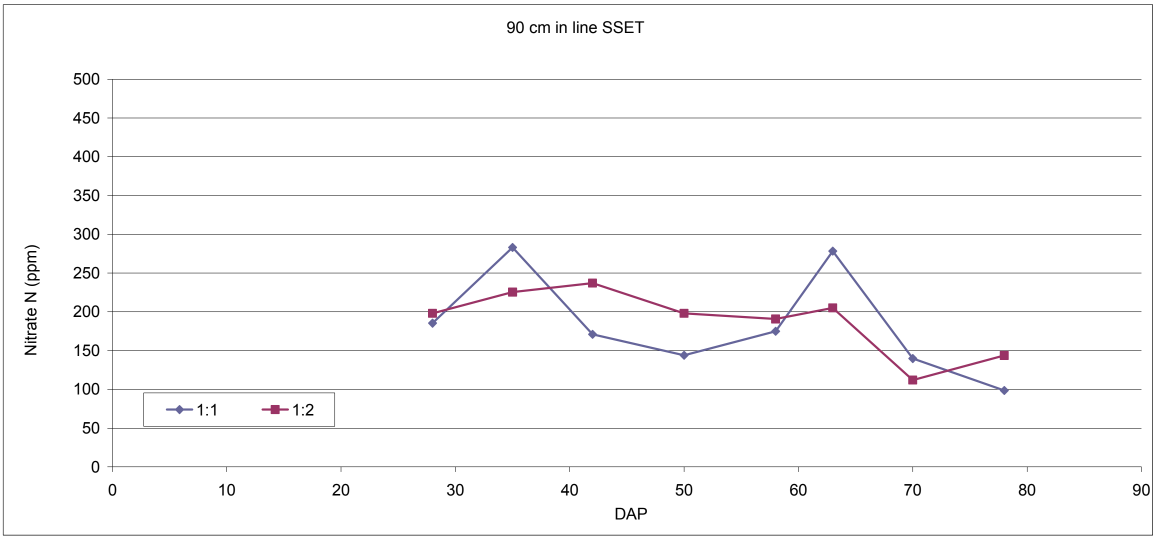

Figure 69. Nitrate concentrations in solutes from SSET installed at 90 cm below the drip tubes in two drip arrangements.

Soil water tension

Soil water tension at 15 cm was maintained at less than 45 kPa suction for both treatments. Tensiometers under both drip arrangements remained similar until 60 days after planting, mainly responding to rain at 28 DAP, and from 45-55 DAP (Fig. 70). From 60 days after planting on, the soil tension at 15 cm in the 1:2 treatments gradually increased, only declining slightly at each irrigation. In comparison, the treatments with the drip tube immediately next to the sweet corn, responded rapidly and markedly to each irrigation. Note that they also increased rapidly between irrigations.

Soil water tension data shows soil at 60 cm remained wet until about 40 days after planting. Between 45 and 60 DAP, the decreasing tension suggests water was moving past this point in the profile. From 65 DAP until harvest the soil gradually dried out, which is exactly the process we were chasing. Note that at this time in both drip arrangements, the soil profile at 60 cm was drying below the sweet corn row (from the tensiometer data). However, the FullStop™ data shows water moving past 60 cm beneath the drip tube in the 1:2 treatments, but not in the 1:1 treatments.

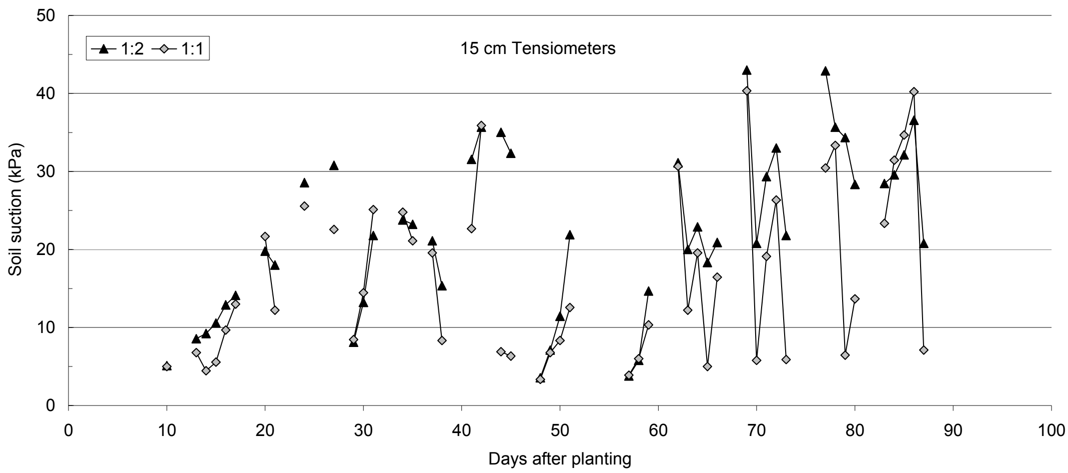

Figure 70. Soil suction at 15 cm in the sweet corn plant row.

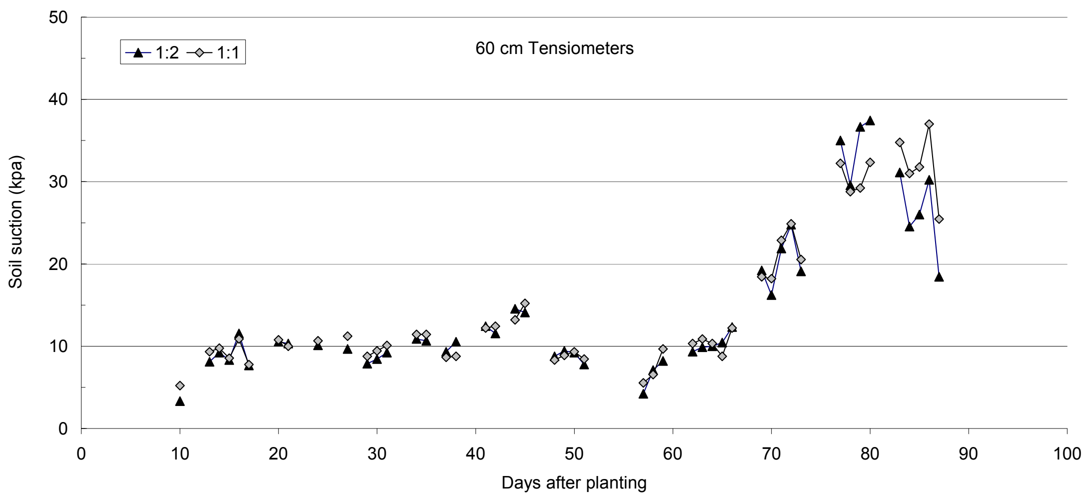

Figure 71. Soil suction at 60 cm in the sweet corn plant row.

Irrigation

The flow meter used on the mains inlet to the experiment was found to be unreliable. It intermittently understated the applied volume and at one stage ceased working entirely. Applied irrigation volumes were therefore calculated based on emitter discharge, spacing, area and run time. We irrigated slight more frequently, and with slightly higher volumes in the 1:2 treatments, compared to the 1:1 treatments. This was because we needed to apply more water to get sufficient lateral water movement, particularly early in the growing period. Experience also shows that there is a greater risk of not being able to get lateral water movement in these soils if they are allowed to dry too much. Where the drip tube is adjacent to the plant row, it is easier to take risks in delaying water application, because we know we can immediately supply water to the plant if required. The total irrigation applied by the single line drip tape per bed treatment was 150 mm in comparison with the single drip line per plant row, which had 114 mm applied. Thus 24% less irrigation water was applied to the single drip line per plant row treatment. Rainfall in this experiment markedly reduced the irrigation water required. It is likely some rain in the initial week, and 40-55 DAP was ineffective, due to runoff and leaching.

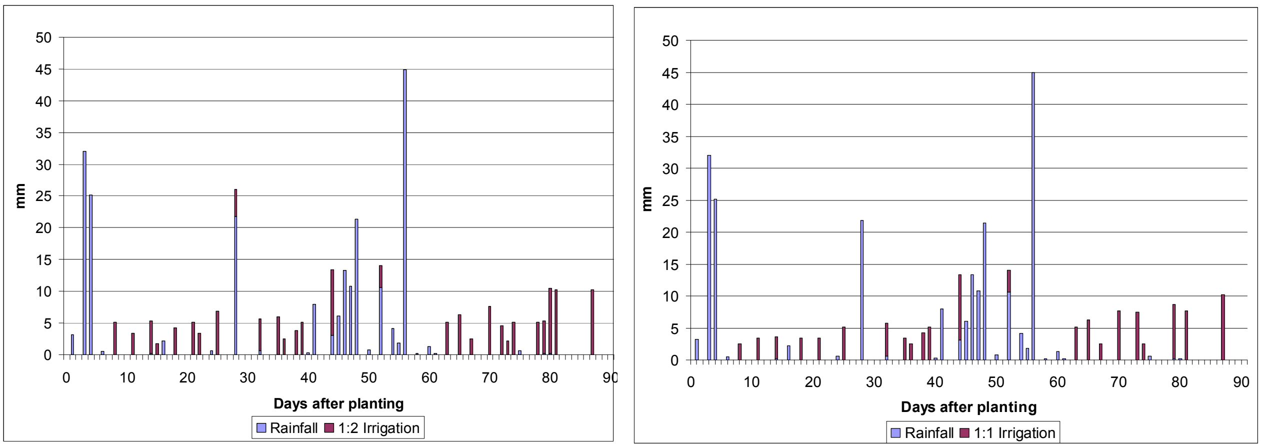

Figure 72. Irrigation and rainfall sequences for two drip irrigation arrangements in sweet corn.

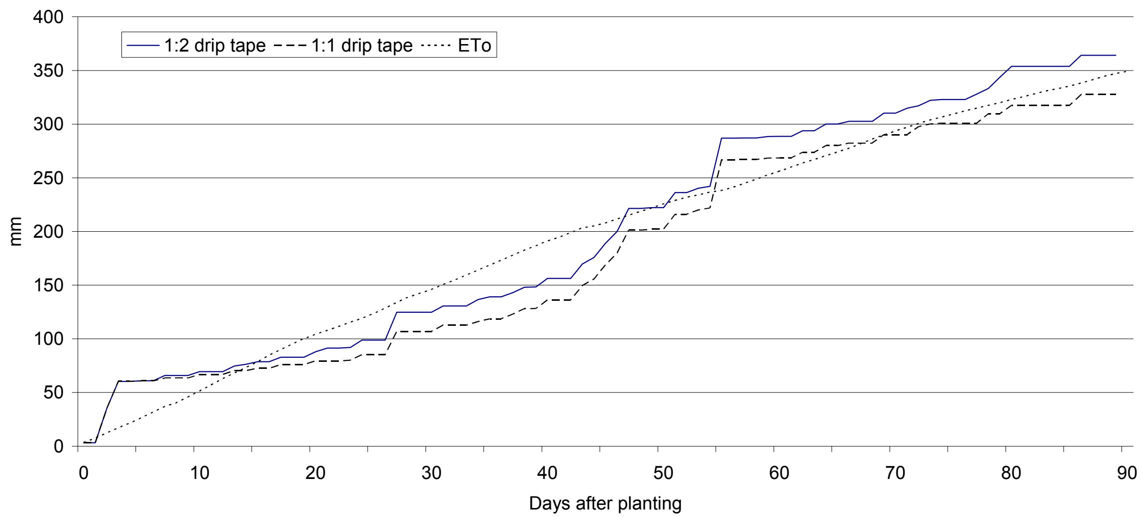

Figure 73. Cumulative water additions for two drip irrigation arrangements in sweet corn.

Discussion

Did the 1:1 drip tube arrangement improve crop performance?

The use of drip tape in a configuration of 1:1 was associated with a 15% improvement in crop yield. The main reason for the difference in performance appears to be a function of plant population maintenance. We suggest this is because of insufficient or ineffective irrigation application during plant establishment in the 1:2 treatment. This does reflect the problem of ensuring lateral spread, particularly with inexperienced irrigation operators. It may have been able to be averted by ongoing use of overhead irrigation further into the cropping period, additional drip irrigation.

Scheduling during early crop establishment is difficult to refine due to small plant rooting zones and higher sensitivity to moisture deficits. Only a relatively small amount of water need be applied during plant establishment to wet the plant root zone during establishment in a one drip tape per row configuration, in comparison with a one drip tape per two rows configuration. Those making irrigation management decisions can also be confident that only a small amount of water per application is necessary to maintain the wetted plant root zone. Managers using one drip tape per two plant rows may need to apply significantly more water to wet the plant root zone, due to the amount of lateral movement required. One solution now being widely used in the industry is to push the rows closer together on the bed, with greater gaps between rows on different beds.

Did the 1:1 drip tube arrangement improve water use efficiency?

The 1:1 treatment received 24% less drip irrigation that the 1:2 treatment. If we had to apply additional irrigation during crop establishment for the 1:2 treatment, this would have further exacerbated these differences. Expressed as irrigation water use efficiency, the 1:2 treatment produced 10.9 t sweet corn per ML, compared to 16.4 t/ML for the crop with a row of drip tube per row of sweet corn. This was an improvement of 45%. The tensiometer and FullStop™ results suggest there was less water moving deeper than 60 cm in the 1:1 treatments than in the 1 2 treatments.

Did the 1:1 drip tube arrangement improve nitrogen use efficiency?

There was no nitrogen treatment impact on yield, and all tests indicated that N contents of even the least fertilised treatments were in the luxury consumption levels. Thus, it is very hard to make any claims about nitrogen use efficiency from this experiment. However, we could see that the plants in the 1:1 treatments took up more of the applied nitrogen (higher sap N concentrations). The FullStop™ results indicate more nitrates moving past 60 cm in the 1:2 treatments, and similarly the SSET samples showed more nitrates moving at depth, particularly where the highest rates of N were applied.

Did the 1:1 drip tube arrangement make management simpler?

Scheduling irrigation in the 1:1 irrigation configuration was relatively easy, particularly at crop establishment. We could apply small amounts and be confident that we were replenishing the root zone of the small seedlings. This was not the case in the 1:2 system, where we had to rely on lateral spread from the drip line to the crop row. This made judging the amount of water that needed to be applied to refill the root zone much more difficult. We appear to have under estimated the amount required, which subsequently lead to plant population decline.

The substantial differences in tensiometers reactions to applied water during the latter part of the experiment demonstrate the difficulty that can be faced in maintaining an appropriate soil water tension in the upper root zone under the plant row in a1:2 drip system configuration. This is consistent with the findings of previous studies of drip tape configuration in broccoli production conducted at the same site (Henderson, Yeo et al. 2008). Some of the difficulties that arise in managing the in line root zone soil water tension may be able to be attributed to the decrease in soil hydraulic conductivity associated with an increase in soil water tension. The reality is that we often have to keep the soil wetter than we would otherwise like, just to ensure we can move water laterally to the plant. The use of two dimensional soil water model, with an integrated plant root growth and water uptake model such as Hydrus 2D, may be useful in scoping changes in crop management factors such as row spacing and most appropriate placement of tensiometers in a 1:2 drip based system in a variety of crop, soil and climatic scenarios.

In general, we found the 1:1 drip system more forgiving, less risky, and more intuitive to manage.

Did the 1:1 drip tube arrangement improve root zone salinity management?

The FullStop™ results suggest the low-volume irrigations in the 1:1 treatments were building up salts in the 30 cm zone of the sweet corn rows. These salts were mobilised by the rain. We weren't picking up hazardous levels in the SSET, however they confirm a slight increase during the season. The beauty of the 1:1 treatment however, is that a flushing via irrigation is relatively easy to achieve. Under the 1:2 treatment, we were seeing more salty water move past the 60 cm FullStops™. We weren't however picking up any major build up of salt in the various soil profile layers, via the SSET.

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Woolworths Supermarkets (2007). Produce Specifications, Corn. http://www.woolworths.com.au/resources/corn.pdf, Woolworths Supermarkets.

Wright, R., P. Deuter, et al. (2005). Sweet Corn Growers Handbook. Brisbane, Queensland Department of Primary Industories and Fisheries.

Biophysical modelling

Key findings

- The CSIRO team within the project have developed biophysical crop models for broccoli, sweet corn, green beans, and lettuce. These models are available for use through the APSIM platform, (based at www.apsim.info). The intent is that these models will be used by experienced or trained users (scientists, consultants), either in group situations with growers in workshops, or as a service to individual farmers.

- The current model versions are good at predicting crop phenology (development stages, time to harvest), input use (water, fertiliser) and environmental impacts (nutrient, salt movement). They are good at predicting total yields.

- The models do not currently handle environmental extremes, and their impacts on marketable yield, nor do they deal with impacts such as pests or diseases.

- The models require re-calibration for new cultivars (particularly phenology). We hope to have a ready method for re-calibrating using simple records a grower may have access to. The models also require additional modules to deal with 3-dimensional drip irrigation.

- The two most immediate applications for the models are understanding/predicting/manipulating harvest dates, and understanding/predicting/manipulating nitrogen movements in vegetable cropping systems.

Emerging opportunity

The project team recently held discussions with a producer about managing broccoli production. The producer recognised that unusual temperatures can impact on the expected harvest date of broccoli, and cause both gluts and gaps in product at market. They wanted to firstly understand and more accurately quantify how significant those delays or bring forwards in harvest could be. We could use the broccoli model to predict harvest date changes, based on immediate and predicted temperature conditions. We would first have to calibrate the model for the producer's cultivars. We are hoping to be able to do that using existing production records.

The producer was actually interested in whether there was a way of simplifying the model into a user-friendly spreadsheet system, where they could put in the planting date, type of planting (direct sowing vs. transplanting), and observed (or expected) expected temperatures, to predict days to harvest.

The next step the producer was interested in is whether days to harvest could be manipulated by any agronomic practices. The first scenario is whether you can shorten days to harvest by manipulation at planting - (you can lengthen it by delaying planting, particularly when direct seeding the crop). Alternatively, once they have an established crop, what can they do to either shorten or lengthen days to harvest - any sort of agronomic manipulation – e.g. nutrition or water?

This is a good example of where the models can have immediate application (predicting harvest date under different environmental conditions), and supporting experimental work re: manipulation of harvest date by agronomic practices.

The following description of the biophysical modelling component of the project was provided by Neil Huth and Allen Peake, CSIRO, Toowoomba.

The APSIM Model

APSIM (Keating et al., 2003) is a cropping systems modelling environment specially designed to allow a plug-in-pull-out approach for the integration of various simulation models via a common modelling protocol (Moore et al., 2007). It is a product of the Agricultural Production Systems Research Unit (APSRU). APSIM can be configured with modules suitable for the simulation of many different systems. Whilst these initially concentrated upon dryland cropping systems, APSIM’s usage has broadened and now it is also being used in the study of forestry (Paydar et al 2005), agroforestry (Huth et al 2002) and pasture (Snow et al 2007) systems. As part of this project, the development of horticultural crop models for broccoli, sweet corn, lettuce and French bean have now been initiated. As part of the standard APSIM development protocols, the source code, parameterisations and test datasets have been included within the APSIM open source version control system and are freely available for further development and testing by other APSIM users.

The APSIM French Bean Module

The APSIM French Bean model has been developed using the APSIM Plant2 development framework (Holzworth and Huth, 2009). Whilst many concepts and parameters were available from previous development of the APSIM Navy Bean model (also *Phaseolus vulgaris*) a suite of experimental studies were undertaken to provide further detailed information on growth, development, leaf appearance and resource use by French Bean. A brief summary of the experimental program and measurements undertaken is described below.

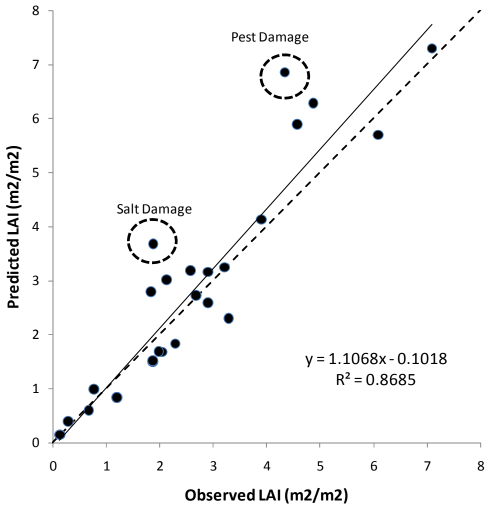
Table 11. Experimental Program used to generate data for development and testing of the APSIM French Bean Model.

			Measurements Undertaken						
Location	Sowing Date	Harvest Date	Phenology*	Biomass Partitioning**	Leaf Area+	Canopy Development++	Yield#	Soil Water##	Nitrogen Partitioning&
CSIRO, Gatton, Qld.	1-Oct-08	5-Dec-08	✓	✓	✓	✓	✓		
	21-Oct-08	n/a†	✓						
	10-Nov-08	n/a†	✓						
	16-Dec-08	11-Feb-09	✓	✓	✓		✓		
	6-Jan-09	9-Mar-09	✓	✓	✓	✓	✓		
	25-Feb-09	20-Apr-09	✓	✓	✓	✓	✓	✓	
DEEDI, Gatton, Qld.	9-Mar-09	11-May-09	✓	✓	✓	✓	✓		
NSW DPI Yanco, NSW.	16-Feb-09	28-Apr-09	✓	✓			✓	✓	✓

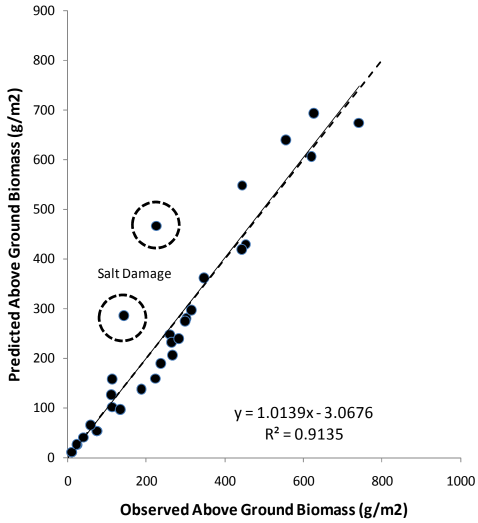
† Crops damaged by extreme flooding
*Sowing, emergence, flowering, harvest dates
** Mass of green leaf, dead leaf, stem and pod.
+ Green leaf area index (LAI)
++ Total, green and senesced leaf numbers per plant and number of main stem nodes.
# Marketable and nonmarketable pod fresh mass
Temporal variation in soil water content
& Nitrogen concentration in green leaf, dead leaf, stem and pod.

Model Development and Testing

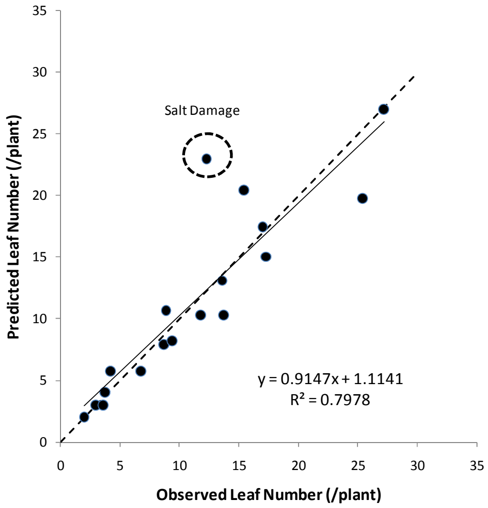
Data from the above-mentioned experiments was used to derive models and parameters for canopy development (leaf appearance, expansion, senescence, branching), partitioning of assimilate, changes of nitrogen content of organs during crop development, resource use (water, light, nitrogen) and yield determination. Much of the model structure was taken from previous work on field crops. The model was configured to simulate each of the experimental datasets and the results are shown below. In most cases, the model was able to capture the variation in the data. Most of the error in the following graphs of predictions versus observation is above the 1:1 line (dotted line). This indicates a prediction that is higher than observation. In most cases, these data are associated with factors that are not captured by the model (salt, flood or pest damage; flower abortion). This indicates that further work should be targeted at understanding and modelling the impacts of these extreme events and environmental conditions.



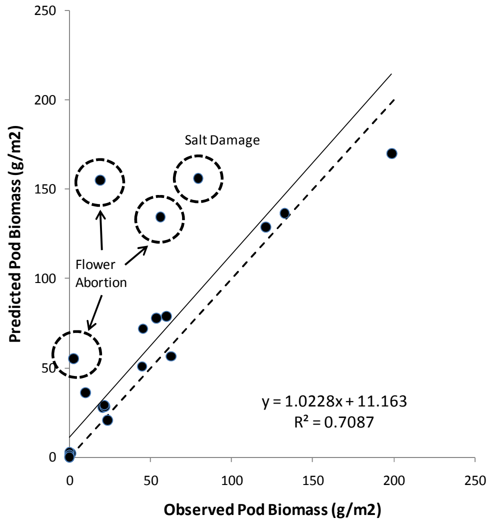
Predicted Vs Observed Leaf Area Index for datasets from Gatton. Outliers for plantings suffering from salt or flood damage are shown.



Predicted vs Observed Above Ground Biomass for datasets from Gatton and Yanco. Outliers for planting suffering from salt damage are shown.



Predicted Vs Observed Leaf Number for datasets from Gatton. Outlier for planting suffering from salt or flood damage is shown.



Predicted vs Observed Pod Biomass for datasets from Gatton and Yanco. Outliers for plantings suffering from salt damage, flood damage or flower abortion are shown.

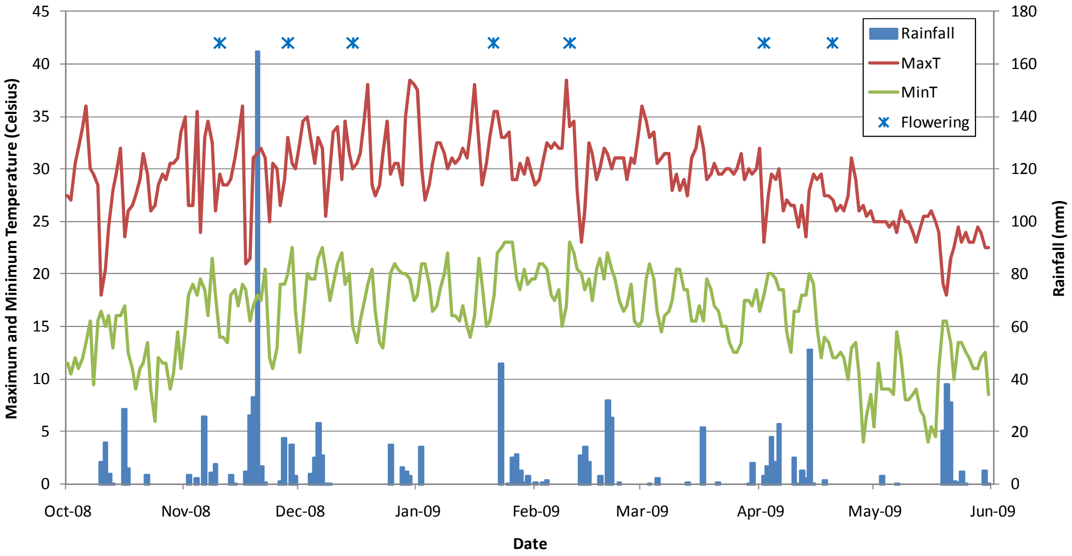


Figure 74. Plot of daily air temperatures and rainfall for the Gatton Research Station. Flowering dates for each of the Gatton plantings are shown (*).

Rainfall exclusion shelter used at CSIRO Gatton research farm for measurement of soil water extraction rates.

Beans at Gatton Research Station within the Lysimeter farm.

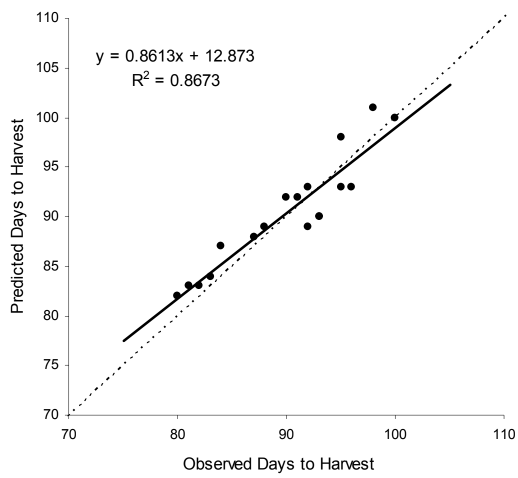
The APSIM Sweet Corn Module

The APSIM Sweet Corn model has been developed using the APSIM Maize model. The biggest challenge faced in the development of the sweet corn model related to the modelling of ear yield. The maize model has been designed to predict grain yield formation, but the *sh2* gene that gives sweet corn its sweetness but also means that sweet corn produces much less seed biomass. In addition to modelling total ear yield, it was also necessary to model the percentage of the ears that can be marketed (marketable yield), given that stress events can impact marketable yield heavily while having only a small impact on total ear yield.

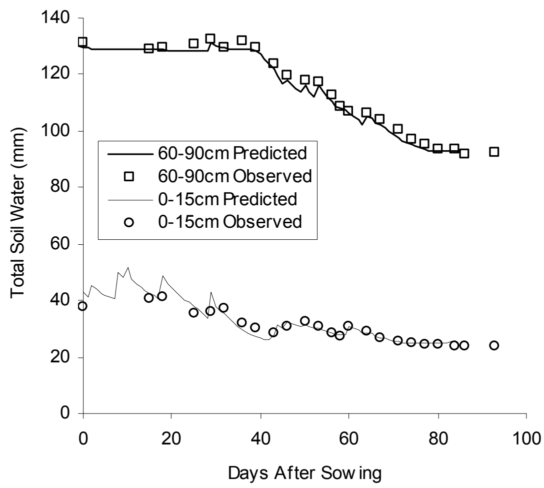
The graphs below demonstrate the ability of the sweet corn model to predict phenology (flowering date), total plant biomass, total ear biomass, marketable ear biomass, and soil water extraction. The final chart shows the range of moisture contents at which the experiments were harvested, to determine the optimum moisture content that fresh weight yields will be reported at (78%).

			Measurements Undertaken						
Location & Treatments	Sowing Date	Harvest Date	Phenology*	Biomass Partitioning**	Leaf Area^{+}	Canopy Development^{++}	Yield$^{\#}$	Soil Water$^{\#\#}$	Nitrogen Solute Soil Sampling
CSIRO, Gatton, Qld. *Timing of terminal stress*	13-Jan-09	30-Mar-09	✓	✓	✓	✓	✓	✓	
Mulgowie Farming Company *Lockyer Valley: On-Farm Monitoring*	28-Dec-05	11-Feb-06	✓	✓	✓	✓	✓		
	7-Feb-06	9-Mar-06	✓	✓	✓	✓	✓		
	24-Feb-06	20-Apr-06	✓	✓	✓	✓	✓		
DEEDI, Gatton, Qld. *Irrigation scheduling*	21-Nov-05	13-Feb-06	✓	✓	✓	✓	✓	✓	
3 Plant populations, terminal water deficit	21-Nov-05	12-Feb-06	✓	✓	✓	✓	✓	✓	
Lysimeter water use, 3 plant populations	19-Jan-10	15-Apr-10	✓	✓	✓	✓	✓	✓	
Nitrogen leaching	29-Jan-10	15-Apr-10	✓	✓	✓	✓	✓	✓	✓
QLD Wide Phenology Data Survey Bowen *(Data provided by DEEDI, HSR Seeds, Pacific Seeds)*	Various	Various	✓						
Lockyer Valley, Bonshaw *(Data provided by Mulgowie Farming Company, Pacific Seeds)*	Various	Various	✓						

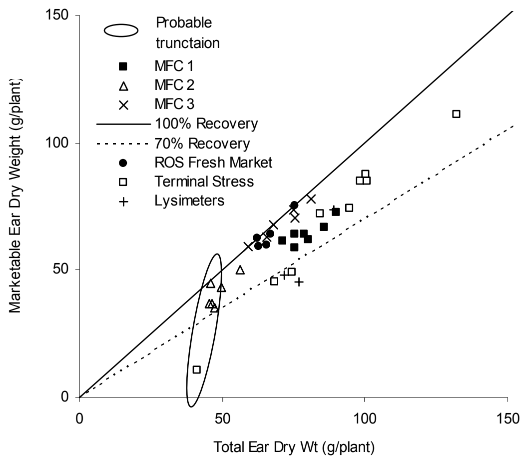
*Sowing, emergence, flowering, harvest dates
** Mass of green leaf, dead leaf, stem and ears.
$^{+}$ Green leaf area index (LAI)
$^{++}$ Total leaf numbers per plant.
$^{\#}$ Marketable and/or total ear biomass
$^{\#\#}$ Temporal variation in soil water content
$^{\&}$ Nitrogen concentration in green leaf, dead leaf, stem and ear.



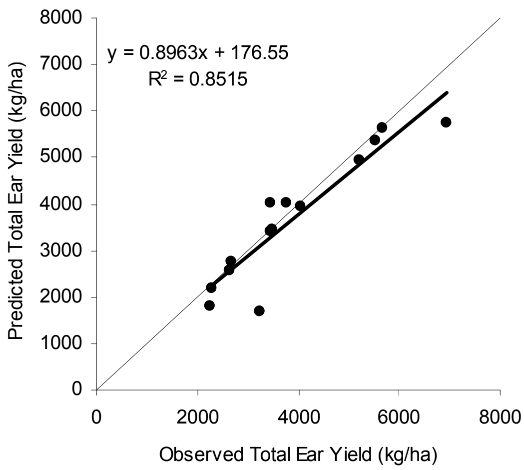
Predicted vs Observed harvest date for Pacific H5, data from Gatton, Bonshaw, Bowen.



Predicted and observed soil water from the terminal water stress experiment, for two soil layers in the 5.5 plants m^{-2} treatment



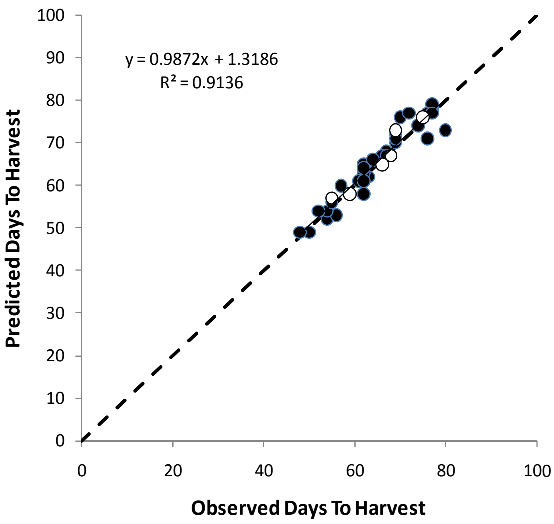
Marketable yield vs total yield for a range of experiments. The proposed truncation point indicates the likely point at which ears become too small to be marketable.



Predicted vs observed total ear yield for the range of experiments

The APSIM Lettuce Module

Several difficulties face the model development process when using the APSIM plant modelling framework to develop a lettuce model. Whereas all existing crop models within APSIM consider plants established using seed, lettuce can also be established using transplanted seedlings. There are also a large number of cultivars used within the industry, and those used in previous research are often outdated. Furthermore, the form of this plant species is very different to most field crops and so assumptions about canopy shape and leaf distribution are no longer valid. The development of an APSIM Lettuce model has commenced with an analysis of crop phenological data in an attempt to identify any trends or similarities in thermal time to harvest for a range of cultivars propagated using seed or seedlings.



Predicted vs Observed Days to Harvest for Iceberg Lettuce for Transplant (solid) and Seed (open) crops.

Propagation	Cultivar	Thermal Time
Transplant	Annie	775
	Aztec Sun	775
	Oxford	702
	Patagonia	712
	Raider	701
	Titanic	754
Seed	Raider	874
	Target	937

Table showing thermal time from sowing or transplanting to harvest for different cultivars.

Table 12. Summary of data used in development and testing of thermal time models for predicting time to harvest in lettuce.

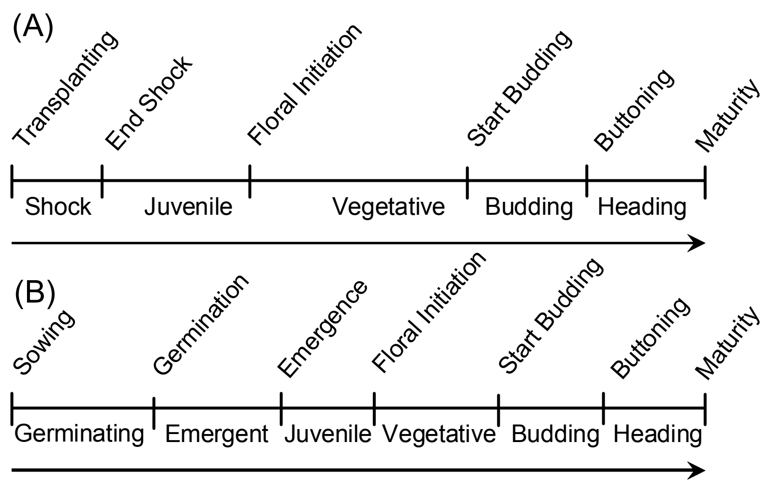
Propagation Method	Cultivar	Sowing Date	Harvest Date	Data Source*
Transplants	Raider	29-Mar-04	18-May-04	1
		30-Mar-04	17-May-04	1
		15-Jul-04	20-Sep-04	1
		16-Jul-04	20-Sep-04	1
		27-Jul-04	27-Sep-04	1
		12-Jul-01	17-Sep-01	2
	Oxford	27-Apr-04	29-Jun-04	1
		03-May-04	06-Jul-04	1
		18-May-04	26-Jul-04	1
		12-Jul-01	18-Sep-01	2
	Titanic	26-May-04	11-Aug-04	1
		07-Jun-04	23-Aug-04	1
		12-Apr-07	05-Jun-07	2
		16-May-01	19-Jul-01	2
	Annie	03-Apr-07	29-May-07	3
		11-Apr-07	04-Jun-07	3
		17-Apr-07	11-Jun-07	3
		24-Apr-07	15-Jun-07	3
		17-Jul-07	24-Sep-07	3
		26-Jul-07	28-Sep-07	3
		01-Aug-07	02-Oct-07	3
		08-Aug-07	08-Oct-07	3
	Patagonia	02-May-07	28-Jun-07	3
		09-May-07	10-Jul-07	3
		15-May-07	23-Jul-07	3
		23-May-07	01-Aug-07	3
		30-May-07	10-Aug-07	3
		05-Jun-07	20-Aug-07	3
		12-Jun-07	28-Aug-07	3
		22-Jun-07	04-Sep-07	3
		25-Jun-07	13-Sep-07	3
		03-Jul-07	17-Sep-07	3
	Aztec Sun	09-Aug-07	10-Oct-07	3
		14-Aug-07	15-Oct-07	3
Seed	Raider	25-Jan-08	20-Mar-08	4
		1-Feb-08	31-Mar-08	4
	Target	8-Feb-08	14-Apr-08	4
		15-Feb-08	23-Apr-08	4
		22-Feb-08	1-May-08	4
		27-Feb-08	12-May-08	4

1=M.Titley, Gatton Qld. 2=C.Henderson, Gatton Qld. 3=Commercial plantings, Lake Clarendon, Qld. 4=T. Napier, Hay NSW.

The APSIM Broccoli Module

APSIM-Broccoli calculates plant growth, development and water use on a daily time step. Predictions of phenological development emerge from calculations of various growth processes. For example, time to floral initiation is calculated from thermal time adjusted for accumulated vernalisation from germination or transplanting, and time to buttoning is dependant upon the thermal time required for the appearance of all leaves initiated prior to floral initiation. Photosynthesis is calculated using a light use efficiency, which is affected, by temperature, water and nitrogen stresses. A simple phytomer approach is used for canopy development where each successive leaf on the main stem is defined in terms of the length of its growth, lag and senescent phases. Assimilate is partitioned to individual leaves based upon daily growth rates determined by temperature-dependant leaf expansion processes. Canopy water demand is calculated using a Penman-Monteith formulation within the APSIM Micromet module (Snow and Huth, 2004). Extraction of soil moisture to satisfy this demand is calculated using the approach of Meinke et al. (1993).

The basic model of phenological development is illustrated in the following figure. Thermal time is used to describe the rate of crop development through these growth phases. A different phenological model is applied for sown and transplanted crops. The duration of each growth phase is dependant upon several parallel processes. The duration of the juvenile phase is dependant upon accumulated vernal days (T_{min} 0°C, T_{opt} 2°C, T_{max} 15°C) as described by the vernalisation model of Robertson et al. (2002). The duration of the vegetative phase is calculated from the number of leaf primordia produced prior to floral initiation and a leaf appearance rate. The remaining growth phases have fixed thermal time durations.



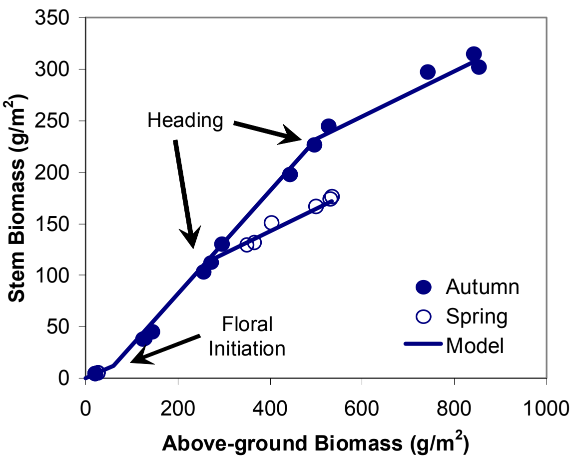
APSIM-Broccoli Phenological Stages and Phases for a) transplant, and b) sown crops

Canopy development is calculated using a phytomer-based approach. Leaf appearance on the main stem is calculated using a fixed leaf appearance rate, or phyllochron, expressed on a thermal time basis. Final leaf number is calculated in a similar manner using accumulated thermal time since germination, assuming three leaf primordia are present in the seed at germination. Once a leaf emerges, it goes through three distinct growth, lag and senescent phases. The duration of the growth phase increases with node number on the main stem and can be equated to the number of expanding leaves observed on the plant when that particular node completes expansion. Duration of the senescent phase has been set to 200 degree days and the remaining duration of the lag phase is fitted to observations of leaf senescence.

Daily growth in plant biomass is calculated from daily intercepted shortwave radiation using a light use efficiency, which is affected, by various soil and climatic factors. In these analyses, only temperature and water supply are assumed to be limiting although the model can account for other limitations such as inadequate nutrition. Interception of solar radiation is computed assuming an exponential decay of light within a canopy. Daily biomass production is partitioned into the various plant organs (Leaf, Root, Stem, Floret) using partition fractions which change with crop growth stage. For example, the following figure demonstrates the changes in partitioning of growth into stem for Autumn or Spring grown Broccoli. Prior to floral initiation, 20% of above ground growth goes into stem. This increases to 50% during the vegetative phases but then decreases to 22% once heading commences

This model description has been also described in more detail in Huth et al (2009).

Partitioning of above-ground biomass into stem across growth phases for Autumn or Spring crops of Broccoli grown at Gatton in 2006 (see experiment descriptions)



Model Development and Testing

The APSIM Broccoli model has been developed using the APSIM Plant2 development framework (Holzworth and Huth, 2009). Whilst many concepts and parameters were available from previous development of the APSIM canola model (*Brassica napus*) some of experimental studies were undertaken to provide further detailed information on growth, development, leaf appearance and resource use by broccoli. Some high quality datasets on phenological development were also collated. A brief summary of the experimental program and measurements undertaken is described below.

Table 13. Experimental Program used to generate data for development and testing of the APSIM Broccoli Model.

			Measurements Undertaken					
Location	Treatments	Sowing Date	Phenology*	Biomass Partitioning**	Leaf Area+	Canopy Development++	Yield#	Soil Water##
DEEDI, Gatton, Qld.	3 Irrigation Regimes	4-Apr-06	✓	✓	✓	✓	✓	✓
	3 Irrigation Regimes	29-Jun-06	✓	✓	✓	✓	✓	✓
	Single Crop	20-Jul-09	✓	✓	✓			
UQ, Gatton, Qld. (Tan et al, 2000)	3 Cultivars x 8 Sowings	11-Mar-97 To 22-May-97	✓			✓		
Brookstead, Qld. (Tan et al, 2000)	60 commercial sowings		✓			✓		

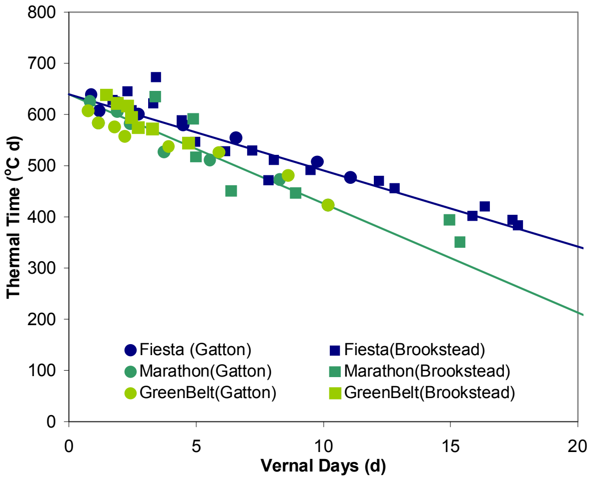
*Planting, buttoning, harvest dates
** Mass of green leaf, dead leaf, stem and head.
+ Green leaf area index (LAI)
++ Total, green and senesced leaf numbers per plant and number of main stem nodes.
# Marketable and nonmarketable head fresh mass
Temporal variation in soil water content

Photo of broccoli irrigation trial at Gatton Research Station on 8th September 2006 showing position of rainfall exclusion tent.

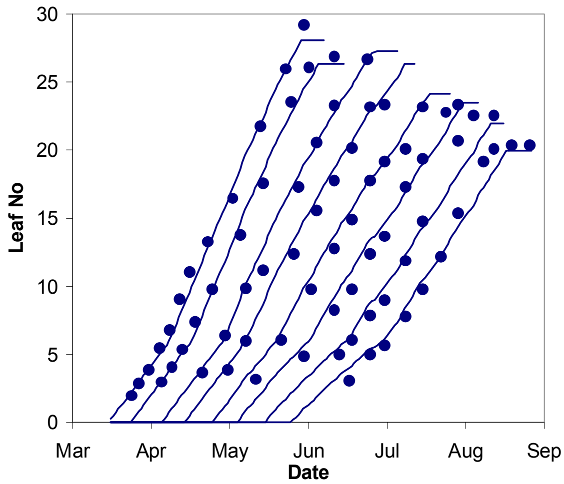
Rainfall exclusion tent used in the measurement of the lower limit of plant extractable soil moisture for broccoli.

The data of Tan et al. (2000) provides a large and detailed dataset for model development and testing including timing of emergence, floral initiation, maturity and leaf appearance for three Broccoli cultivars at two locations (Gatton and Brookstead) encompassing a wide range of sowing dates. Accumulated thermal time and vernal days was calculated for each crop from germination (assumed 1 day after sowing) to floral initiation. Cardinal temperatures for vernalisation were taken from Robertson et al. (2002). Accumulated thermal time from emergence was compared with regular counts of visible leaf number. Base, optimum and maximum temperatures for development were optimised to maximise the proportion of the variation accounted for in estimates of timing of floral initiation and leaf appearance.

The following figures demonstrate some of the results for the proposed model. The fitted cardinal temperatures (T_{base} 5°C, T_{opt} 25°C, T_{max} 35°C) enable the model to describe both crop development and leaf appearance on a common thermal time basis. Tan et al. (2000) showed the absence of a photoperiod response in broccoli and applied a simple model with a fixed thermal time requirement for floral initiation. Both the floral initiation and final leaf number data of Tan et al (2000) indicate a likely vernalisation response in broccoli, which was not available in the model used by the original authors. The incorporation of a vernalisation sub-model into the overall phenological model within APSIM-broccoli explains not only the timing to key growth stages such as floral initiation, but helps to explain the variation in leaf numbers between planting dates. It also suggests that all of the cultivars may share a common thermal time requirement prior to vernalisation but may only differ in their vernalisation response (i.e. common intercept but different slope in the first figure). Moreover, two of cultivars seem to share a common vernalisation response. These two points significantly reduce the burden of parameterisation for phenological development.



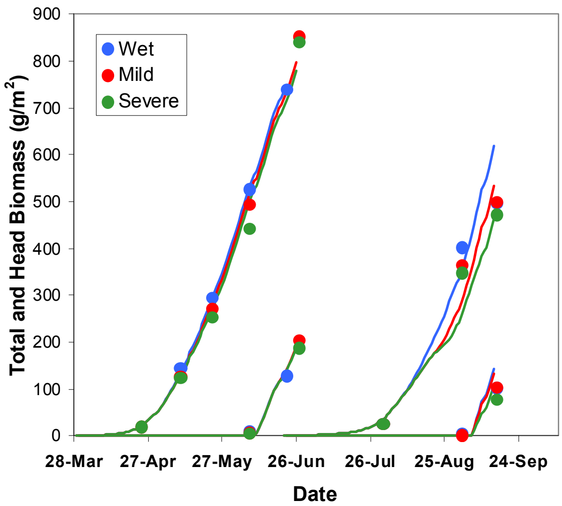
Change in thermal time from sowing to floral initiation as affected by accumulated vernalisation for three cultivars at Gatton and Brookstead in 1997.



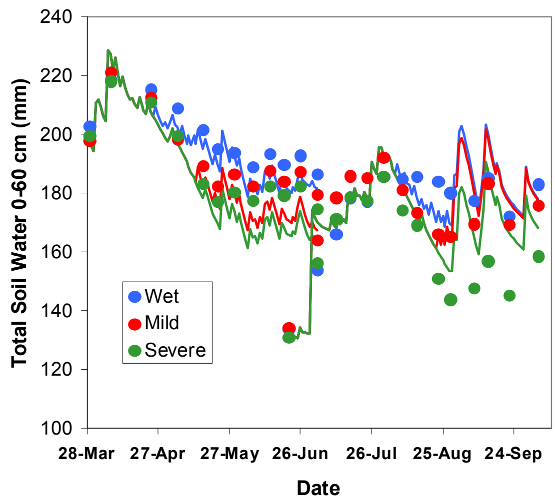
Observed and Predicted impact of time of sowing on leaf appearance rates and final leaf numbers for Broccoli (cv. Marathon) grown at Gatton in 1997.

Experiments conducted at the Queensland Department of Primary Industries and Fisheries Gatton Research Station (27.55° S, 152.33° E) were used to study the impact of differing levels of water stress on broccoli growth, development and yield. Two planting dates were used: 4^{th} April 2006 and 29^{th} June 2006. Three water regimes were established for each planting. The first provided a water non-limiting control. The second sought to induce a mild mid-season water stress condition by withholding irrigation for several weeks. The final treatment sought a severe water stress condition by withholding irrigation for a longer duration but ensuring stress was relieved before buttoning. Soil water content was monitored using a Neutron Moisture Probe. Biomass production and canopy area was measured via destructive sampling through the season. Leaf appearance and expansion of individual leaves was monitored on nine tagged plants within each treatment. Weather data was collected from the on-site meteorological station.

The model is able to adequately describe the growth of broccoli under the different irrigation and climatic conditions experienced within the experiment. The following figures shows that the predicted time course of crop biomass is generally well captured, apart from a slight underestimate of treatment response within the first sowing, and an overestimate of the treatment response in the second sowing date. The reasons for this are likely demonstrated in the figures. Water use is overestimated in the autumn sown crop and underestimated in the spring-sown crop. Simple sensitivity analyses and investigation of the model output indicated that the amount of water lost to evaporation from the soil surface was an important determinant of crop growth in such a drought-sensitive crop. In these systems, planting bed design and planting geometry as well as trickle irrigation placement can impact on evaporation losses. The simple one-dimensional description of the system used in the current model may be inadequate to describe this. Similarly, trickle irrigation systems with broccoli result in a partial root system wetting as only the inner section of the bed is watered. This is likely to impact on crop water extraction and water stress levels. The following figure shows that the first crop stressed at higher water contents than the second crop. This is likely due to gradients across the crop bed. A simple two-dimensional spatial capability is possible in APSIM and has been used to study tree-crop interactions, including spatial variation in tree root water uptake (Huth et al., 2002). We would suggest that this should be employed in future simulations to see if this can assist in describing the changes in irrigation efficiency of these systems.



Observed and predicted total crop biomass and head/floret mass for three irrigation regimes and two sowing dates at Gatton in 2006.



Observed and predicted total soil water to 60 cm depth for three irrigation regimes and two sowing dates at Gatton in 2006

Demonstration of APSIM for Evaluating Irrigation Practices

A French Bean Scenario analysis was performed for presentation to a group of farmers and industry representatives at the Gatton Research Station project field day. The aim of the scenario analysis was to determine the value of the various soil water monitoring and irrigation scheduling approaches being tested as part of this project. APSIM was used to simulate the water requirements, deep drainage and leaching losses for French Bean crops planted across the sowing window for Gatton, Qld. Two irrigation regimes were evaluated: 1) A fixed weekly irrigation schedule where irrigation is applied on a purely calendar basis, and 2) a flexible irrigation schedule where irrigation timing and volume were determined via knowledge of the field soil water conditions. Improvement in water use and drainage or leaching losses would demonstrate the value of soil monitoring for irrigation management on farms.

The model was configured using soil data gathered for the Gatton Research Station during monitoring of previous experimental horticultural crops. Simulations were performed for crops sown each month from September to February in every year from 1970 to 2000. Cultivar *Simba* was sown at 25 plants/m^2 at 75 cm row spacing. Fifty kg/ha of nitrogen as urea was applied to each crop at sowing and supplemental fertiliser was applied 30 days later as required to raise soil mineral nitrogen levels in the surface 60 cm to 150 kg N/ha. Twenty millimetres of irrigation was applied at sowing for all crops. Forty millimetres of water was added at the end of each week in the fixed irrigation scenario. Irrigation management in the flexible scenario was designed to mimic targeted irrigation volumes derived from monitoring with tensiometers. Irrigation was applied whenever the soil water content of the 15-30 cm soil layer decreased below drained upper limit (c. 10 kPa). The volume of irrigation applied was calculated as that amount required to restore the soil profile to drained upper limit to a depth of 30 cm.

The simulations suggest that the flexible irrigation management option could significantly reduce irrigation water volumes in January and February in many years. Losses of water via deep drainage were approximately halved in most years with a similar reduction in nitrate leaching. These results suggest that careful irrigation management, using soil monitoring techniques, should prove very effective in improving irrigation efficiency and decreasing environmental impacts.

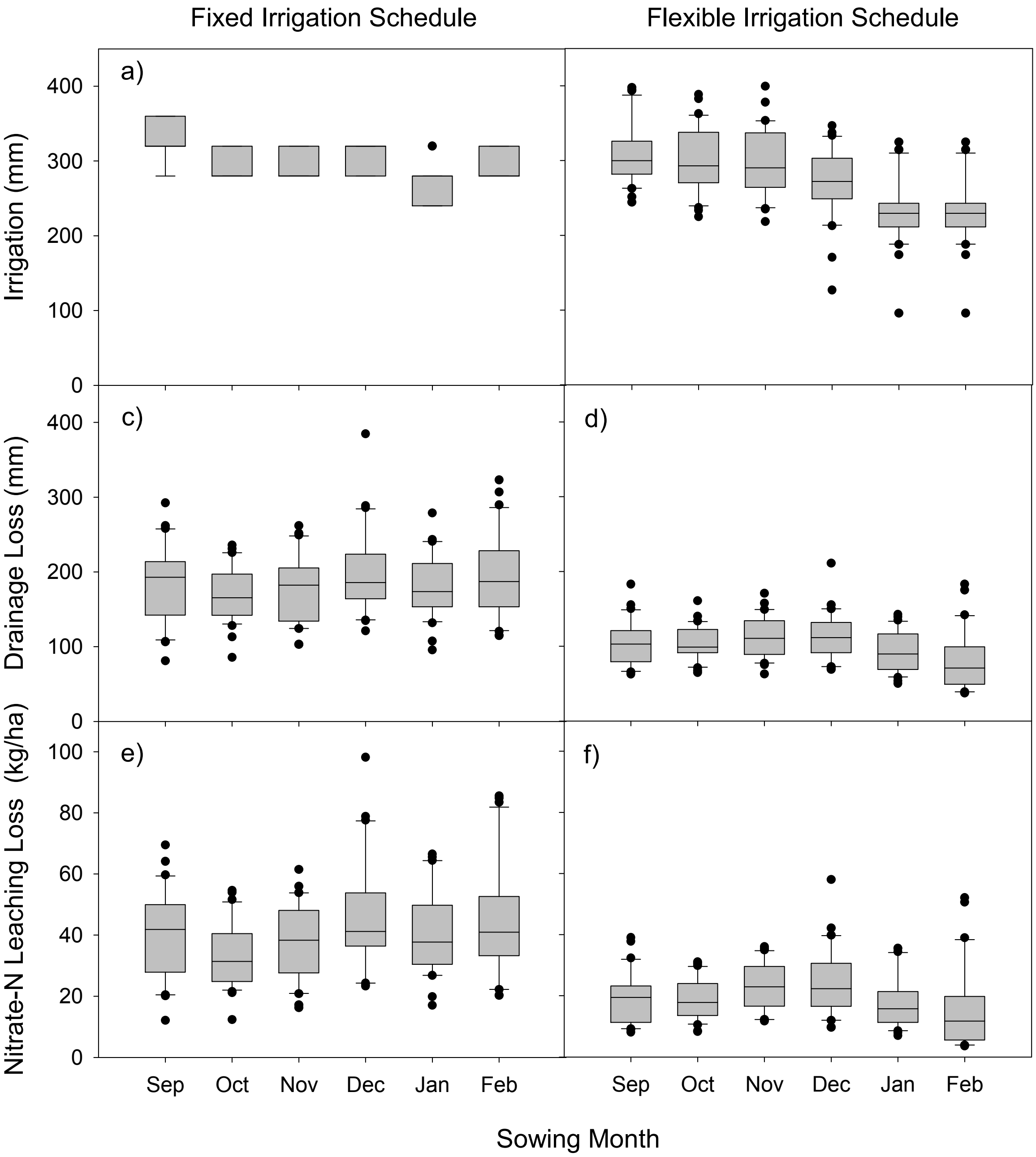


Figure 75. Simulation results for the Fixed and Flexible Irrigation scenarios performed for Gatton (1970-2000) for French Bean sown September to February. Results include total irrigation water (a,b), deep drainage loss (c,d) and nitrate leaching losses (e,f) for Fixed irrigation scheduling (a,c,e) and Flexible irrigation scheduling (b,d,f).

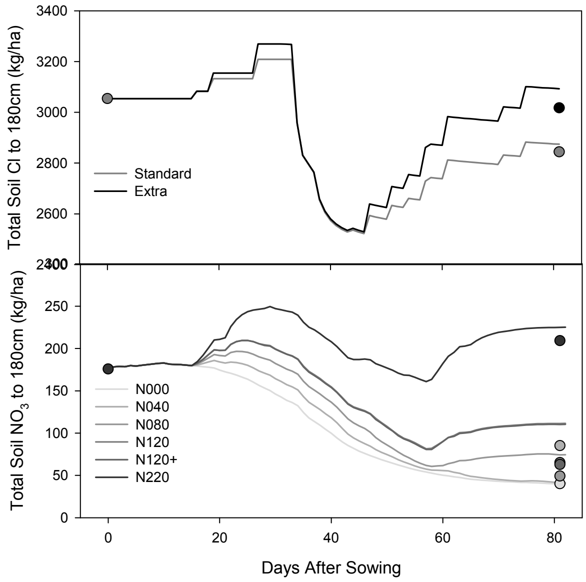
Demonstration of APSIM for Analysing Experimental Results.

Simulation tools such as APSIM provide a great means for exploring experimental results and testing various hypotheses for explaining crop behaviour. Mechanistic models allow the experimentalist to study complex plant and soil processes, many of which are very difficult to measure in the field. In this example, we use APSIM to explore the water balance and leaching processes that would have occurred during an irrigation management trial for Sweet Corn conducted at the Gatton Research Station, Qld in 2010. This experiment has been described in detail elsewhere in this report.

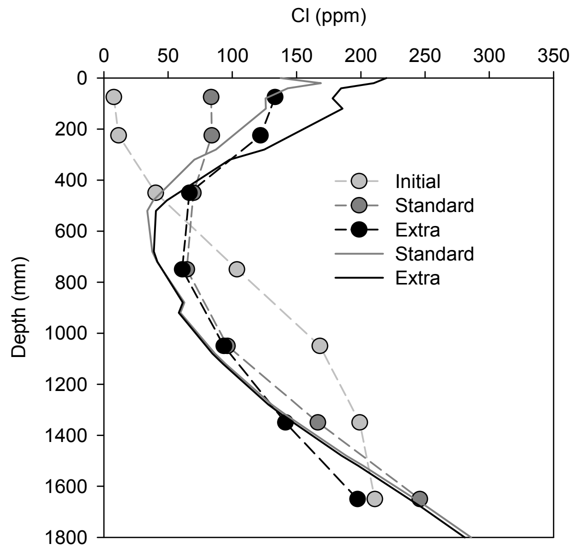
Weather data was obtained from the GRS automated weather station. Soil properties were obtained from measurements taken during sweet corn trials performed on neighbouring fields as part of this project. Irrigation timing and volumes were applied in the model as recorded for the trial. The model was used to simulate leaching of nitrate and chloride within the soil profile. Large amounts of chloride exist within the soil profile as a result of the salt content of irrigation waters. Chloride is often used as a chemical tracer for soil water movement and so the ability of the model to capture changes in soil chloride distribution will give confidence in predictions of soil water balance. Two irrigation volumes were used within the experiment (standard, extra) and this would represent two levels of chloride accession via irrigation water. The concentration of nitrate in the soil water solution at two depths (15 cm and 60 cm) was monitored using soil water solution samplers. Model predictions for nitrate concentration in the soil pore water were therefore calculated for these two depths.

The model was able to capture the overall chloride balance in the whole soil profile (0-180 cm) for the two levels of irrigation water. Though measurements are only available for pre sowing and post harvest conditions, the model suggests that large fluctuations in chloride would have taken place due to additions in irrigation water and leaching of salts during a period of high rainfall half way through the crop season. The model was able to capture the significant changes in chloride distribution within the soil profile (0-180 cm). These give confidence that the model is adequately capturing the overall water balance and redistribution of these waters within the soil profile.

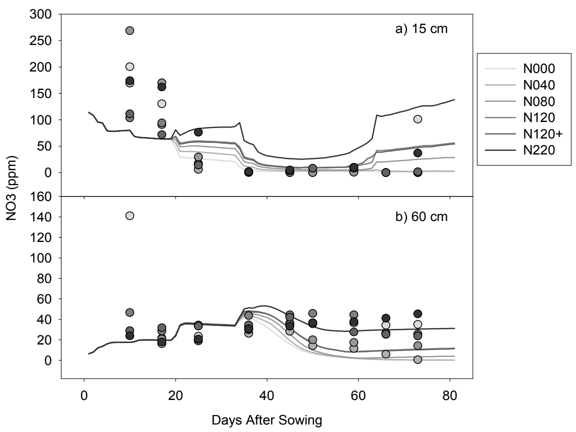
The model was also able to capture the variation in nitrate concentration in the soil water at the different depths. There are many reasons for discrepancies between prediction and measurement of these values. The soil solution samplers take some time to equilibrate with the soil pore space and this is reflected in the large variation between treatments early in the season before treatment effects should be expected. Later in the season, the small soil sampling volume of the solution samplers could cause some differences with simulated values for the entire soil volume at each depth. However, once the samplers had settled in, there is a fair level of agreement with simulated results. This demonstrates the value of the model for evaluating the data quality of instruments after installation.



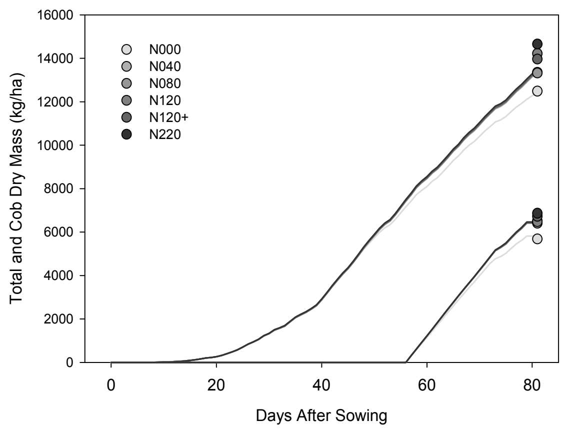
Predicted and observed time courses in total soil chloride and nitrate-N to 180 cm depth.



Initial soil chloride profile and predicted and observed soil chloride after harvest for the standard and extra irrigation water treatments.



Predicted and observed time courses of measured soil solution nitrate-N concentration at 15cm and 60cm depths.



Predicted and observed time courses of total and cob dry mass for the various irrigation treatments.

Further model development needs

Models of phenological development including key growth stages have been successfully developed for all four horticultural crops. Currently, all models except the lettuce model have been developed to a point at which they can be effectively employed in studies of irrigation water demand. Some of this has been demonstrated in this report. In the case of the lettuce model, further enhancement of the APSIM framework would be required to simulate such a horticultural crop.

Model	Model Functionality							
	Phenological Development	Biomass Production	Canopy Development	Nitrogen Uptake	Dry Mass of Yield Component	Marketable Yield	Soil Water Extraction	
Sweet Corn	✓	✓	✓	✓	✓	✓	✓	
Broccoli	✓	✓	✓		✓		✓	
French Bean	✓	✓	✓	✓	✓		✓	
Lettuce	✓							

Other model limitations identified within this project are as follows:

- Marketable yield prediction for Broccoli and French Beans. Currently only dry mass of head and pods is available. Further research would be required for developing models of size distributions.

- Impacts of extreme weather conditions. High temperatures and rainfall can impact on total yield and marketability. This has especially been demonstrated for the French bean datasets. Such models will need to be developed, however insufficient data currently exists in a form suitable for model development.

- Model parameters for new genotypes. The use of new cultivars is rapid in the horticultural industry, particularly for lettuce and broccoli. The parameter sets currently developed for these crops may become outdated. This issue is being addressed within the APSIM community for wheat via the development of methods that map genetic traits to model parameter sets. A similar approach could be employed with horticultural crops.

Availability of the APSIM models for further use

The APSIM Initiative (AI) aims to encourage entrepreneurial research and development by all interested parties through broad licensing of the APSIM Software. APSIM is available either for non-commercial or commercial purposes, through the APSIM Community Source Framework. Through this framework, the intent is to develop a high quality and enduring agricultural production systems modelling platform with global reach. APSIM may be used for applications in agricultural systems, for developing science-based enhancements to the modelling capability, or a combination of both. All access will be through approved licence agreements.

For non-commercial purposes, access to APSIM will be free of charge to approved third parties, who in turn relinquish ownership of improvements to the AI. Non-commercial use of APSIM means public-good research & development and educational activities. It includes the support of policy development and/or implementation by, or on behalf of, government bodies and industry-good work where the research outcomes are to be made publicly available. The AI will provide regular official releases of APSIM free of charge for non-commercial use to those who agree to the terms of the license agreement.

The AI enables developments in agricultural systems modelling to be captured more rapidly and effectively within the APSIM infrastructure, regardless of membership. Specifically the Objectives are to:

1. Create a joint venture of research bodies that wish to lead and contribute to the ongoing development and use of APSIM;

2. Co-develop and manage APSIM as a high quality, world class research tool in its field and;

3. Ensure that APSIM is developed by the facilitation of broadly based collaborative science.

To achieve these objectives the AI provides:

•An open and transparent 'APSIM Community Source Framework' (a modified Open Source Framework) facilitating broadly based collaborative science;

•Best practice Software Development and Maintenance;

•Science quality control;

•Free public good licensing (for R&D, extension and educational use);

•Commercial licensing (authorised by the AI Steering Committee)

•APSIM Training (as a fee for service activity)

•APSIM Support (via a web based support forum)

Further information can be obtained from the APSIM web site (www.apsim.info).

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Evaluation of other irrigation enabling technologies

Key findings

- Most of the irrigation monitoring tools were suited to use and interpretation by experienced consultants, rather than vegetable producers.

- Technologies/sensors that generate maps or images are very popular. They help with planning, as well as provide a picture that stimulates discussion. In conjunction with personal contact, they have proven to be the best way of communicating with clients.

Plant-based sensing

- For vegetable cropping, plant-based sensing tools are still mainly research focussed, with little obvious application in production. Leaf and fruit dendrometers may be simple and reliable enough for monitoring some crops, although there are still issues with being point source measurements and their cost effectiveness.

EM38

- A commercial priority is the development of practical protocols for using EM38 equipment to analyse field variability and irrigation/soil management practices. Research by colleagues suggests there may be more opportunities for profitably using this equipment than we first recognised – such as irrigation design and installation, correct placement of monitoring equipment, and in the future, implementation of precision horticulture systems.

- The equipment can involve vertical and horizontal mapping to elucidate treatment impacts, such as the addition of polyacryalmide soil conditioners to extend time between irrigations, and improve uniformity of moisture improvement. Another example is identifying areas with increased risk of waterlogging, and thus disease susceptibility.

NDVI

- The most common rendition used by our project team is a series of active Greenseeker™ sensors towed behind a quad cycle, operating at heights of 1-3 m. Active sensors (using a calibrated light source) are preferred to passive sensors using incident light. The latter can only be used at suitable times of the day, and require ongoing calibration to current light levels. Tow-behind systems are better able to be onsite at a time suitable for the producer, as well as to relate to immediate problems needing diagnosis. If the NDVI systems are being used to assess percent effective cover, tow-behind systems need to be able to correct for crop height; therefore require additional sensors to NDVI.

PIMS and DSL

- These are both excellent diagnostic tools for consultants to evaluate irrigation system performance and problem solve. In high value infrastructure, they can also be integrated as monitoring/warning tools, to identify component irregularities, before major failure.

Plant-based sensors

We undertook an initial international literature review of plant-based sensors for monitoring crop stress, and a scientific review describing vegetable plant physiological responses to water stress, including how those responses impact on vegetable yields and quality. Our rationale was to understand which measurement tools best help us assess those processes, and thus which are likely to be worth further evaluation. We followed that up with a review of plant-based sensors available in Australia for research and commercial purposes. This review is nearly completed; it is currently being updated with latest availability and pricing information. It will be published via the DEEDI and SEQIF irrigation resource websites; the initial reviews were already published on the Horticulture Water Initiative website.

The summary from the physiological review is extracted below, whilst the contents pages for the sensor review are included overleaf.

There is also an example case study from South Australia, where we interviewed IDO Michael Cutting for his views on the use of dendrometers in vegetable production.

Isohydric and anisohydric characterisation of vegetable crops: The classification of vegetables by their physiological responses to water stress - Summary

Research on the physiological response of crop plants to drying soils and subsequent water stress has grouped plant behaviours as *isohydric* and *anisohydric*. Drying soil conditions, and hence declining soil and root water potentials, cause chemical signals—the most studied being abscisic acid (ABA)—and hydraulic signals to be transmitted to the leaf via xylem pathways.

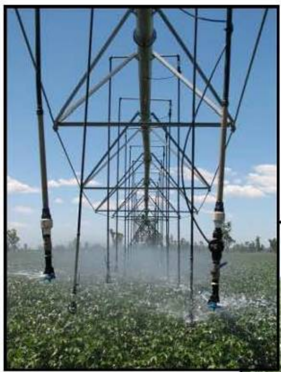
Isohydric responses occur when receptors in and around stomatal guard cells react to both these chemical and hydraulic signals to close stomata, and maintain leaf water potential, despite declining soil and root water potentials. The result is relatively constant leaf water potential, but declining stomatal conductance as the stomata are closed. Consequently, there is little initial relationship between soil water potential and leaf water potential.

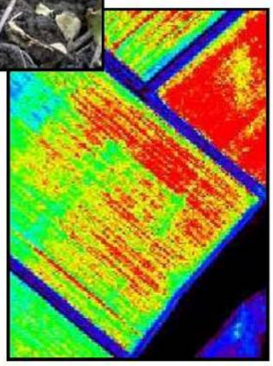
By contrast, anisohydric responses occur when receptors and guard cells do not react to hydraulic signals, but instead leaf water potentials decline in sync with declining soil and root water potentials, with little initial control of stomatal conductance. In anisohydric behaviour, there is a good initial relationship between soil water potential and leaf water potential.

In deciding what plant-based measurements may be useful in making irrigation decisions, the above discussion is important. For example, it would be sensible to focus plant-sensing using leaf water potential on vegetables showing predominantly anisohydric behaviour. Another example may be the use of regulated deficit irrigation—predominantly anisohydric vegetables may be at greater risk of sudden yield or quality deterioration, due to their less regulated stomatal control.

Researchers have attempted to allocate crops as isohydric or anisohydric. However, different cultivars within crops, and even the same cultivars grown in different environments/climates, can exhibit both response types. Nevertheless, understanding which behaviours predominate in which crops and circumstances may be beneficial. This paper describes different physiological water stress responses, attempts to classify vegetable crops according to reported water stress responses, and discusses implications for irrigation decision-making.

Plant Based Sensing for Irrigation Scheduling: An information package for vegetables



SC White, S Limpus, CW Henderson and SR Raine

Disclaimer

Note all prices and costs in this report are indicative only and given in Australian dollars as at March 2011

TABLE OF CONTENTS

Plant based monitoring for irrigation scheduling in vegetable horticulture - A case study in South Australian onions

(Experiment report prepared for circulation via online placement

Sarah Limpus and Michael Cutting

Gatton Research Station, Agri-Science Queensland

Summary

Direct measurement of plant water status for irrigation scheduling may be more sensitive, and promote better horticultural crop quality, than indirect methods such as soil moisture monitoring. In our research project, we sought to identify instances where direct methods of plant-water status had previously been used in horticultural crops in Australia. We present the outcomes, suitability or obstacles for adoption by horticultural producers. This report presents a case study from the point of view of researcher Mr Michael Cutting, from the Murray-Darling Basin Natural Resources Management Board of South Australia. He used a stem and bulb diameter sensor (Phytech Monitoring System – Phytech Limited) with several South Australian onion growers. The purpose was to ascertain whether the Phytech system was a more accurate method for irrigation scheduling in onions than soil moisture monitoring. After four seasons of data collection, Mr Cutting and the growers involved had a better understanding of the water relations of the onion plant. They were also able to manipulate irrigation scheduling to achieve desirable crop quality outcomes ($/ML). In this report, Mr Cutting explains the suitability of the Phytech equipment for horticultural production. He discusses the problems overcome during the experiment. Some of the problems occurred in the communication between the sensors and the data collection device, or with the loggers themselves. The location of technical support and maintenance was also an issue. Finally, he talks about some of the issues that could prevent its adoption in horticultural production. These issues include the cost of the Phytech system and the need for multiple bulbs and plant monitoring to make irrigation management decisions.

Figure 76. The Phytech monitoring system in an onion crop (Photograph supplied by M. Cutting)

Introduction

In the pursuit to grow more food with more consistent quality, there has been a re-evaluation of past and recent research into plant-based monitoring for irrigation management. Many current grower-adopted methods of irrigation scheduling use evapotranspiration or soil moisture monitoring. However, these are indirect measurements of plant water status. They do not completely describe the status of the plant-soil interface, nor the plants internal environment. Monitoring of the plant's water status directly may give a more detailed and accurate picture of the plant's ability to continue it's productive processes (Jones 2004). Numerous plant-based devices have potential for irrigation management. However, few are investigated for their ability to be integrated into an actual production system regarding their performance, ease of use and ease of interpretation.

In our project, we sought to identify the current state of knowledge in plant-based water sensing for irrigated vegetable production, and develop priority areas for ongoing research and development. Part of this role is to validate case studies where plant-based sensing technology is used in irrigation management in vegetable crops. However, instances where these devices are tested or incorporated into commercial vegetable production in Australia (rather than as research tool) are limited.

We developed this case study after we found that a researcher, Mr Michael Cutting (Murray-Darling Basin Natural Resource Management Board of South Australia) had several years experience with a plant monitoring system developed by an Israeli company, Phytech Limited. A number of Phytech systems [seen here in Fig. 76) were set up to monitor onion crops in South Australian with several growers involved. The purpose was to identify an alternative, more responsive method of crop monitoring for irrigation scheduling, compared to soil moisture monitoring. The following interview documents Mr Cutting's experience, thoughts and concerns, identified through the monitoring onion crops with this tool. A detailed description of this research can be found in "Plant Based Monitoring and Irrigation Management in Vegetable Crops: An Overview of Trials Conducted in the SA Murray-Darling Region" (Cutting 2008).

The monitoring tool

What kind of monitoring tool was utilised in the onion crop?

"Phytech Limited an Israeli Company, with Australian distributor trading as Isis Phyto Monitoring (www.phytech.com). The tool's components monitored "in canopy air temperature and relative humidity; soil moisture (single depth); stem diameter and 15-70 mm fruit (bulb) growth sensors (Fig. 77 display the stem and fruit sensors in crops]. Data was downloaded using a portable concentrator that extracts data from the field sensors (via radio link) and is then plugged into a computer and downloaded into specialised PhytoGraph software. In 2008 we purchased a field radio that automatically extracted data from the field sensors into which a laptop directly plugs to download the data."

Desired outcomes

What was the desired outcome of utilising this monitoring tool?

The first trial commenced in 2004 purely to see if the plant based system was an alternative to traditional soil moisture monitoring. The initial work focused on interpreting what the data was telling us rather than rigorous record keeping. However, in recent times, we have incorporated the data into more detailed trial works. We endeavoured to provide access to the equipment to as many growers as we could so that a range of different management practices could be captured.

“

Figure 77. Left: Photograph of the Phytech stem diameter sensor monitoring a capsicum plant and right: a fruit (or bulb) diameter sensor in greenhouse tomatoes. (Photographs supplied by VP Marketing, PhyTech Ltd.)

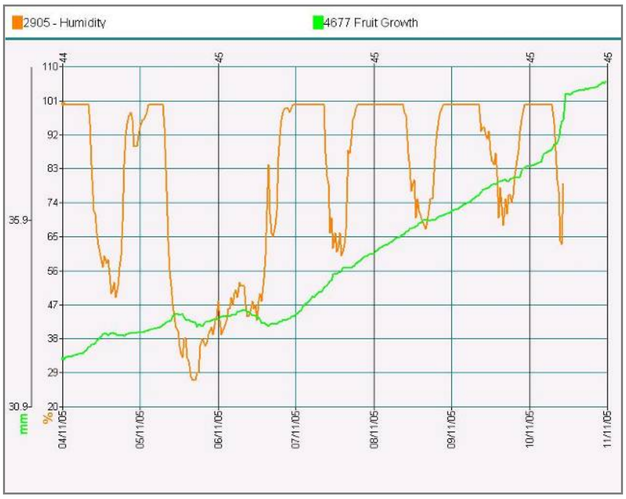
Now that we have four seasons of data, we do believe we have gained a much improved understanding of plant water relations and how to manipulate irrigation to generate desirable outcomes.”

The achievement of outcomes

Was the monitoring tool successful in achieving this outcome?

“The product certainly did prove a viable alternative to standard soil moisture based systems, and almost all growers involved in the work were impressed by the outputs of the system. Results did vary between growers and were largely a function of how willing the growers were to react to the information the system was showing them. Many growers involved in the trial continued with normal irrigation management practices, and therefore any changes that were observed could not be solely accredited to the system. The benefit of this however, was that clear growth response trends (both positive and negative) were observed between the different management regimes.

One particular grower was very reactive to the data and implemented significant changes to his management practices in response to the observed data trends. This grower utilised the strong correlation between onion bulb growth and humidity and scheduled irrigations to prolong humidity levels (this bulb vs. humidity relationship can be seen in Fig. 78 below). It should be noted that this is largely at odds with standard industry practices due to the increased disease pressure that such practices create. However, the resultant increases in yield and quality generated by this grower more than paid for the additional costs associated with enhanced disease control. In summary improved yields and quality (and hence $$/ML) were observed rather than significant reductions in water use (ML/ha)."



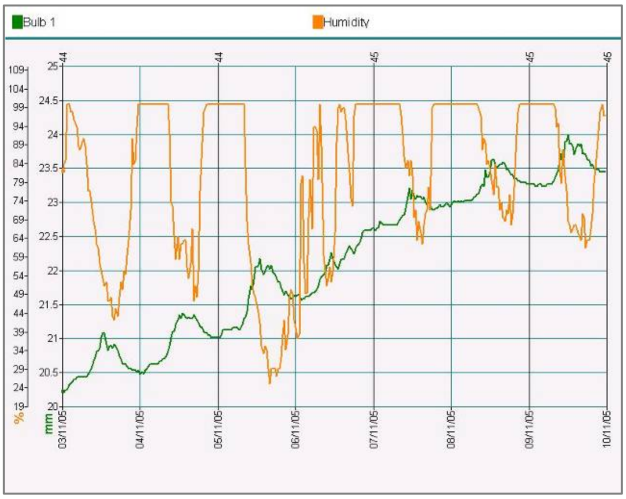


Figure 78. Graphs showing bulb growth response to humidity (Output of the Phytech monitoring system). Left: shows a consistent upward trend in bulb growth response from management practices that aim to keep the canopy humid and Right: shows bulb "stop-start" growth of an onion crop with the "standard" irrigation management. (Supplied by M. Cutting)

The potential use in horticultural production in Australia

In light of the monitoring tool's success, would you consider it as 'cost effective' in the long term?

"The Phytech system is not cheap, approximately $12-$15,000 for a system with a field radio and in reality, unless the cost reduces, wider uptake is likely to be low. However if you were to speak with growers that made good use of the system, they would likely say that the tool is cost effective.

From a Natural Resources Management Board perspective, I feel our investment in two of these systems has been very worthwhile, as we have been able to provide growers with exposure to a new system and learnt collectively about how the plant responds to different management practices."

How did you (or those working with you) find the monitoring tool's ease of use?

"The system does take a bit of work to set up but assuming communication is reliable, this is relatively seamless after you have done it a few times. Downloading from the field is also simple but the portable concentrator model requires that all the sensors be close together otherwise issues with communication can arise. In general, communication issues have been an endless source of frustration particularly now that the sensors are a few years old. This issue can dampen the enthusiasm of growers very quickly.

On-going issues with communication drove us to purchase a field radio station in 2008 at a significant cost (approximately $2,000) however; it did largely overcome the communication problems. Sensors have also stopped logging in the field at critical times during the growth cycle, which again disheartens growers when data gaps appear. On-going maintenance is likely to overcome many, if not all of the above issues, however technical support is in Brisbane, Queensland, so any time something needed to be sent away it was not a simple exercise. Having said this, the Australian representative was always available by phone to guide us through any technical issues we encountered, meaning the large majority were quickly resolved."

What is your opinion on the monitoring tool's adoption in a commercial production system?

"Personally I believe the tool is suitable for broader adoption across the commercial onion growing industry, however costs would need to reduce before this would happen. Obviously, the representativeness of the site being monitored is critical as the response of one or two onion bulbs is being used to guide irrigation management. With staggered planting dates, it would be beneficial to have systems across all plantings but the cost of this would be very high. However, in this day and age, and with access to the latest technological advances, I would suspect that similar plant based monitoring tools could be developed at a much lower cost.

One comment we have had from growers is that they may use the system for one or two seasons and monitor the crops response before settling on a management practice that achieves the desired production but without validation from the system. Personally, I do not support this, as I strongly believe that good management is a product of good monitoring but that is only an opinion.

Note: This same system was also trialled on two potato crops but was largely unsuccessful as the sub surface nature of the tuber does not allow for the growth to be accurately measured."

Acknowledgements

Thank you Michael Cutting for taking the time out of your schedule to provide us with your experience and views on the Phytech system Thank you also for the personalised guided tour of your management region and imparting your expertise about the issues facing irrigated horticultural production in the Lower Murray region of South Australia. Thank you also to Craig Henderson, who, as always, is there to bounce ideas off and give a helpful critique.

References

Cutting, M. D. (2008). Plant Based Monitoring and Irrigation Management in Vegetable Crops: An Overview of Trials Conducted in the SA Murray-Darling Region. Adelaide, South Australia, Australia, South Australian Murray-Darling Basin Natural Resources Management Board.

Jones, H. G. (2004). "Irrigation scheduling: advantages and pitfalls of plant-based methods." Journal of Experimental Botany **55**(407): 2427-2436.

SEQIF irrigation management tools

During our initial project meetings, and at various showcase events, team members presented information on relatively new irrigation tools (EM38, NDVI, PIMS and DSL) being developed or extended by the NCEA / SEQIF organisations. These tools are also being promoted by other agencies and consultants. Our role was to help producers and agribusiness become aware that these tools and services existed, and discuss their potential use in vegetable industries. In post-meeting evaluations, there was significant interest in particular in the tools; the following proportions of attendees saw these technologies as applicable to their situation: DSL (100%), EM38 (86%), PIMS (77%). We encouraged our project partners to follow up on this interest and opportunity.

Factsheets on these tools and their uses can be found at SEQIF website using the following pathway

http://www.seq.irrigationfutures.org.au

Home: Resources: Information sheets: SEQIF Trials – monitoring tools

SEQ Irrigation Futures R&D Support — Monitoring Tools

EM38 — Assessing soil spatial variability

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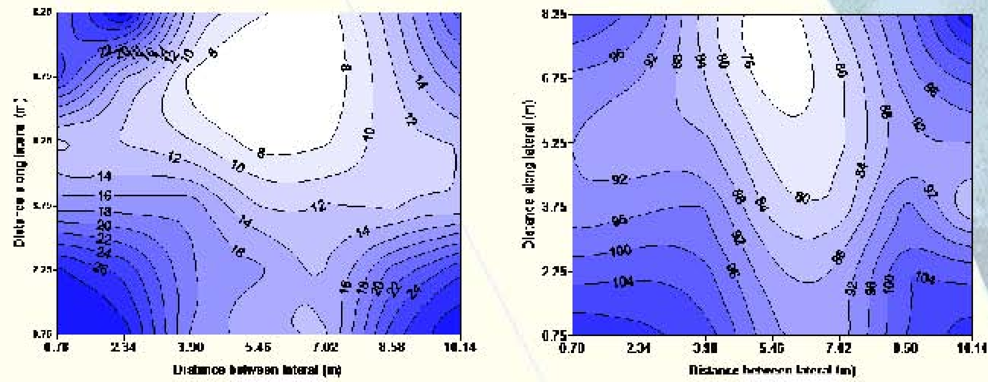
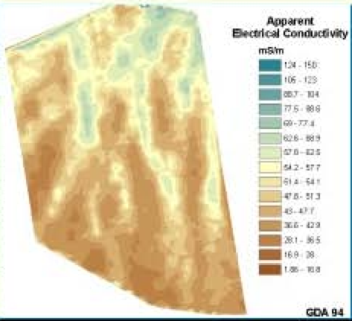
Electromagnetic induction (EMI) techniques are regularly used to assess soil spatial variability, type, salinity and the risk of deep drainage of water. EMI provides a measure of the apparent electrical conductivity (ECa) of the soil profile, which is affected by differences in soil moisture, therefore it can measure variability of soil moisture across fields.



(a) (b)

Relationship between Pattern of (a) irrigation water application (mm) and (b) EC_a (mS/m) in lettuce production under solid set irrigation in the Lockyer Valley, Queensland.

- Traditional methods of soil moisture monitoring have been employed with some success but limitations in utilising them efficiently across both time and space have led to restrictions in their use.
- The chief value of the EMI lies in its ability to detect variations in soil type and moisture across a wide area in single point static mode or in mobile surveys. Then utilise that information to eliminate or at least manage the spatial variation.
- There is potential to use EMI to measuring irrigation uniformity and irrigation performance evaluation.



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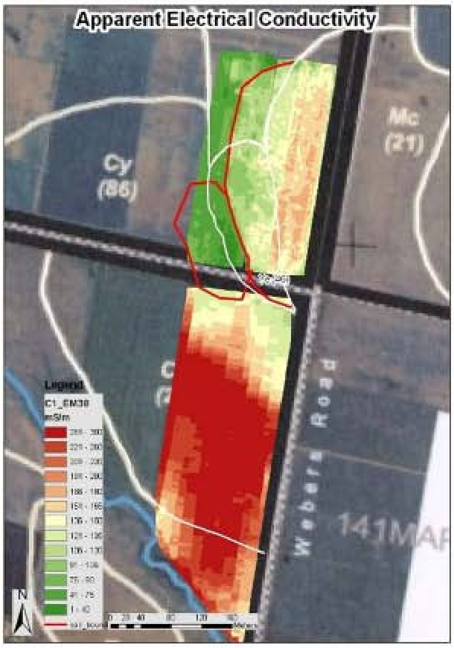
EM38 — Assessing soil spatial variability

EM38 is lightweight and at one metre long, it provides rapid surveys with excellent resolution at multiple soil depths. Measurements are made in either vertical or horizontal mode by placing the instrument on the ground or stand and recording the meter reading, or vehicle mounted in PC mode for spatial surveys.

Precision Agriculture. Farmland can be surveyed by EM38 tracking along the tramlines of a Controlled Traffic Farming system with a GPS-equipped ATV vehicle, efficiently. An onboard laptop synchronizes the streams of EC and dGPS data, which are collected at 2-3s intervals. Including geostatistical data interpolation and GIS map construction, 50-150 ha can be surveyed per day.



Dairy fodder production site with known salinity issues (lower zone) in red and realignment of soil survey boundaries (upper zone).

Subsoil constraints. Poor use of subsoil moisture by a crop is often indicative of subsoil constraints such as, salinity, sodicity, compaction, water logging, and other chemical constraints. The use of EM38 surveys in agriculture are an effective tool to determine zones of subsoil constraints.

Soil moisture deficit. The output from EM38 from irrigated cropping is well correlated to volumetric soil moisture. Surveys can provide a rapid non destructive assessment of the volume of water required to meet soil moisture deficit, thus minimising deep drainage and conserving natural resources.

Irrigation uniformity and crop water use. EMI techniques can provide a quick and efficient means for monitoring soil moisture patterns in cropping. Soil moisture data from cotton and lucerne fields in Central and SEQ clearly identified irrigation uniformity issues.

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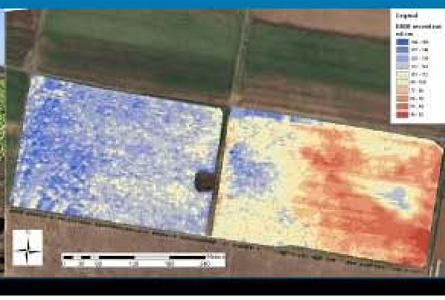

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University of Southern Queensland • West Street • Toowoomba Qld 4350
Ph: 07 4631 1871 • Fax: 07 4631 1870 • Email: ncea@usq.edu.au
www.ncea.org.au

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The Wireless Pressurised Irrigation Monitoring System (PIMS)

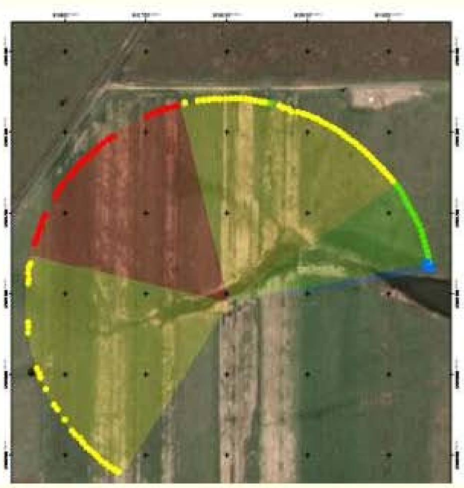
PIMS is a versatile tool kit which caters to irrigation consultants conducting irrigation performance assessments. Continuous irrigation system monitoring with the PIMS adds value to performance assessment by providing data on irrigation parameters across the complete irrigation cycle, which is essential if the pump performs variable duties during that cycle.

PIMS remotely monitors: Pump suction and storage or bore water level simultaneously and multiple pressure points. Additional sensors to monitor water quality, fuel consumption and global position of the mobile irrigator can be added to the system. Further optional customisations (eg 3G Modem) are also possible.

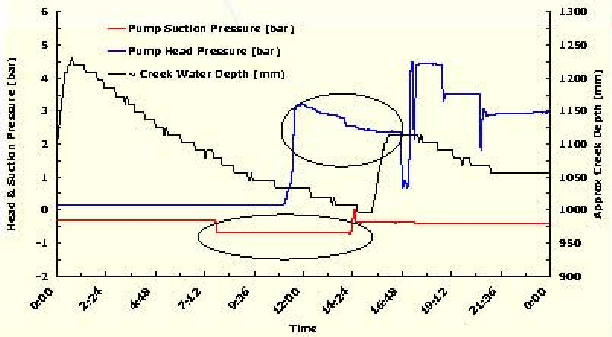
Pat Daley from Daley's Water Service says "I am very impressed with what a little information can give you, which often goes unaccounted. For example, initial data from a side roll irrigator has highlighted a pump suction problem when it is filling the spray line; it is taking far too long to get up to pressure at the sprays. I see the PIMS as being useful in logging the variable pressures you might have when operating a travelling irrigator or centre pivot over undulating ground. The assessment work I have carried out has shown 60% of distribution uniformity problems are from incorrect pressure at the water applicator. This particular trial data allowed me to calculate the pay back time of costs incurred rectifying system performance."

Possible applications include:

- **Irrigation performance assessment**
- **Dynamic asset monitoring**
- **Block & complete duty cycle monitoring**
- **Identification of limitations**
- **Assessment of modifications**
- **Continuous resource monitoring**
- **Pressure uniformity mapping**
- **Disaggregation of water application**



Pressure variation at the end of a centre pivot operating on undulating country.
< 7 kPa   7.1-10 kPa   11-18 kPa   > 18 kPa



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The Wireless Pressurised Irrigation Monitoring System (PIMS)

Operating Principle: PIMS was developed to continuously monitor water pump performance, storage water level, bore water level, irrigator applicator pressure, fuel consumption and position over single or multiple irrigation events. It does this whilst providing real-time display and logging capacity of the information in a central coordinator and the capacity for expansion. A wireless array of sensors and loggers are designed to adapt to all pressurised irrigation systems in all terrains under a range of operational conditions.

Telemetry: The PIMS internal wireless system offers a flexible approach to telemetry. It can be operated with short distance telemetry modules up to 1km and greater distances with external antennae. The transmission frequencies are in the free license range. The system is battery operated and can be deployed for weeks on end depending on the logging interval. It can be deployed indefinitely with a small solar cell. The wireless system comprises a coordinator unit and several end nodes.

End nodes: A device connected to the sensors outputs. It can interface with analogue outputs, frequency outputs from flow meters and digital switches. The end node is interrogated via telemetry from the coordinator and it sends the current readings. However the end nodes have the capacity to log sensor data independently of the coordinator, should it lose signal or not be warranted.

Coordinator: A coordinator interrogates the end nodes at a user specified time interval and logs the data onto an SD card for later retrieval. In the fully customised version, data can be retrieved via a 3G modem.

PIMS is flexible and can be customised to your specific application, which can provide:

- **An irrigation consultant tool kit to assess irrigation performance.**
- **Real time and remote monitoring of resources and irrigation assets.**

Dr A.D. (Jack) McHugh
Senior Research Scientist
University of Southern Queensland
CRC Irrigation Futures
West Street
Toowoomba, 4350
Tel: 07 46311873
Fax: 07 46311870
Mob: 0400706722
Email: mchugha@usq.edu.au

Dr Jochen Eberhard
Research Engineer
University of Southern Queensland
CRC Irrigation Futures
West Street
Toowoomba, 4350
Tel: 07 46311989
Fax: 07 46311870
Mob: 0428765372
Email: eberhard@usq.edu.au

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University of Southern Queensland • West Street • Toowoomba Qld 4350
Ph: 07 4631 1871 • Fax: 07 4631 1870 • Email: ncea@usq.edu.au
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'SMART' Water Metering Data Signature Logger (DSL)

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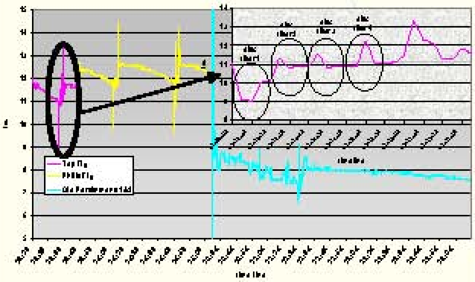
Farm irrigation schemes often consist of complex hydraulic delivery networks and obtaining detailed water use can be expensive and technically difficult. 'Smart' technology can be coupled with a meter to measure water use and provide information that can lead to improved irrigation practice and efficiency.

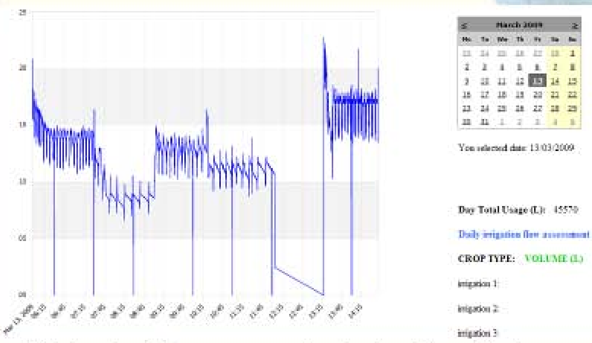


Drilling down into high resolution flow data identified individual disc filter operations, highlighting flow rate, flushing frequency and effectiveness.

The logger captures data at <0.5secs intervals providing a unique Hydraulic signatures of water flow which can monitor system condition. Disaggregation of water flow can optimise individual irrigation components for peak performance.

Block recording compares each block in the system, ensuring efficiency is maintained and impending maintenance issues are recognised.

Continuous monitoring adds value to performance assessments by providing data on irrigation parameters and components across the complete irrigation cycle.
A DSL connected to a water meter allows the continuous electronic reading and display of water consumption data back to your PC.
Actively managing your water consumption is the cornerstone upon which any modern water use efficiency scheme should be built.



Web based, real time signatures identify when different blocks are irrigated. Filter back-flushing occurs every 3 minutes, highlighting the low capacity of the disc filtration system and possible impact on sprinkler performance.

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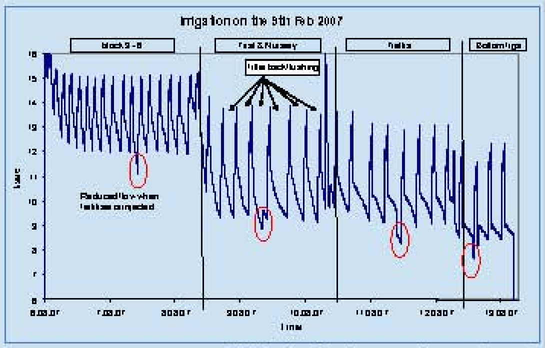
Data Signature Logger applications

THE BENEFITS

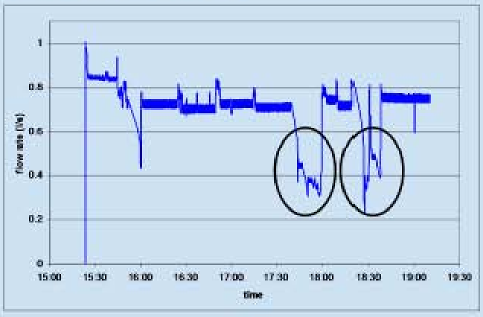
- Understand water consumption and flow patterns
- Track changes in trends and demand
- Highlight anomalies
- Warn of high or low flows
- Identify waste minimisation opportunities

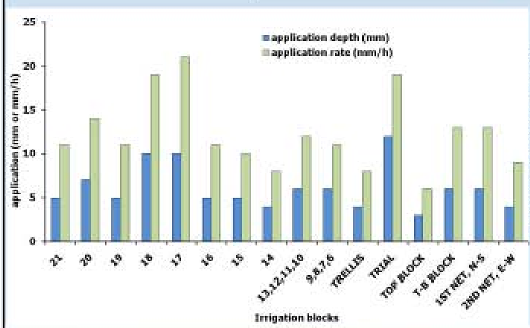
"SMART METERING: A SIGIFICANT COMPONENT OF WATER CONSERVATION"



Multiple block recording indicated variable flow rate between blocks and high frequency back flushing. The occurrence and impact of fertiliser injection was able to be monitored for each block (red circles).

Faulty (sticking) solenoids were identified in two blocks before detrimental effects occurred on high value rose production





Smart water metering identified highly variable application of daily irrigation water between individual blocks. The irrigator was alerted to possible water consumption, irrigation optimisation, distribution uniformity and power consumption issues.

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Normalised Difference Vegetation Index (NDVI) - Measuring crop performance

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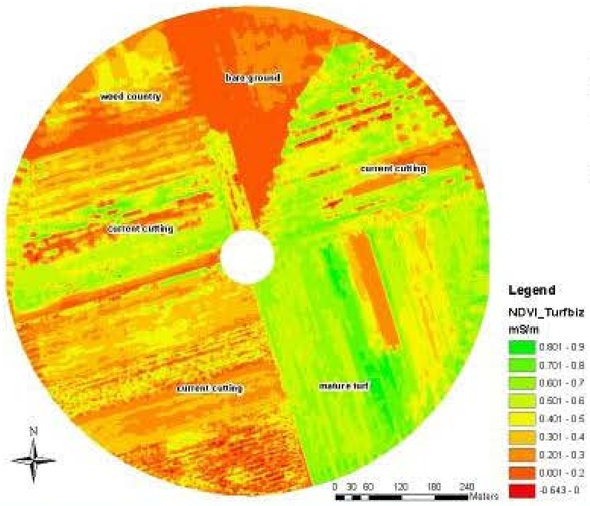
NDVI technology is becoming common place in conducting on-farm trials and determining farming input recommendations. It assists in fine-tuning your knowledge of variability within fields and the contrasts that exist among management histories.

Greenseeker® ground-based optical sensor contains its own red and near-infrared (NIR) light source, allowing measurements to be taken at any time, day or night. NDVI is a common measurement of plant health or vigour because chlorophyll in plants absorbs red light as a source of energy. Simplistically healthier plants (more chlorophyll) will absorb more red and reflect more NIR, and consequently have a higher NDVI. Using Greenseekers®, researchers, agronomists and farmers can map crop health.



NDVI survey indicating levels of ground cover, crop vigour and spatial variability in turf production under a centre pivot irrigator.

Common applications

- Remote sensing and agronomic research.
- Biomass and plant canopy measurement.
- Nutrient response, yield potential, pest & disease impact measurement.
- Crop responses to irrigation performance and topography changes.

Common outputs

- **Turf growers** can better predict quality and quantity well before harvest.
- **Pasture management** can be improved by identifying areas affected by heavy animal movement, overgrazing or in need of replanting.
- **Cotton, wheat and corn producers** have used GreenSeeker® to make variable rate applications of nitrogen, based on a yield potential approach.

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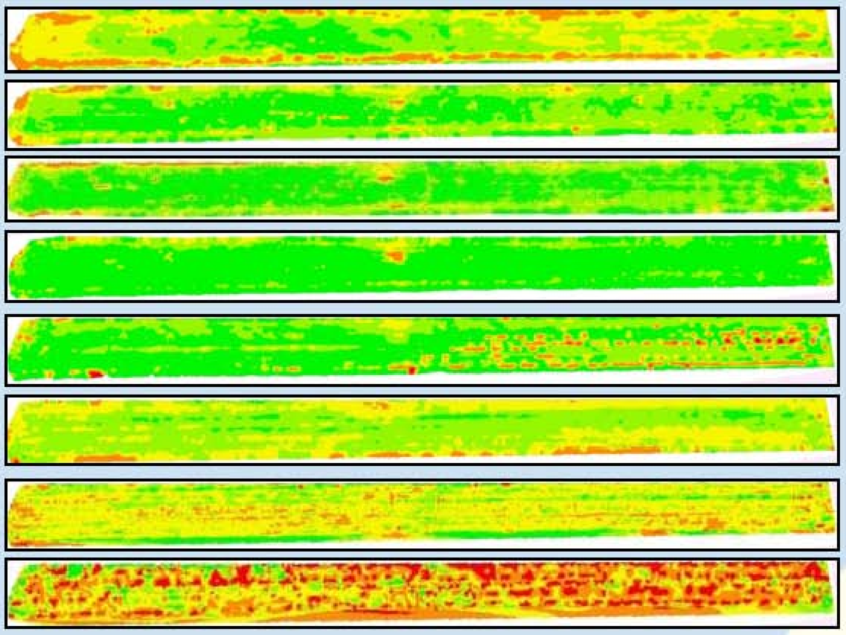
NDVI Sensor Application

Turf quality evaluation has been slow and subjective in the past. The NDVI sensor speeds up vigour evaluations and makes rapid plant health/quality observations verifiable. Time series NDVI sensor data was used to map field variability as a result of irrigation, climate and various management decisions.



21-11-2008
3 wks post harvest

24-11-2008

28-11-2008

05-12-2008
95% Groundcover

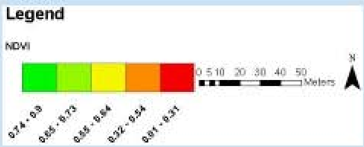
15-12-2008
Irrigation failure

08-01-2009
Drought conditions

12-02-2009
Uneven mowing

04-03-2009
Harvest

NDVI time series surveys of turf production from post harvest (21/11/08) to harvest (4/3/2009), demonstrating the impact of an irrigation breakdown (Dec to Jan) on crop growth and close mowing (Feb 2009) on quality.



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Incorporating uncertainty in economic decision making

Key findings

- Vegetable growing enterprises are too complex to develop a single economic model that can incorporate the vast array of farming structures represented. A colleague took over 4 months to incorporate a single farm's operations into a model suitable for examining the economic impact of controlled traffic farming.

- Most growers do not have the information, time or enthusiasm to provide the necessary input into individually tailored farm models. They would inevitably require the assistance of a trained consultant or modeller to undertake the preparation and analyses. Our most successful approach has been to use either Gross Margin tools to provide input to our risk/probability add-on in a training/workshop situation.

- The major influences on accumulated profit are price and yield. It is very important to be as accurate as possible in ascertaining what the assumed yield and price ranges are. Lowering the required inputs (e.g. irrigation requirement, fertiliser requirement) is unlikely to have a major influence on accumulated profit. However, if a resource is constraining (e.g. available irrigation water), it is usually most profitable to maximise return per unit of that resource.

Model development

We started out with the intention of developing whole farm models for vegetable production systems. We investigated work that had been done in other industries, such as the Smart Peanut suite of tools (DPI 2007), or APSFarm (Owens et. al. 2009). In discussions with growers at our initial irrigation showcase events at Gatton and Yanco, we determined that their farm structures were so different, it would take an enormous amount of effort to develop those models for just one business, much less be capable of representing the majority of vegetable businesses.

Our concerns on taking the whole farm approach were confirmed when we noted how long it took a trained economist to develop a partial farm model for a single vegetable growing enterprise (O'Halloran and Page 2010). The exercise took over four months of intensive effort, and involved numerous one-on-one interviews with the grower to collect the information. The model developed as a result was extremely complex, and specifically tailored for the particular situation and analysis. It could not be transferred to another enterprise without significant adaption by an experienced economist.

When we attended a simple gross margin workshop run by colleagues in DEEDI, we encountered major gaps in information able to be provided by the attending horticultural producers. This confirmed to us that it would be very unlikely that growers would utilise a complex farm model without significant assistance.

As a result of these observations, and the feedback we got at our various extension events, we decided it was more appropriate to develop our models for 'example' farms, to demonstrate principles for ongoing investigation and discussion.

We have developed a series of linked spreadsheets that take information from simple gross margin tools as their base settings. The current version can compare up to four different technology options at one time (see attached lettuce example). It adjusts the gross margin for each option, and presents the profitability (and a range of other indices) for each option.

The model has an example farm structure that places constraints on the resources the grower has to work with. In the current version, these constraints are land available, water available for irrigation, and amount of product that the market will accept. It would be possible to change these constraints, or with some effort, add others. Note that these constraints can be give values such that they are not actively constraining.

The spreadsheets and associated programming generate a range of seasonal scenarios, including variability in rainfall, crop yields and prices. The range and probability of that variability is changeable. We have also incorporated linkages between those variabilities, for example we currently have a higher probability of greater than average yields in a drier than normal season. These linkages are adjustable.

For each technology option, we determine the likely impact on variable inputs/outputs. For example, we consider that irrigation scheduling has benefits for irrigation saving and crop yields. The size and probability of achieving these benefits are also adjustable, for each of the investigated technologies.

Refer to the attached case study for specific examples of how these probabilities, linkages and benefits could be related.

The final stage of the spreadsheet is the generation of a sequence of growing periods. To run a single season, we initiate a macro that generates a random rainfall for that season (either Dry, Below Average, Average, Above Average or Wet). It also generates a yield and price for that season, based on all the linked associations and benefits associated with the technology option adopted. The spreadsheet then looks at the constraints applying in that season, and maximises production within those constraints. It calculates the profit from that level of production. The profit for each of the different technology options is output to a separate spreadsheet.

The macro can be set to run a single season at a time, so we can closely look at why we achieved a certain profit result. It can also be run in sequential mode, where it generates a sequence of random seasons, and the associated accumulated profit over that sequence of seasons.

Refer to the attached case study for an example of how the model can generate information for a range of technological options and seasonal influences.

Learnings

The major influences on accumulated profit are price and yield. It is very important to be as accurate as possible in ascertaining what the assumed yield and price ranges are. It is also very important to identify what are reasonable estimates of impacts of proposed technologies on yields (and input requirements).

Lowering the required inputs (e.g. irrigation requirement, fertiliser requirement) is unlikely to have a major influence on accumulated profit. This is because most individual inputs are only a small proportion of total production costs. For example, irrigation costs are generally only 2-6% of total pre-harvest costs for many vegetables. The one exception is where the input is scarce, or regulated (see below).

If a resource is constraining (e.g. available irrigation water), it is usually most profitable to maximise return per unit of that resource. However, it is important to identify the yield/risk/price profile associated with any technology used to achieve that maximisation.

Further development

Currently, we still need to adjust the spreadsheets for each new scenario to be investigated. We are able to do this in conjunction with the people/organisations seeking evaluations, on a case by case basis.

We would like to develop the spreadsheets further, so that those adjustments are quicker and more transparent. This will probably involve access to an experienced spreadsheet programmer; this has proven difficult in the past. We intend to discuss our ideas and options with industry in the future.

References

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Owens JS, Cox H, deVoil P, Power B, Conway M, Routley R (2009) APSFarm: a new framework for modelling mixed cropping and grazing farm businesses. Presentation at 18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009.

The economics of irrigation decisions, evaluating economic consequences with inbuilt uncertainties - Case study using a lettuce cropping scenario

(Extracted from presentation at Gatton and Yanco Irrigation Showcase events)

Craig Henderson

Gatton Research Station, Agri-Science Queensland

Key findings

- Relatively low-cost changes, (e.g. irrigation scheduling), are reliably 10-15% more profitable over a sequence of 20 cropping cycles than ‘business as usual’, provided they can deliver even small yield improvements. They are particularly advantageous (20% more profitable) where water shortages are limiting production.

- High-cost changes, such as switching irrigation systems, require significant water shortages, reliable yield benefits (>10%), or reduced risks of low crop prices, to be consistently profitable investments.

Plate 6 Standard overhead irrigation system in Lockyer lettuce.

The scenario farm

A lettuce producer has access to 40 ha of land, with 200 ML of irrigation water available for the growing period in question. The target yield under normal conditions is 3650 cartons per ha, with an average market price of $12.30 per carton. The grower is contemplating arranging for a worker to schedule the lettuce irrigation, using a low cost method such as tensiometers. The grower has estimated that this will cost around $200 per/ha. Another option is to switch from overhead irrigation to drip irrigation, which is estimated to cost an additional $1600/ha. Of course, the producer also has the option of undertaking both new technologies.

The uncertainties

The scenario model includes the capacity to generate seasons with rainfall ranging from 40% below normal, to 30% above normal. There are probabilities associated with getting the various amounts of rain within that range. The model randomly generates yields between 85% and 120% of average. The yield variability is caused by factors such as pest or disease incidence, adverse weather, and the inevitable operational issues such as broken equipment, quality of labour etc. There are probabilities associated with each of the yield outcomes. The model similarly generates prices between 60% and 150% of average prices, probably a conservative reflection of actual market fluctuations. There are probabilities associated with each of the price outcomes.

Based on experience, the scheduling with tensiometers reliably reduces irrigation requirement by 10-15%, and improves yields by 0-20%, with a probability of achieving improvements within those ranges. In this scenario, the model operates on the assumption that drip irrigation saves 10-20% of irrigation water, and improves yields by 0-20%. It should be noted that yield increases above the average are limited to a maximum of 30%, no matter what technologies are implemented, or how favourable the seasons are.

In this particular scenario, we have incorporated linkages between the uncertainties, which affect the probabilities of events occurring. These are:

- Lower yields are more likely in very wet or very dry seasons (wet seasons bring diseases and problems with operations and harvesting; very dry seasons may be associated with high temperatures, and damaging winds)
- Higher prices are more likely in very wet or very dry seasons, because of the above.
- Irrigation scheduling is more likely to save irrigation water in wet seasons (indicates when irrigation is not required), and improve yields in dry seasons (indicates when water would be beneficial before stress is obvious)
- Drip irrigation more likely to save water and improve yields in drier seasons (less evaporation, and better ability to be able to irrigate when required, e.g. in hot windy conditions)

None of the above linkages guarantees the above things happen; they just make them slightly more likely.

All of the above uncertainties, probabilities and linkages are adjustable (with different levels of effort and re-programming).

The outcomes

The graphics below show the accumulated profit after growing 20 seasons of lettuce crops under the aforementioned systems. Each year, the model is constrained by the amount of land available for cropping, the amount of water available for irrigation, or the amount of product the market is prepared to buy. In this simple scenario, it presumes the market will take all the lettuce the grower can produce, and the maximum area cropped is no more than 40 ha. Each season, the model randomly generates rainfall, yields, and prices, and calculates the profit (or loss) for that season. The four lines in the graphics show the accumulated profit for:

- Control - the producer decides not to invest in either irrigation scheduling or drip systems
- Sched - the producer only invests in the irrigation scheduling option
- Drip - the producer only invests in the drip irrigation option
- Combo - the producer invests in both the scheduling and drip system options

Business as usual

In the situation where the external environment is the same as initially indicated, there are small but consistent advantages from adopting either, or both of the irrigation technologies (Fig. 79). The low investment scheduling technology is a slightly better option than switching to drip irrigation, and adopting both systems is a consistently better option. Note that in Years 6 and 7, all options are actually unprofitable. It's only in a few years that the irrigation technology options substantially outperform the do nothing option. In this scenario, there is probably sufficient incentive to adopt the low-cost irrigation scheduling option, but less incentive to go with the conversion to the drip system.

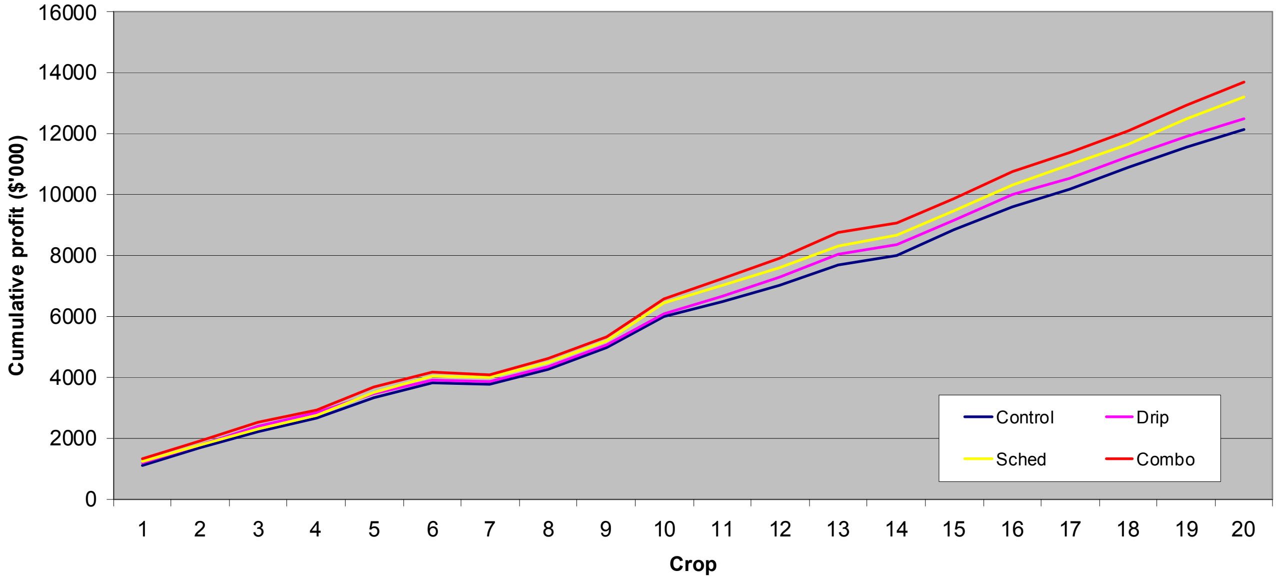


Figure 79. **Accumulated profit from a range of lettuce production systems under a standard seasonal scenario run for 20 cropping periods.**

Long term drought

In this scenario, through a combination of natural resource depletion and/or regulatory impositions, the amount of irrigation water available to the grower has been limited to 80 ML per season, down from the initial 200 ML in the initial setup, and used in the scenario described previously. We can immediately see major differences from that previous scenario. Firstly, the accumulated profit if the producer does not implement any irrigation changes is around 25% less than previously. Secondly, there are major and consistent advantages from adopting either irrigation technology, and it would make obvious sense to adopt both.

The reason for this outcome is that the amount of lettuce the grower can produce is constrained by the amount of water available. In the Control situation, and even when they adopt one or the other irrigation technology, they can't grow their full 40 ha of production. It's only when they maximise their irrigation efficiency by employing both irrigation strategies that the producer can stay in full, or close to full production.

Interestingly, that is exactly what we have seen played out in Queensland in the last twenty years. When water has become restricted, we have seen vegetable growers switch to irrigation systems that use less water, so they can maintain their whole-of farm production levels. They often make less per hectare, but they maximise the amount of land they can crop, and their production from a set amount of water.

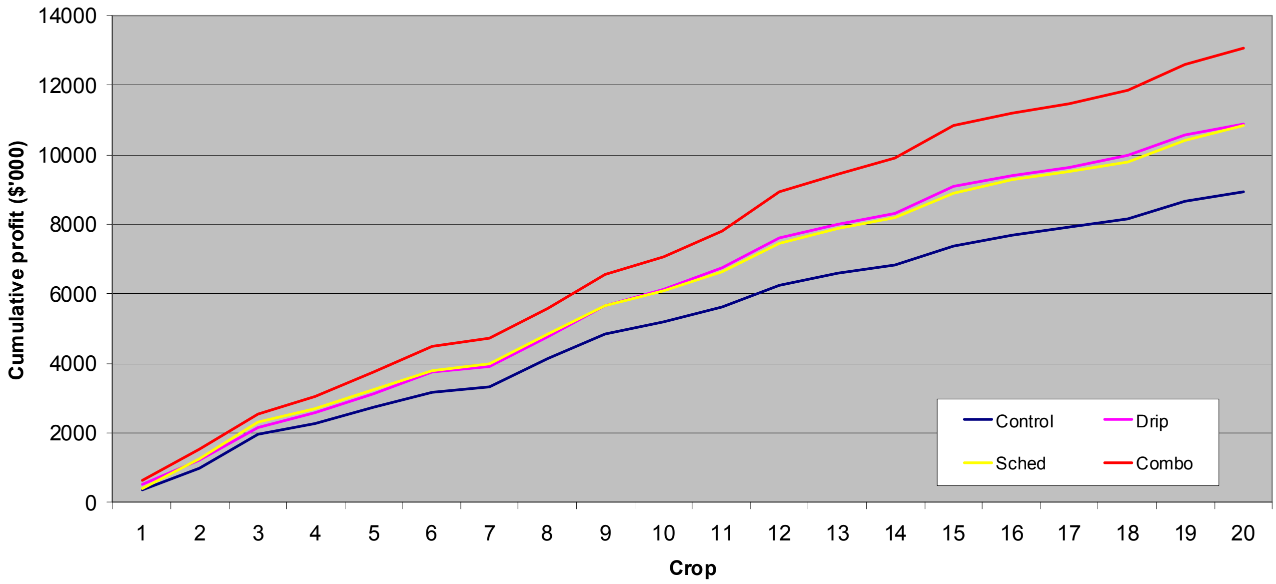


Figure 80. Accumulated profit from a range of lettuce production systems under a drought affected seasonal scenario run for 20 cropping periods.

Low prices

We ran this scenario particularly for people in the policy, regulatory and environmental management sectors. We often hear comments along the line of 'growers just need to be more water efficient, and adopt new technologies and then they could achieve their production whilst using less water'. One of the main reasons this does not always happen, and particularly in vegetable growing situations, is the vulnerability to adverse price movements for their products.

In this scenario, we still have the restricted water allocation of 80 ML per season. However, on top of that, we have a situation where the average price the market is prepared to pay is now only $10 per carton, instead of $12.30. You can see the dramatic impact this has on profitability, and the 'obvious' choices for the lettuce producer (Fig. 81).

Firstly, the 19% drop in average price per carton has meant estimated accumulated profit over the 20 seasons for the producer dropped by 63%. That was for the producer in the water-restricted situation, who chose not to adopt any technology. When lettuces were $12.30/carton, the grower accumulated around $9M over the 20 seasons; at $10/carton that dropped to $3.4M. Note that in many years, the producer lost money growing the lettuce, no doubt due to prices or yields in the low range during those seasons. In this water availability, low price constrained environment, low cost scheduling was still a good idea. It maximised your chances of making money when prices were OK, but didn't expose you to major losses when they weren't. In contrast, the benefits of better water use efficiency from the higher cost drip system were negated by the increased losses made when prices were lower than average. Put simply, there is no advantage from growing more hectares of an unprofitable crop! These simple demonstrations also show why anticipated product price is such a huge driver of decision making in vegetable production.

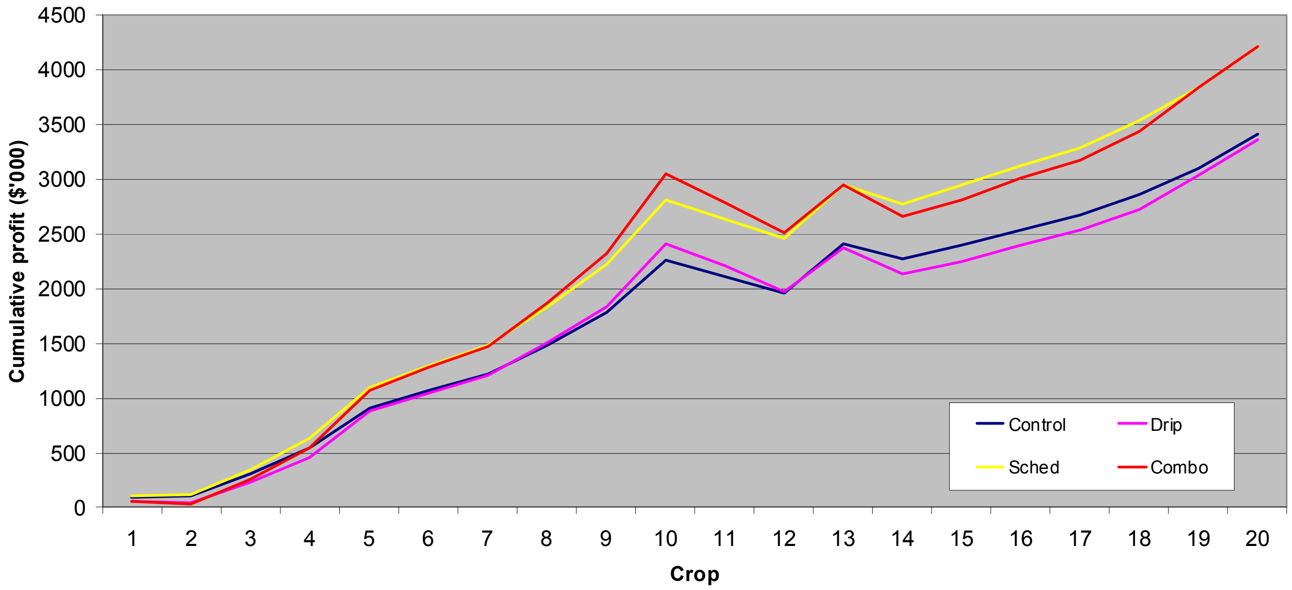
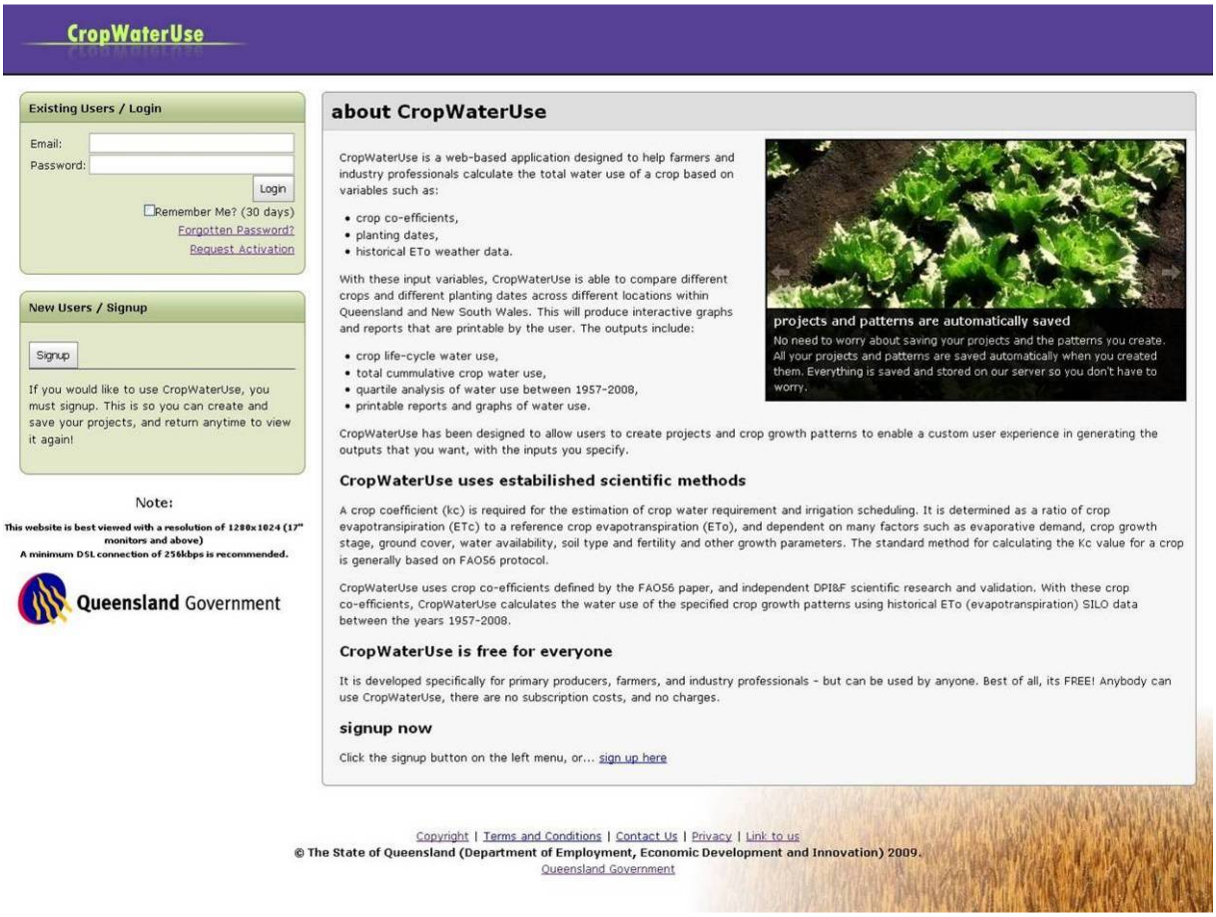


Figure 81. Accumulated profit from a range of lettuce production systems under a drought affected, low price seasonal scenario run for 20 cropping periods.

Vegetable components in the CropWaterUse online tool

As part of our project, we have provided vegetable crop information toward the development of the CropWaterUse tool (www.cropwateruse.dpi.qld.gov.au). These irrigation / crop water use planning tools are available to farmers in Queensland and Northern NSW at this stage. We have provided information on canopy development and crop phenology for broccoli, capsicum, green beans, lettuce and sweet corn. Because the tool was initially targeted at broad acre producers, some of the assumptions about irrigation frequency still require adjustment for vegetable production systems. This is an ongoing activity. Producers wishing to find out more about using the tool can contact the project leader via the website for more information.



Technology transfer

During the project, we conducted a program of ongoing communication and extension activities. Our published information output included 11 articles in industry journals and general media, 6 papers delivered to national and international conferences, 10 website articles and newsletters and 17 formal presentations to regional industry forums.

We also conducted over 70 separate extension events as outlined below. As well as these group events, we provided substantial individual advice and consultative effort on at least 25 occasions, to groups as diverse as HAL officers, R&D administrators, parliamentarians, others scientists/researchers/IDOs, and individual producers as part of their day-to-day business.

Project extension will continue as part of our ongoing commitment to vegetable RDE, as well as finalising publishing of various project outputs. We will focus on demonstrating the use of the technologies we have explored in this project with commercial consultants and service businesses, to ensure ongoing support and development beyond the life of this project. Apart from tools we have investigated, we have also assisted vegetable industries by giving advice on vegetable farming context for technologies such as controlled traffic farming, and remote sensing by unmanned aerial vehicles.

We have been very encouraged by the interest at policy levels in our project (see Extension Activities with policy level – parliamentarians, policy and environmental agencies, regional bodies). I believe we have effectively used our data in discussions to demonstrate that policy environments advocating a single ‘best-practice’ recipe are flawed, as they fail to take into account external variabilities, different farm structures and objectives.

Extension activities

Publications

Henderson CWL (2008). VG07023 R&D project preview. Vegetable Australia (3.4), 36.

Henderson CWL (2008). VG07023 R&D project. HAL vegetable annual industry report 2007-8.

Henderson CWL, Yeo MB, Finlay G (2008). Customising drip irrigation for profitable vegetable production. Paper and presentation at Irrigation Australia National Conference, Melbourne, May 2008.

Hussain A, Raine SR, Henderson CWL (2008). Preliminary evaluation of relationships between irrigation non-uniformity and crop responses in lettuce. Paper and presentation at Irrigation Australia National Conference, Melbourne, May 2008.

Hussain A, Raine SR, Henderson CWL, Jensen T (2008). Evaluation of a proximal vision data acquisition system for measuring spatial variability in lettuce growth. Poster at Australian Society of Agronomy Conference, Adelaide, September 2008.

Limpus SA (2008). Plant-based sensing for irrigation-key technical reviews. Circulated nationally to irrigation scientists, included as resource on Horticulture Water Initiative website.

Henderson CWL, O'Halloran J (2009). Irrigation research in horticulture. SEQ Hort Report **1**, August 2009.

Henderson CWL (2009). VG07023 summary for HAL Annual Report. In 'HAL Vegetable Industry Report 08-09', p 45.

Huth NI, Henderson CWL, Peake A. (2009) Exploring irrigation management of a horticultural crop using APSIM. Presentation at 18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009.

Limpus SA (2009). Isohydric and anisohydric characterisation of vegetable crops: The classification of vegetables by their physiological responses to water stress. Circulated nationally to irrigation scientists, included as resource on Horticulture Water Initiative and SEQIF websites.

Limpus SA (2009). Field day in May. Gatton Star Newspaper, 6 May 2009.

Limpus SA (2009) Thirsty veges get their fill. In 'Good Fruit & Vegetables' **20 (2)** p 43. (Rural Press: Cleveland, QLD, Australia).

Limpus SA (2009) New water conserver. In 'Gatton, Lockyer and Brisbane Valley Star (Gatton, Queensland, Australia).

Limpus SA (2009) How thirsty are Queensland Vegetables? In 'Central & North Burnett Times, ('Kingaroy, QLD, Australia).

Limpus SA (2009) Discovering how thirsty region's crops really are. In 'South Burnett Times' p 57, (Kingaroy, QLD, Australia).

Henderson CWL (2010). VG07023 summary for HAL Annual Report. In 'HAL Vegetable Industry Report 09-10.

Hunt AG, Henderson CWL, Finlay GP (2010). Electrical conductivity of root zone soil water, and marketable yield of an iceberg lettuce (*Lactuca sativa*) crop, irrigated with different water qualities. In 'Australian Irrigation Conference, Sydney, 6 June 2010.

Limpus SA (2010) Call to arms for irrigation tool. In 'Vegetables Australia' **5 (4)**, p 11. (AUSVEG: Mulgrave, Victoria, Australia).

Limpus SA, Henderson CWL, Finlay GP, Singh D, Payero J (2010) Optimizing profitability of sweet corn by understanding high plant density effects on water use, phenology and yield. In 'Australian Irrigation Conference, Sydney, 6 June 2010.

Hunt A, Carey D, Henderson CWL, Finlay G (2011). Successfully managing root zone nutrients and salts in a Granite Belt lettuce crop - a case study using FullStop™ wetting front detectors. Report for lodgement on DEEDI website www.dpi.qld.gov.au once renovation of website completed. March 2011.

Hunt A, O'Halloran J, Henderson CWL, (2011). Nitrogen movement in a Lockyer Valley cabbage crop - a case study using SSET for root zone monitoring. Report for lodgement on DEEDI website www.dpi.qld.gov.au once renovation of website completed. March 2011.

Hunt A, Limpus SA, Henderson CWL, Finlay G (2011). Soil solute sampling in irrigated vegetables – root zone solute monitoring in vegetables. Factsheet for lodgement on DEEDI website www.dpi.qld.gov.au once renovation of website completed. March 2011.

Hunt A, Limpus SA, Henderson CWL, Finlay G (2011). Soil solution extraction tubes – root zone solute monitoring in vegetables. Factsheet for lodgement on DEEDI website www.dpi.qld.gov.au once renovation of website completed. March 2011.

Hunt A, Limpus SA, Henderson CWL, Finlay G (2011). FullStop™ wetting front detector – root zone solute monitoring in vegetables. Factsheet for lodgement on DEEDI website www.dpi.qld.gov.au once renovation of website completed. March 2011.

Limpus SA, Henderson CWL, (2011). Management of recycled water irrigation on vegetable crops - a case stud: Wren's Valley, Stanthorpe. Report for lodgement on DEEDI website www.dpi.qld.gov.au once renovation of website completed. March 2011.

Limpus SA, Henderson CWL, (2011). In-situ monitoring of salt and nitrate-N in capsicum root zones irrigated with Class B recycled water. Report for lodgement on DEEDI website www.dpi.qld.gov.au once renovation of website completed. March 2011.

Shaw K, Henderson CWL (2011) Irrigatio: tools for profitable practice change. In 'Vegetables Australia' March/April 2011, p 44-45. (AUSVEG: Mulgrave, Victoria, Australia).

Group presentations

Huth NI, Peake A, Henderson CWL, Limpus SA, Hunt A (2009). Conducted field tour of modelling experiments and technology evaluations for senior CSIRO Science management group, Gatton, 19 February 2009.

Henderson CWL, Limpus SA, Hunt A (2009). Conducted presentations and field tour of technology evaluation experiments for senior Chinese agricultural officials, Gatton, 26 March 2009.

Gatton Irrigation Showcase, 14 May 2009. Attended by 30 growers, service industry representatives and allied scientists. Included field / workshop presentations on irrigation technologies, crop monitoring tools, use of crop models, analysing impacts of uncertainties on profitability, and a research needs prioritisation exercise.

Limpus SA, Hunt A (2009). Follow-up telephone discussions with all Gatton showcase attendees re: key issues for field and modelling investigations, June/July 2009.

Limpus SA (2009). Presentation to Stanthorpe recycled water users on techniques for monitoring nitrates and salts in vegetable root zones, 25 June 2009.

Limpus SA, (2009). Conducted field tour of modelling experiments and technology evaluations for visiting Bangladesh scientists, 5 August 2009.

Henderson CWL, Limpus SA (2009). Are plant stress indicators currently useful for making farming decisions? PowerPoint Presentation to 30 H&FS Agronomy and Physiology Scientists, Bundaberg, 12 August 2009.

Henderson CWL, Limpus SA, Hunt A (2009). Conducted field tour of modelling experiments and technology evaluations for QPIF Innovation Group, 9 September 2009.

Limpus SA, Hunt A (2009). Conducted field tour of modelling experiments and technology evaluations for visiting University of Queensland graduate groups, 9 September 2009 and 8 October 2009.

Henderson CWL, Limpus SA, Hunt A (2009). Conducted field tour of modelling experiments and technology evaluations for the 2009 CIGR International Symposium of the Australian Society for Engineering in Agriculture Field Tour, 16 September 2009.

Yanco Irrigation Showcase, 1 October 2009. Attended by 25 growers, service industry representatives and allied scientists. Included workshop presentations on use of crop models, analysing impacts of uncertainties on profitability, sap testing and use of EM38 soil conductivity, and root zone monitoring. Also a practical field inspection of root zone monitoring and irrigation scheduling tools.

Henderson CWL, Napier T (2009). Yanco Irrigation Showcase. Radio interview, ABC Riverina Radio, 10 October 2009.

Henderson CWL (2009). Presentation on Gatton Water Science research (including HAL Project VG07023) to visiting Agricultural delegation from Pakistan. 5 November 2009.

Limpus SA (2009). Introduction to 'CropWaterUse' software tool and research program. Presentation to Young Growers (HAL Project VG09081), Gatton, 25 November 2009.

Limpus SA (2009). Introduction to 'CropWaterUse' software tool and research program. Presentation to Young Growers (HAL Project VG09081), Stanthorpe, 3 December 2009.

Limpus SA, Henderson CWL, Hunt A (2010). Presentation on Gatton Water Science research (including HAL Project VG07023) to Irrigation Australia training course attendees. 04 February 2010.

Limpus SA, (2010). Conducted field tour of modelling experiments and technology evaluations for visiting CSIRO scientists. 26 February 2010.

Hunt AG (2010). Solutes in crop root zones. Presentation at Young Growers Workshops, Gatton, 24 March 2010.

Hunt AG (2010). Irrigation management for efficient fertilizer use. Presentation at Efficient Nutrient Management in Vegetables Field Day, Tenthill, 15 April 2010.

Hunt AG (2010) Soil solute monitoring in irrigated vegetables. Presentation at 'International Climate Change Conference - post-conference tour', Gatton, 2 July 2010.

Limpus SA, Henderson CWL, Hunt AG, Finlay GP (2010) Optimising vegetable production and understanding water use. Presentation at 'International Climate Change Conference - post-conference tour', Gatton, 2 July 2010.

Henderson CWL (2010) Water science at Gatton Research Station. Presentation to '19th World Congress of Soil Science' p. 13. Post-conference tour, Gatton, 7 August 2010.

Henderson CWL (2010) Water science at Gatton Research Station (including HAL Project VG07023). Presentation to Chinese irrigation science delegation, Gatton, 22 September 2010.

Henderson CWL (2010) Water science at Gatton Research Station (including HAL Project VG07023). Presentation to Chinese irrigation science delegation, Gatton, 22 September 2010.

Henderson CWL (2010) Griffith Irrigation Seminar, 7 October 2010. Attended by 20 growers, service industry representatives and allied scientists. Included updated workshop presentations on use of crop models, analysing impacts of uncertainties on profitability, and root zone monitoring.

Henderson CWL (2010) Water science at Gatton Research Station (including HAL Project VG07023). Presentation to 2nd Chinese irrigation science delegation, Gatton, 16 November 2010.

Henderson CWL (2010) Water science at Gatton Research Station (including HAL Project VG07023). Presentation to John Dillon Scholarship (ACIAR) group, Gatton, 21 March 2011.

Group discussions / workshops

Henderson CWL, Limpus SA, Hunt AG (2008 & 2009). Participated in two SOLUTE SIGNATURES Masterclasses, under the auspices of the CRC Irrigation Futures, in November 2008, and March 2009. Presented initial results from our vegetable root zone monitoring.

Henderson CWL (2009). Discussion on potential remote sensing tools with scientists from Southern Cross University Geo-informatics unit, 16 January 2009.

Henderson CWL (2009). Presented VG07023-based information to inform policy discussions for:

Sustainable Farm Practices Symposium and Workshop, Brisbane, 22 June 2009

Managing per-urban Agriculture Symposium and Workshop, Brisbane, 7 July 2009.

Development of the QLD Coal Seam Gas Industry Technical Workshop, Toowoomba, 10 July 2009.

Use of the ABCD framework for evaluating sustainable horticultural practices, Gatton, 17 August 2009.

Henderson CWL, Limpus SA (2010). Discussion on Gatton Water Science research (including HAL Project VG07023) at Plant-based Water Stress Sensing Forum, Toowoomba, 4 March 2010.

Limpus SA, Hunt AG (2010). Discussion on Gatton Water Science research (including HAL Project VG07023) at Nutrient Budgeting Tool Workshop, Toowoomba, 8 March 2010.

Limpus SA, (2010). Discussion on Gatton Water Science research (including HAL Project VG07023) and tour of field experiments with visiting agronomists from Indonesia, Gatton, 25 March 2010.

Henderson CWL, Limpus SA (2009). Discussion on Gatton Water Science research (including HAL Project VG07023) and tour of field experiments at official industry launch of 'CropWaterUse' software tool, Gatton, 20 April 2010.

Hunt AG, Limpus SA (2010). Discussion on Gatton Water Science research (including HAL Project VG07023) to Vegetable Growers R&D Forum, Gatton, 20 May 2010.

Henderson CWL, Hunt AG, Limpus SA (2010). Discussion on relevant Gatton Water Science research (including HAL Project VG07023) during Drip Irrigation Workshop (Irrigation Australia Conference), Sydney, 7 June 2010.

Henderson CWL, Hunt AG, Limpus SA (2010). Discussion on relevant Gatton Water Science research (including HAL Project VG07023) during Value Chain Opportunities Workshop, Gatton, 22 July 2010.

Henderson CWL (2010). Provided commentary at SEQ NRM Science and Policy integration Forum (including information based on results from HAL Project VG07023), Brisbane, 29 July 2010.

Limpus SA (2010). Discussion on relevant Gatton Water Science research (including HAL Project VG07023) during Soil Instrumentation Workshop, Toowoomba, 29 July 2010.

Henderson CWL (2010). Discussion on Gatton Water Science research (including HAL Project VG07023) at Controlled Traffic in Vegetable Farming Field Walk, Kalbar, 5 August 2010.

Henderson CWL (2010). Provided irrigation technology (including HAL Project VG07023) discussion and prioritisation at HAL sponsored workshop on MARRS R&D activities, Marburg, 8 September 2010.

Henderson CWL (2010). Discussion on irrigation research (including HAL Project VG07023) at Sweetpotato industry update meeting, Bundaberg, 29 October 2010.

Henderson CWL (2010). Provided irrigation technology (including HAL Project VG07023) discussion and prioritisation at demonstration of MARRS technologies by CSIRO, Pullenvale facility, 25 November 2010.

Henderson CWL (2011). Provided irrigation technology (including HAL Project VG07023) discussion and prioritisation at Young Growers (HAL Project VG09081), Gatton, 2 March 2011.

Individual consultation

Henderson CWL (2009). Provision of vegetable industry plant-based sensing information/commentary to Helen Sargent from HAL, for presentation at the 'AUSTRALIAN FORUM ON PROXIMAL CROP SENSORS', held in Adelaide 16-17 February 2009.

Henderson CWL (2009). Commentary on vegetable industry commodity R&D needs for the National Horticulture Research Network, using accumulated knowledge, including information derived from recent project studies.

Henderson CWL (2009). Commentary on vegetable industry impact on the environment reports under development by consultants, using accumulated knowledge, including information derived from recent project studies.

Henderson CWL, Limpus SA, Hunt A (2009). Conducted presentations and field tour of technology evaluation experiments for Michael Cutting, Principal Project Officer - Sustainable Irrigation, SA Murray-Darling Basin Natural Resources Management Board, Gatton, 14-15 May 2009.

Henderson CWL, Limpus SA, Hunt A (2009). Discussions with Western Australian researcher Rohan Princes on collaborating in ongoing irrigation research projects, 22 May 2009.

Henderson CWL, Limpus SA, Hunt A (2009). Discussions with Tasmanian R&D team (Susan Lambert and Colin Birch) on collaborating in ongoing irrigation research projects, 5 June 2009.

Henderson CWL (2009). Presented VG07023-based information to inform policy discussions with Queensland Parliamentarians, Ian Rickuss (MLA) and Andrew Powell (MLA) during the annual Science in Parliament event, Brisbane, 19 August 2009.

Henderson CWL, Limpus SA, Hunt A (2009). Discussions with NCEA and Growcom staff on collaboration opportunities in developing irrigation software, and demonstrating new irrigation technologies, 10 June 2009 and 1 September 2009.

Limpus SA (2009). Discussions with co operator grower on methods for monitoring whilst using recycled water in vegetable cropping. 28 October 2009.

Limpus SA (2009). Discussions with co operator vegetable grower on findings from root zone tool evaluation/demonstration in capsicum crop using recycled water. 5 November 2009.

Henderson CWL (2010). Provided commentary on interpreting root zone monitoring in sweet corn to CSIRO scientist for web blog and NPSI report, Gatton, February - May 2010.

Henderson CWL (2010). Modelling irrigation and water use in Lockyer Valley farms. Ongoing interaction with CSIRO scientists investigating recycled water use schemes for the Lockyer Valley, Gatton, March 2010 – December 2010.

Henderson CWL (2010). Provided commentary to scientific team investigating irrigation options for the Healthy Headwaters (Murray-Darling Basin) project, (including information based on results from HAL Project VG07023), Toowoomba, 18 March 2010.

Henderson CWL (2010). Provided commentary on Soil Health Manual for Vegetable Production (including information based on results from HAL Project VG07023), Gatton, 12 April 2010.

Hunt AG (2010). Discussions with Dr Tony Patterson on use of FullStop™ Wetting Front Detectors, 19 May 2010.

Henderson CWL (2010). Enhancing drip irrigation performance in sandy soils. Telephone interactions with Department of Agriculture and Food scientist, Gatton, 4 June 2010.

Henderson CWL (2010). Understanding root zone monitoring. Interactions with H&FS scientists and growers, Bundaberg, 21 June 2010.

Henderson CWL, Hunt AG, Limpus SA (2010). Managing high salinity irrigation water in vegetable cropping. Teleconference with Southern Regional Water, Werribee, 20 July 2010.

Hunt AG (2010) Cabbages: SSET trial results summary. Individual report to collaborating grower, Thornton, 23 July 2010.

Henderson CWL (2010). Provided commentary to committee developing National Irrigation R&D framework, (including information based on results from HAL Project VG07023), Gatton, 30 July 2010.

Henderson CWL (2010). Discussion on Gatton Water Science research (including HAL Project VG07023) with visiting international scientist (Clemson University, USA), Brisbane, 10 August 2010.

Henderson CWL (2010). Discussion on Gatton Water Science research (including HAL Project VG07023) with visiting Research Team Leader (Katherine Research Station, Northern Territory), Gatton, 11 August 2010.

Henderson CWL (2010). Understanding root zone monitoring. Interactions with H&FS scientists, Bowen, 17 August 2010.

Henderson CWL (2011). Provided irrigation technology (including HAL Project VG07023) information at MARRS forward development discussion with QUT/DEEDI, Brisbane, 15 February 2011.

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Project recommendations

Management of solutes in vegetable root zones

Vegetable growers will remain under pressure to efficiently use irrigation water, and manage salts on their farms, as well as export of salts to the environment. Similarly, they will be increasingly accountable for movements of nitrogen, as an unwanted addition to waterways, or as a greenhouse gas contribution. At the same time, they will have to manage those salts and nutrients effectively within their crop root zones, to maintain or improve crop performance, and ultimately productivity.

Our project recommends the use of FullStop™ wetting front detectors, in conjunction with a measure of soil water status, accompanied by periodic sap and soil tests, as a cost effective method of evaluating salt and nutrient balances in current vegetable cropping systems. Because they require some expertise, and are relatively labour intensive, we recommend they be used to address specific problems, or as a periodic auditing strategy. We do not believe there are any systems currently available for cost-effective, routine crop monitoring.

Whilst Soil Solution Extraction Tubes can initially be easier to install, they are more difficult to interpret than the FullStop™ devices, and can be just as difficult to remove from a paddock.

The biggest impediment to using the FullStop™ tool is the time taken for installation and retrieval. This is particularly onerous in short-term vegetable crops. Practical research on how this time could be minimised, or alternatively how more permanent installations could be retained in vegetable cropping systems, would be very useful. It may well be that if the vegetable industries move to more precision horticulture systems, this may become more feasible. We are aware that the company Measurement Engineering Australia is developing an automated version of the FullStop™, which can continuously log at least EC. The company should be encouraged in this endeavour. The company does have a track record of innovative, cost-effective monitoring equipment.

There are currently numerous programs around the country investigating nitrogen use efficiencies and allied research areas in vegetable cropping. These programs should be encouraged to adopt some form of root zone monitoring.

In our research, we routinely found high levels of residual N in research station and on-farm soils, with subsequently little crop yield response to additional nitrogen fertiliser. In the light of improvements in irrigation efficiency (and thus presumably less leaching), it may be timely to re-examine nitrogen budgets and recommendations for vegetable crops.

Other irrigation tools and technologies

We are seeing substantial interest in precision horticulture, mechanisation, automation, robotics, remote sensing, and high investment production systems. One of the key components/directions for these technologies is to take the variability out of the systems. Although costly, proximate drip irrigation systems have the capacity to be very precise and responsive in their delivery of irrigation and nutrients to crops. Because of the increased costs, proximate drip irrigation is only likely to be widely adopted in permanent bed systems, where the costs can be amortised over several seasons. Perhaps another favourable situation is where management of salts and nutrients is critical, e.g. very poor quality water, or close to environmentally important ecosystems.

There are a number of very useful irrigation system evaluation and monitoring tools developed and/or promoted by the National Centre for Engineering in Agriculture. It would be useful if the irrigation service industries, consultants, and even producer organisations, could be continually made aware that these tools can be effective in helping irrigators fine-tune, or evaluate their systems.

We suggest that plant-based sensing is still very much in the experimental and research arena. It is unlikely we'll see any major commercially viable systems in vegetable cropping in the near future. The EM38 technologies are already being widely used by consultants in broad acre industries. We feel they have merit as planning and diagnostic tools for vegetable farms, particularly when looking to make most effective use of new infrastructure investments, or the most appropriate locations for crop monitoring tools. The PIMS and DSL systems best fit in the diagnostic consultants' toolbox.

Production efficiency does not always mean using less of an input. It can be as simple as getting more product for the same, or even greater level of input. In our research, we had several instances where by managing inputs better, we improved yields (e.g. population density in sweet corn). In vegetable cropping in particular, this can often be about improving the proportion of total yield that is marketable, rather than just increasing total yield. New technologies that drive in that direction are often the most beneficial, and readily adopted.

Biophysical vegetable crop models

We see these models have immediate phenological application for sweet corn, broccoli, green beans and lettuce. We would like to pursue this work with vegetable producers, as it has obvious commercial application. One of the frustrations for vegetable value chains is peaks and troughs in product availability, brought about by normal weather fluctuations. If industries could predict, and ultimately manage their systems to smooth out the fluctuations, it would reduce wastage and inefficiencies in the system. Further advancements would be integrating these tools with long-term weather forecasting capability. They are also being looked at to evaluate potential impacts of greenhouse-driven climate change.

As alluded to by the crop modellers, each of the vegetable models still have deficiencies in the conversion of total yields to marketable product. This is particularly problematic when we factor in extreme weather conditions. There is also the issue of how to deal with a high turnover of vegetable cultivars, and the requirement to re-parameterise the models for the new genetics. Rather than try to attack these issues on several fronts, we believe it would be most useful to focus on a single vegetable crop type. It would also probably be best achieved in conjunction with another project (e.g. a precision horticulture system for sweet corn), rather than as a stand-alone modelling project.

Economic models

Most vegetable growers do not have at hand sufficient information to drive even simple gross margin models. Their business structures are such that we believe it is virtually impossible to develop a one-size-fits-all whole farm model. As our project progressed, we became more convinced that the best use of the models was to demonstrate principles and interrelationships. This is best achieved in a workshop or training situation.

We would like to further develop the spreadsheets we used in this project to be more adaptable to various forms of input (e.g. the AUSVEG GM tool), and easier to adjust the linkages between technology options, yield, seasonality and price outcomes. However, we are uncertain as to the demand for this type of information. We have found growers much more willing to talk about technical aspects of their farming operations, as opposed to their financial issues.

Policy extension

We continue to encounter issues in the regulatory and policy arena that don't seem to mesh with experiences and knowledge in the vegetable growing world. For example, we often hear statements in the non-vegetable growing community like:

- Growers with restricted water allocations should shift to higher value crops
- Growers should use drip irrigation – it's more efficient
- Growers are polluting the environment with pesticides and fertilisers
- For growers to be more efficient irrigators, they need to use less water
- There's a whole lot of expensive, electronic irrigation technology out there; if growers were any good they'd be using it
- All the above things are obvious. The only reason they're not happening is because growers are unaware, don't care, or they just need a financial incentive.

It has been an important part of our project that when points like those above arise in discussions, we demonstrate that they are mostly untrue. As mentioned in the previous extension section, we have been forthright in presenting what we see as the facts as opportunities arise. By using economic models, experience, hard data from experiments and case studies, and logical argument, it is actually relatively easy to negate most of the bullet points above.

It would be very useful to be able to provide industry with the resources, facts and ongoing tools to be able to demonstrate the ongoing, positive improvements vegetable industries have been making in terms of irrigation and general production efficiency. Then it's just a matter of dealing with the politics, which is a whole other story.