UNIVERSITY OF SOUTHERN QUEENSLAND

NCEA

National Centre for Engineering in Agriculture

Improving irrigation efficiency through precision irrigation in South East Queensland

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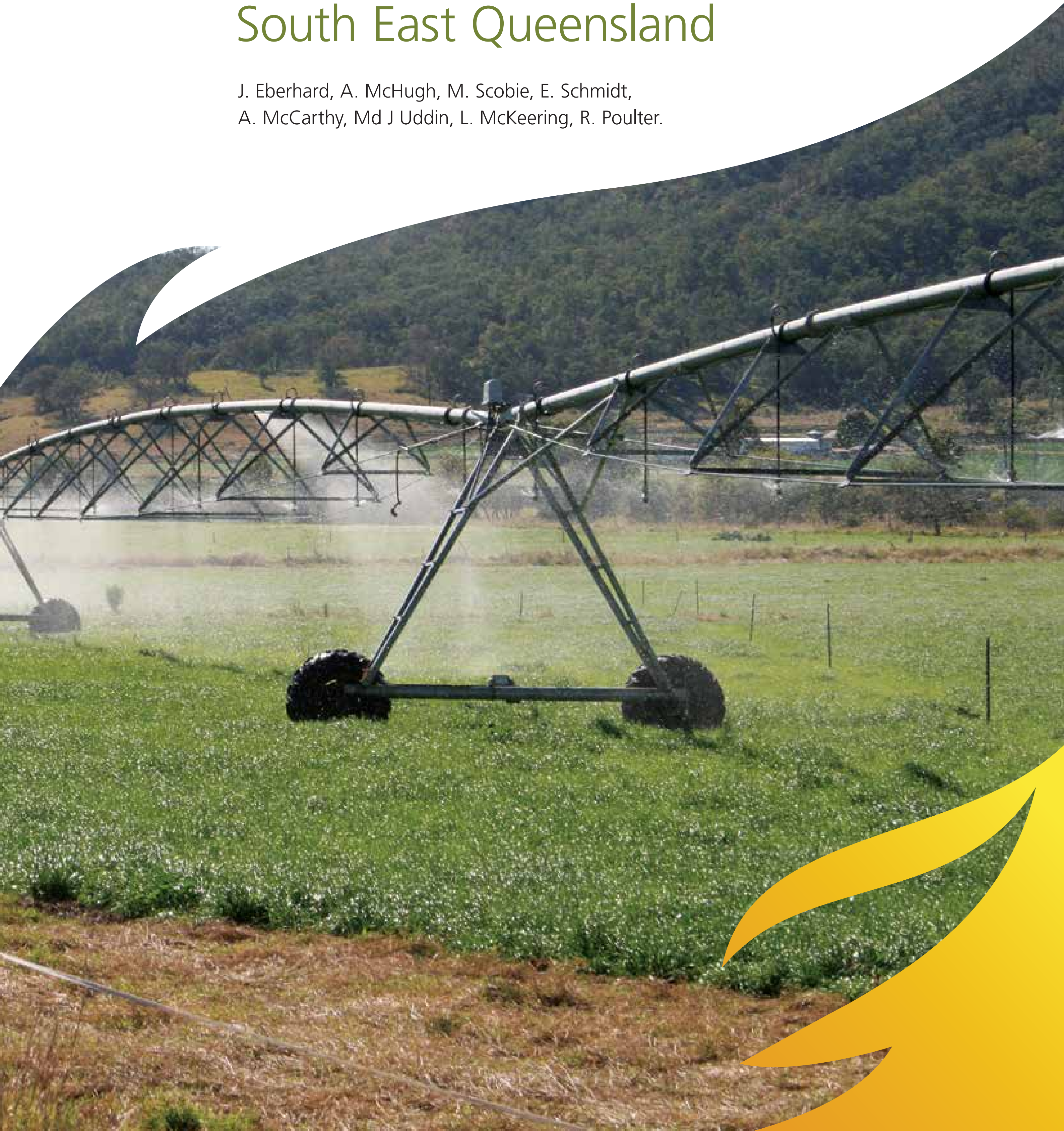


About this knowledge harvest document

This document provides an overview and summary of selected activities of Research and Development Support (RADS) through the South East Queensland Irrigation Futures (SEQ-IF) program and the tools and technologies investigated by the NCEA. The document is not a comprehensive and all inclusive handbook for modern day irrigation practice but outlines many issues encountered in South East Queensland irrigation communities. The report highlights the opportunities for and potential solutions towards improving irrigation efficiency through precision irrigation.

While technical detail has deliberately been kept to a minimum, examples of leading edge technologies are provided, with sufficient technical background and case study examples to illustrate the use of these technologies for improved irrigation management.

Acknowledgements

The significant financial support of the Queensland Department of Natural Resources and Mines is gratefully acknowledged. Growcom Ltd, Queensland Turf Producers Association, Nursery and Garden Industry Queensland, Queensland Dairy Organisation and Flower Association of Queensland Inc are thanked for their close collaboration and in-kind support.

Disclaimer

Preface

Collaborative research

South East Queensland Irrigation Futures (SEQ-IF) represents a partnership between the Queensland Government through its Natural Resources and Mines Department and South East Queensland's five major irrigation industry groups (Growcom Ltd, Queensland Turf Producers Association, Nursery and Garden Industry Queensland, Queensland Dairy Organisation and Flower Association of Queensland Inc).

A key component of the SEQ-IF program has been Research and Development Support (RADS) which has been provided since 2006 by the National Centre for Engineering in Agriculture, a research centre within the University of Southern Queensland. Extension of the RADS project has been provided primarily to irrigators through their Industry Development Officers (IDOs).

Program objectives

Key objectives of the RADS program have been to:

- Provide collaborative research and development outcomes that would underpin a 10% improvement in water use efficiency (WUE).
- Provide the basis for changes in on-farm water management practices and/or uptake of more water efficient equipment and operations.
- Assist in improved irrigation practice through better definition of best management practices and efficiency targets.
- Provide up to date research for SEQ-IF stakeholders by conducting research at a local level, while having access to broader national research developments. This objective was supported through engagement in the CRC for Irrigation Futures research programs.

An overarching goal has been to support improvement in irrigation efficiency in South East Queensland through a move towards precision irrigation.

Methodology

The RADS program was delivered in close collaboration with industry representatives. Priority focus areas, objectives and activities were negotiated on an annual basis with each industry representative. Key aspects in project delivery included:

- Supporting establishment and maintenance of irrigation trial sites in SEQ.
- Providing technical development, local testing and intensive application of tools and technologies as well as decision support technologies to improve irrigation management.
- Providing technical support and mentoring to IDOs and assisting in the delivery of research findings among farmer groups.

The RADS program had a strong technology focus and information generated aimed to:

- Identify and test component tools and technology that improve water management strategies.
- Assess the effect of precision irrigation on crop response and system performance.
- Introduce technologies such as decision support systems, proximal sensing, and energy calculators to provide opportunities for improved risk management, especially under climate variability and change impacts.
- Improve information regarding infield variability to support decisions and risk reduction potential.
- Provide the basis for change in management practices and thus motivate for adoption of irrigation innovation.

Priority research areas

A number of priority research areas were identified with the industry groups during the RADS program. These included:

- irrigation management practice and system performance improvements
- irrigation scheduling and crop water use
- monitoring and measurement for improved water use efficiency
- water storage and delivery systems
- irrigation and nutrient management
- optimising performance and managing infield variability
- measuring and improving energy utilisation
- industry support though extension support and adoption of best management practices.

The research has supported the industry groups in monitoring irrigation and crop production performance, benchmarking, development of best management practice and adoption of technologies to improve irrigation efficiency in South East Queensland. Training, technical support, promotion and communication of research outputs have been important components of the program. Some of the outputs can be viewed under: **http://rads.nceastg.usq.edu.au/RADS/**

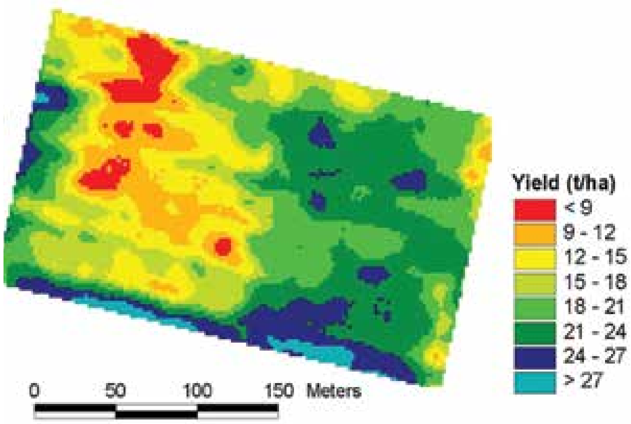
Precision irrigation

An overriding theme of the Research and Development Support (RADS) program in South East Queensland has been research towards improving irrigation efficiency through precision irrigation. The project has developed and evaluated a wide range of monitoring tools, management approaches and control processes that can be applied to precision irrigation as detailed in the chapters that follow.

The traditional meaning of precise irrigation is about applying precise amounts of water to crops at precise locations (e.g. within the soil profile) and at precise times – but uniformly across the field. While this traditional definition is still widely used, precision irrigation as a concept differs substantially from this common usage (Smith et al., 2010). Ultimately precision irrigation focuses on individual plants or small areas within a field, while the traditional irrigation practice takes a 'whole-field' approach (Smith et al., 2010). Precision irrigation:

- involves the optimal management of the spatial and temporal components of irrigation
- is holistic, it should combine seamlessly the optimal performance of the application system with the crop, water and solute management
- is not a specific technology, it's a way of thinking, a systems approach
- is adaptive, it's a learning system
- is applicable to all irrigation application methods and for all crops at appropriate spatial and temporal scales.

Spatial variability in crop production (for example in the following figure) occurs as a result of spatial and temporal variations in soil structure and fertility; soil physical, chemical and hydraulic properties; irrigation applications; pests and diseases; and plant genetics. It is argued that this variability can be managed and economic benefit from irrigation maximized by meeting the specific irrigation needs of individual management zones through a precision irrigation approach.



Paddock-scale yield variation of wine grapes, Sunraysia, Victoria (Cook, Adams and Bramley, 2001)

Four essential steps of a precision irrigation system

There are four essential steps in the process (see figure on next page): data acquisition, interpretation, control, and evaluation (Smith et al., 2010). This Knowledge Harvest document provides many examples of each of these process steps, developed and deployed to support improved irrigation efficiency and precision irrigation in South East Queensland.

In its ultimate form, precision irrigation represents a convergence of advanced irrigation management and application technology with sensing, modelling and control technologies. This implies automation and real-time adaptive control, an example of which is the VARIwise system described later in this document. Similarly, spatially varied irrigation has to a large degree, been driven by the advent of various high technologies, for example, real-time positioning using GPS, proximal soil and crop sensors, remote sensing, variable-rate technology and GIS. This might lead to the perception that precision irrigation is about the use of high technology. However this is not universally true. Precision irrigation is a systems approach to optimise crop yields through systematic gathering and handling of information about the crop and the field. In its most basic form a human being (the irrigator) may provide the data gathering and handling, the learning and adaptation, the control response and the evaluation.

Main themes

The Knowledge Harvest Document has collated many examples of components of the precision irrigation concept under the framework outlined below:

- measuring irrigation system performance
- measuring crop water demand
- managing soils and media
- assessing the effects of infield spatial variability
- managing infield spatial variability
- measuring energy utilisation.

[1]Smith, Rod and Baillie, Justine (2009) *Defining precision irrigation: a new approach to irrigation management*. In: Irrigation Australia 2009: Irrigation Australia Irrigation and Drainage Conference: Irrigation Today - Meeting the Challenge, 18–21 Oct 2009, Swan Hill, Australia.

Knowledge management systems

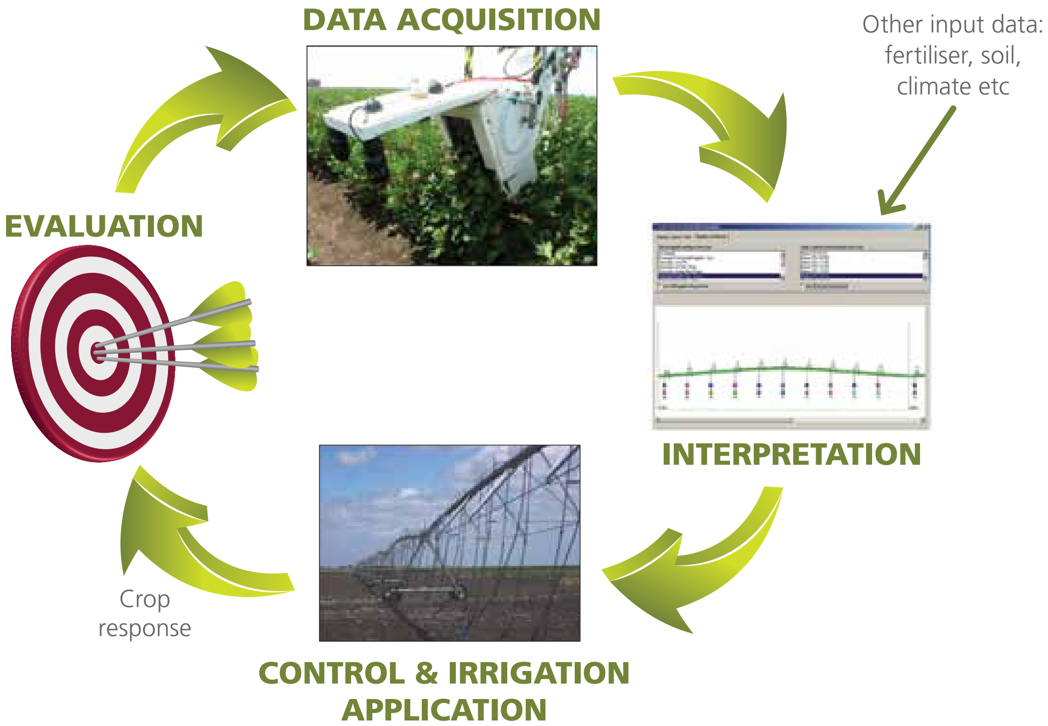
Information management across irrigation landscapes in the region has been identified as a key process to support the on-farm objectives of SEQ-IF. A detailed strategy for a Knowledge Management System for Irrigation in SEQ (KMSI-SEQ) has been developed.

South East Queensland Irrigation Futures (SEQ-IF) is the delivery framework established by DERM for Rural Water Use Efficiency in SEQ. SEQ-IF is focused on improving on-farm water use efficiency in the key regional industries, fruit and vegetables, dairy, turf, production nurseries and cut flowers.

Based on extensive consultation it was recognised that end users, including irrigators, industry bodies, consultants, and NRM agencies require a co-ordinated approach to irrigation information management in the region. There is some information available in the region; however this information is often fragmented, at different scales across the region, requires different levels of interpretation to be useful, out of date, and is not accessible to end users and decision makers.

The goal of KMSI is systems that will improve irrigation information and knowledge exchange in SEQ, particularly relating to:

1. Irrigation extension information – reports and research and simple tools.
2. Databases for irrigation auditing and benchmarking.
3. On-farm mapping.
4. Region-wide information on irrigated area and water use (current and historical).
5. Sundry other information relevant to irrigation in the region Individual applications have been grouped into a structure that covers all aspects of agricultural irrigation.



Precision Irrigation Cycle: (I) Data acquisition (II) Interpretation (III) Control, and (IV) Evaluation (Smith and Baillie, 2009)

Knowledge management system for irrigation

Farm Dams	**ReadyReckoner [Free Access]** The ‘Ready Reckoner’ performs a simple, site-specific economic assessment of the viability of evaporation mitigation systems. The user enters appropriate data to customise the ‘Ready Reckoner’ to their site.
Irrigation Assessment	**Ipart** The Irrigation Performance Audit and Reporting Tool (IPART) is designed to assist in the evaluation and collation of infield irrigation application system performance data. IPART provides a range of functions including standardisation of infield data record acquisition, calculation and presentation of infield irrigation performance evaluation indices, automated generation of grower recommendations and grower report generation.
	IPART Public Access [Free Access] IPART Public Access is part of IPART and is used to view the Application Uniformity of Irrigation Systems. The performance of infield application systems is normally reported both in terms of the efficiency of application and the uniformity of application. The efficiency of the application system is calculated as the ratio of the water used by the plant relative to the water applied. The efficiency is primarily affected by the management of the irrigation and may vary significantly between irrigation events. However, the uniformity of application is primarily a function of the irrigation system design and maintenance. Low levels of uniformity limit the maximum efficiency achievable.
	Ipert The Irrigation Pump Evaluation and Reporting Tool (IPERT) is designed to assist in the evaluation and collation of onfarm irrigation pumping system performance data. IPERT provides a range of functions including standardisation of on-farm data record acquisition, calculation and presentation of on-farm irrigation pumping system evaluation indices, automated generation of grower recommendations and grower report generation.
	Water Manager Tool The Water Manager Tool is a strategic decision support tool used to assess current irrigation management practices and the interactions between crop and irrigation system. The Water Manager tool also develops a personalised irrigation schedule and water budget for the grower based on the characteristics of the enterprise

Irrigation and Crop Records		**EconCalc [Free Access]** EconCalc is a decision support tool used to economically evaluate the costs and benefits associated with a new irrigation system. EconCalc calculates a number of economic performance indicators such as i) Nett Present Value (NPV); ii) annualised costs / benefits (Annuity); iii) the Internal Rate of Return (IRR) and the Benefit Cost Ratio.
		IRUSTIC [Free Access] IRUSTIC is a database reference tool used to identify the seasonal irrigation demand for crops in South East Queensland (SEQ). The IRUSTIC database contains simulated seasonal irrigation demands for various crop averaged over a period from 1970 to 2007.
		ISID The Irrimate Surface Irrigation Database, known by the acronym ISID is designed to collate field measurements and simulation results to facilitate benchmarking of surface irrigation performance at the farm, catchment and industry levels. ISID is fully compatible with the Irrimate™ system. It provides the ability to record and store all data necessary to conduct simulation runs, system evaluation and optimisation using Irrimate™ procedures. However, the system is generic and may be applied to a range of field measurement and evaluation techniques.
		Nutrient Balance and Reporting Tool Nutrient Balance and Reporting Tool is an online nutrient management calculator designed with an interactive data record management system and tiered reporting capability. It will help with the interpretation of soil test values, and record nutrient requirements, actual fertiliser inputs and subsequent productivity data. The data captured by Nutrient Balance and Reporting Tool can also be used to assist broader-scale interpretation (e.g. district, regional or industry scales) and trend analyses.
		Scheduling Irrigation Diary The Scheduling Irrigation Diary is tactical decision support tool with simple irrigation recording and scheduling features based on evapotranspiration (ET). The Scheduling Irrigation Diary allows irrigators to record irrigation and rainfall while also calculating daily crop water use. The Scheduling Irrigation Diary assesses crop water needs (i.e. supply vs. demand) based on the actual irrigation amount, irrigation frequency, rainfall and crop water use.
		Water Resource Info Tool [Free Access] The Water Resource Info Tool consolidates information used by irrigators such as rainfall, ET, commercial storage levels, surface water and ground water information in a single location. Information publically available via the web and from a range of organisations is presented to irrigators by the Water Resource Info Tool.
Mapping		**Gmap** GMap is a map request and repository tool for irrigators in SEQ. The web portal provides a graphical interface that allows users to identify their particular farm based on a Google Maps environment. GMap facilitates the generation of farm resource maps with the appropriate organisation.
Energy Use and GHGs		**EnergyCalc** EnergyCalc assesses direct on-farm energy use, costs and the greenhouse gas emissions (GHGs) associated with diesel, petrol, LPG and electricity consumption. EnergyCalc examines energy use across key processes within a production system and can be used to evaluate farming practices such as tillage, spraying, irrigation etc.
Benchmarking		**RESSTAT** RESSTAT is an on line irrigation survey questionnaire that can be used to report regional irrigation statistics and benchmark performance. The questionnaire covers details of property ownership and location, irrigated land, water availability and cost, annual irrigated production and area, water use and irrigation management. Questions on demographics, drivers for change and knowledge of rural water use efficiency programs are also included.

http://kmsi.nceaprd.usq.edu.au/

RADs Highlights

Measuring irrigation system performance **PAGE 7**	• Measuring and managing water storage losses. • Measuring water flow rate / system flow rate. • System pressure monitoring (pims). • Irrigation pump evaluation and reporting tool (ipert). • Irrigation performance audit and reporting tool (ipart).
Measuring crop water demand / irrigation scheduling **PAGE 15**	• Water manager tool. • Scheduling irrigation diary. • Historical data analysis. • Relationship between turf yield and irrigation. • Eddy covariance for agricultural crops. • Weight based irrigation scheduling for potted crops.
Managing soil and media **PAGE 24**	• Potting media water retention and degradation.
Assessing the effect of in-field spatial variability **PAGE 26**	• Measuring variability of crops and their development in the field. • Measuring soil variability in the field. • Predicting spatial variability of produce quality mechanically before harvest. • Monitoring and evaluating losses in commercial turf production. • Remote sensing of variability.
Managing in-field spatial variability **PAGE 35**	• Measuring water and nutrient/salt movement in the soil. • Toward adaptive irrigation control of pasture and fodder crops. • Information from in-crop spatial variabillity to improve irrigation efficiency.
Measuring energy utilisation **PAGE 40**	• Irrigation and energy use in the nursery industry.

Measuring irrigation system performance

Measuring and Managing Water Storage Losses

In Australia, more than 40% of the water stored in small farm dams can be lost to evaporation and seepage. In South East Queensland water for irrigation is generally stored only temporarily in small dams which typically range in volume from 5 and 30 ML but can be more than 500 ML. Evaporation from the water surface of up two metres (2000 mm) occurs per year, and seepage losses can exceed evaporation losses on poorly constructed dams. Accurate estimates of seepage and evaporation are required before an assessment can be made on appropriate ways to reduce losses.

It is difficult to accurately measure evaporation and seepage from storages. Evaporation from a free water surface is the result of complex processes affected by incident solar radiation, wind speed, air temperature and humidity, and the energy stored in the water body, especially surface water temperature. Seepage is a function of embankment and basin soils and construction methods.

Regional approximations of long term average evaporation from storage dams can be made from weather station records. Complex models and research equipment such as Eddy Covariance and LIDAR can also be used. A water balance approach provides a much more practical and useful method for estimating losses due to evaporation and seepage.

The NCEA has developed technology to accurately measure and segregate seepage and evaporation losses based on the water balance approach. By measuring changes in water depth for periods when there is no inflow, outflow or rainfall, the components of evaporation and seepage can be directly measured as the change in depth.

Methods to reduce evaporation losses

There are a wide range of methods to reduce evaporation loss. These methods include:

- constructing deeper storages with small surface area
- constructing cells to reduce water surface area
- continuous floating covers
- modular covers
- shade structures
- chemical covers (these are currently being researched by the CRC polymers).

Shade cloth evaporation cover - Stanthorpe

Methods to reduce seepage losses

Once a seepage problem is identified, the nature and location of the seepage loss need to be determined. Seepage could be at a discrete location within the storage, rather than uniformly across the storage floor.

Methods to manage seepage include:

- Incorporation of clay material over suspect areas with appropriate compaction.
- Application of Bentonite which is a type of clay with a very large shrink-swell characteristic that results in a very low permeability.
- Application of Polyacrylamides (PAM), chemicals with typically high molecular weight which can be applied to the soil surface or broadcast over the water body.
- Installation of impervious plastic liners.

The Irrimate™ seepage and evaporation meter

The Irrimate™ Seepage and Evaporation Meter includes an accurate pressure sensitive transducer (PST) which is installed under the water to measure very small changes in water level. An accurate analysis of seepage and evaporation can usually be achieved with approximately 20 days of quality data. As periods of rainfall and storage inflow/outflow cannot be used, the equipment usually needs to be deployed for at least five weeks to ensure enough quality data is collected.

Data analysis is achieved by using regression techniques to compare measured water level changes and local evapotranspiration data. This process allows the evaporation and seepage components of the total loss to be separated, thus determining an average daily seepage rate and a dam evaporation factor, which can be used to convert a local estimate of evaporation to an actual rate of evaporation for a specific water storage. Software (EvapCalc) has been developed to undertake the analysis.

Economics of reducing evaporation and seepage losses

The cost benefit of seepage and evaporation control is a key driver in investment in the technologies described above. The potential cost of installing and operating evaporation or seepage mitigation per unit of water saved ($/ML) will be a function of:

- installation and maintenance costs which are very dependent on site situation and installation issues,
- annual and seasonal losses from storages at the location,
- efficiency of the product or intervention in mitigating evaporation or seepage, and
- storage operating conditions.

Intervention costs need to be compared with the value of water to the landholder in terms of increased crop production, the cost of water to be purchased or the potential to trade water surplus.

Measuring Water Flow Rate / System Flow Rate

Variations in water use efficiency often occur across paddocks and blocks due to mismatched equipment, hydraulic design, leaks, blockages and wear. However, obtaining detailed water use can be technically difficult and expensive as farm irrigation schemes often consist of complex hydraulic delivery networks. 'Smart' technology can be used to measure water use and provide information that can lead to improved irrigation practice and efficiency. This technology may involve using the unique hydraulic signatures of an irrigation system to enable the user to monitor variation in flow rate within a single paddock or block.

Case Study – Dam seepage

An irrigator in South East Queensland was aware that one of his dams was leaking. In an effort to reduce seepage a thick layer of Bentonite was placed around the dam walls. Although the Bentonite appeared to slow the seepage rate, the irrigator was still concerned with the quantity of water being lost.

In an effort to solve this issue he sought the assistance of Growcom Water for Profit staff who used the Irrimate™ Seepage and Evaporation Meter to calculate how much water was actually being lost through seepage. It was estimated that the dam was losing a substantial volume of water, 151 000 litres per day. While the irrigator had been able to tell visually that the dam was leaking he was surprised by how much water was actually being lost when it was presented to him as a number.

A smart water metering system was developed that enabled automatic, high resolution logging of water flow in piped systems measured using connected water meters with an electronic, magnetic or optical output. Post processing of the collected data is implemented to determine the water applied to each block/ paddock and whether there were any inconsistencies in the system

associated with leaks or blockages. The system is battery operated and can be deployed unattended for weeks or months depending on the logging interval. The system could be permanently deployed with a small solar cell. A web-based data presentation was developed within the project.

Possible applications of the smart water metering system include:

- determination of hydraulic signature
- desegregation of water application
- block monitoring
- distribution uniformity mapping
- predictive system maintenance
- irrigation performance assessment
- volumetric water application
- dynamic asset (condition) monitoring
- water resource monitoring
- cost benefit analysis of system changes.

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.

Case Study – Application of ready reckoner

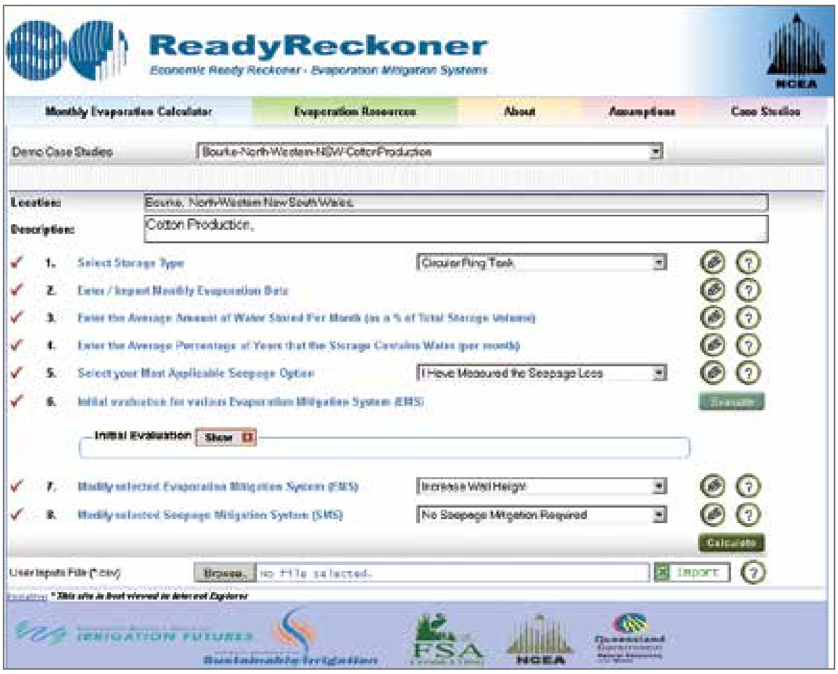
An irrigator with a 700 ML, 16 ha storage in the Lockyer Valley was interested to quantify seepage and evaporation losses. Seepage was not expected to be high based on the heavy black clays which had been well compacted during dam construction. The IrrimateTM seepage and evaporation meter was installed and results confirmed the seepage rates were very low <1 mm/day and evaporation rates were on average 5 mm/day. The Ready Reckoner was used to assess the economic feasibility of reducing evaporation losses by installing a shade cloth cover or by using monolayers. The analysis indicated that a shade cloth cover would save 180 ML/year however when accounting for capital and operating costs this represented an equivalent annual cost of $700/ML water saved.

Monolayers were trialled on the site and were shown to be unreliable and did not achieve the consistent 30% savings required for them to be considered economically viable.

Ready reckoner for evaporation and seepage economic calculation

A Ready Reckoner has been developed (http://www.readyreckoner.ncea.biz) to help undertake a site specific economic analysis of evaporation and seepage interventions. The user enters appropriate data to customise the 'Ready Reckoner' to their site. The 'Ready Reckoner' returns the volume of water saved (in ML) and the cost of the evaporation or seepage mitigation system used to save this water ($/ML saved/year). Inputs include:

- Site location (Latitude and Longitude) to estimate monthly evaporation loss.
- Storage dam size and shape.
- Storage operating conditions in terms of years out of ten the dam is expected to hold water and typical percentage full.
- Anticipated seepage losses.
- Evaporation or seepage mitigation technology to be used.

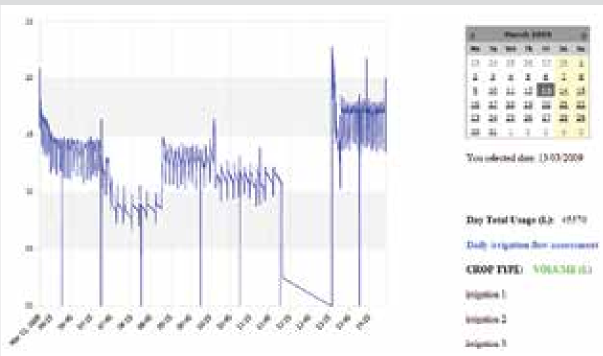


Case Study – Smart water metering system

Stone fruit orchard – micro sprinklers

The smart water metering system was used to monitor water use on an orchard with a number of management blocks and located on the side of a hill. Water was supplied from a waste water dam and the irrigation system was gradually updated using different micro sprinkler bands during the monitoring period. The smart water metering system identified highly variable application of daily irrigation water between individual blocks caused by the variation in elevation and sprinkler bands (real-time hydraulic signatures obtained). The irrigator was alerted to possible water consumption, irrigation optimisation, distribution uniformity and power consumption issues.

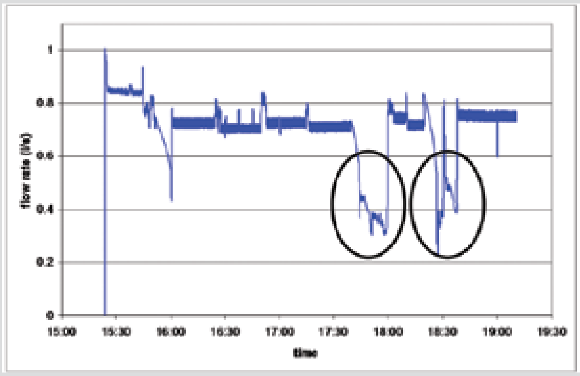
Inspection of the recorded flow measurements also showed frequent, significant fluctuations of the flow rate. This was found to be caused by back-flushing of the disc filters that occurred at an abnormally high frequency (up to three minute intervals). This led to the identification of an incorrect pressure setting for the automatic back-flushing. However, the filter bank had insufficient capacity to handle the sometimes very cloudy (algae) treated waste water and an upgrade was recommended.



Real-time, web-based hydraulic signatures that identify when different blocks are irrigated

Cut flower production – drip irrigation

A small scale drip irrigation system on a cut flower crop was monitored using the smart water metering system after detrimental water stress to a rose crop. This irrigation system used a timer to open solenoid valves and begin each irrigation event. The pump was activated using a pressure switch. The continuous monitoring of the flow rate in this system identified faulty solenoids within two blocks which reduced the water application to lead to the crop water stress.



This case study demonstrates the value of the smart water metering system to detect irrigation system faults in real-time during irrigation events. The system can potentially alert the grower to the system faults which are difficult to detect visually and prevent detrimental crop water stress.

System Pressure Monitoring (PIMS)

Achievement of optimal performance of pressurised irrigation systems depends very much on the maintenance of correct operating pressures. However, irrigation systems are often modified during or after installation to account for topography, varying levels of the water supply factors and this may lead to suboptimal system performance. Wear, aging and blockages in the system can also affect performance. The efficiency and uniformity of the irrigation system can be continuously monitored by measuring pressure water flow at multiple points in the irrigation system throughout an irrigation cycle. The data can be analysed separately or integrated into a performance monitoring system that either adjusts pump speed accordingly, thus saving energy, or informs the operator via wireless technology of any deviation from predefined benchmarks.

A Pressurised Irrigation Monitoring System (PIMS) was developed using a wireless network consisting of independent nodes. This enabled the logging of measurements from analogue and digital sensors to a centralised database. The central unit can send the data via mobile networks for further evaluation and remotely configure the end nodes.

Possible applications of PIMS include:

- irrigation performance assessment
- dynamic asset monitoring
- block and complete duty cycle monitoring
- identification of limitations
- assessment of modifications
- continuous resource monitoring
- pressure uniformity mapping
- disaggregation of water application.

The PIMS internal wireless system offers a flexible approach to telemetry. It can be operated with short distance telemetry modules up to 1 km and greater distances with external antennae. The transmission frequencies are in the free license range (900 MHz or 2.4 GHz) with limitations in undulating landscapes. The end nodes can interface with analogue outputs, frequency outputs from flow meters, digital switches or text outputs. 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. A coordinator interrogates the end nodes at a user specified time interval and logs the data onto an SD card for later retrieval. It also can poll individual end nodes to change their setting (ID, logging interval, communication channel). In the fully customised version, data can be retrieved via a 3G modem.

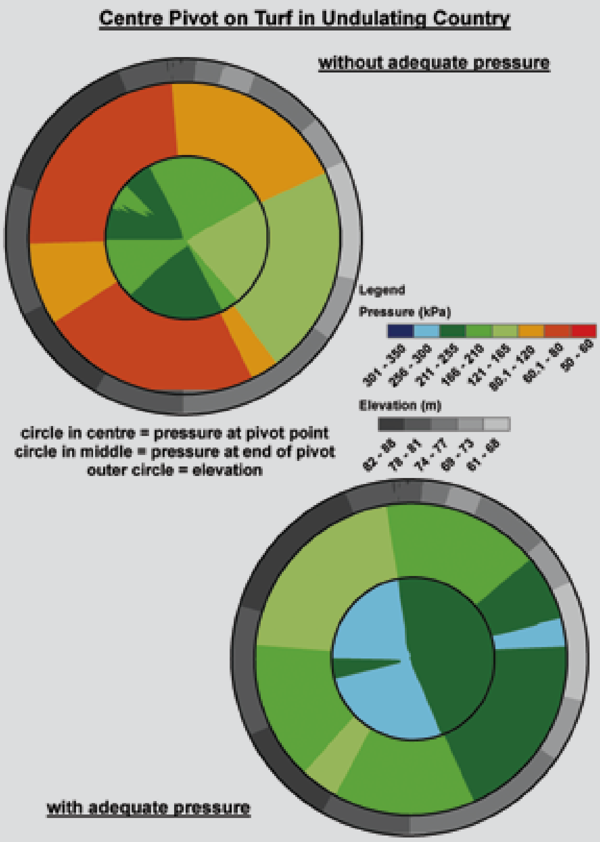
Case Studies - PIMS

Commercial turf production – centre pivot irrigation

A five span centre pivot that covered 23 ha of commercial turf production was monitored using a PIMS. The topography varied up to 25 metres across the field and the water was supplied at the lowest point in the field from open storage. The pump had a variable speed drive but no speed control was installed and the pump was set to run at a constant speed.

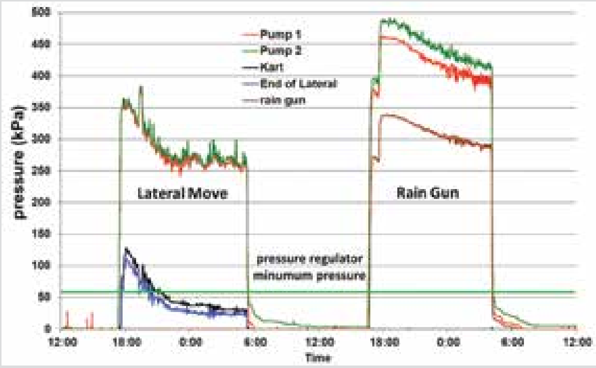
The PIMS measured suction and pressure at the pump, and pressure at the pivot point and the end of third and fifth spans. The first monitored irrigation event revealed that the water pressure at the end of the pivot fell below minimum requirements when the machine travelled over higher ground (which covered half of the irrigated field). This led to reduced performance of the sprinklers at the end of the pivot and the end gun.

The pump speed was adjusted and a second assessment was conducted. This assessment showed there was sufficient pressure when the machine was on higher ground but there was excessive pressure on lower ground. Energy savings and irrigation performance improvements could be achieved with the pump on automatic variable frequency drive.



Dairy fodder production – lateral move irrigation

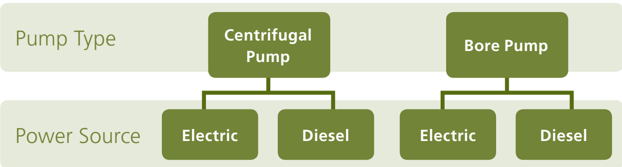
A PIMS was installed on a lateral move irrigation machine that had recently replaced part of a rain gun-based irrigation system. The irrigated field was used for dairy fodder production and the land was sloped. Water was supplied exclusively from bores, where the bores were utilised either individually for the rain gun irrigation system or used in combination for the lateral move. Bore levels fluctuate between seasons and depend on the pumping load. However, traditional methods of irrigation system performance monitoring (e.g. bore capacity, catch can tests) are not coordinated with bore level measurement. PIMS has enabled continuous, synchronised measurements (and comparison) of bore levels, bore pump pressure and the performance of the irrigation system. Inspection of the PIMS measurements showed a significant draw down of the bores and insufficient pressure when the lateral move was on higher ground (diagram, below). To address this issue, the system capacity of the lateral move should be reduced to reduce the rate of irrigation application. This could be achieved by changing the sprinkler package.



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 payback time of costs incurred rectifying system performance."

Irrigation Pump Evaluation and Reporting Tool (IPERT)

The Irrigation Pump Evaluation and Reporting Tool (IPERT) was designed to assist extension staff, consultants and industry development officers in the evaluation and collation of on-farm irrigation pumping system performance data. The program consists of an online data entry interface linked to a database hosted on a centralised server. IPERT provides a range of functions including standardisation of on-farm data record acquisition, calculation and presentation of on-farm irrigation pumping system evaluation indices, automated generation of grower recommendations and grower report generation. Irrigation pumping system evaluations are able to be conducted for the four types of irrigation pumps represented in the graphic below.

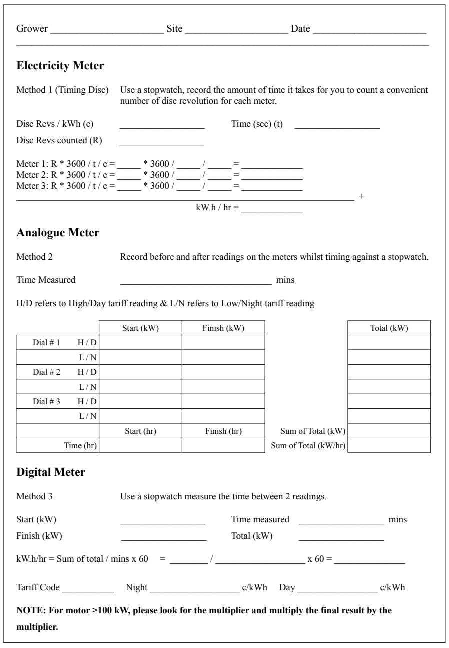


IPERT can import logged sensor data including data obtained using the Pressurised Irrigation Monitoring System (PIMS) units developed by the NCEA. The tool also enables collation and reporting of pumping evaluations at the organisational and regional levels.

IPERT field evaluation data record sheets can be downloaded directly from the IPERT home page. The field data record sheets and the evaluation data entry pages vary for each pumping system but generally include:

- grower contact details
- pump site details
- general conditions under which the evaluation was conducted
- target application system details
- pump and motor details
- measured hydraulic data
- other logged data
- energy consumption details.

All of the major input data characteristics that have been entered are included in the grower report. This report can be tailored to only include information that is of interest to the extension officer or grower. This may include statistics, graphs and other information. The extension officer or consultant can also include any recommendations that may assist the grower to improve the pump efficiency.



Grower ____________ Site ____________ Date ____________

Electricity Meter

Method 1 (Timing Disc) Use a stopwatch, record the amount of time it takes for you to count a convenient number of disc revolution for each meter.

Disc Revs / kWh (c) ____________ Time (sec) (t) ____________

Disc Revs counted (R) ____________

Meter 1: R * 3600 / t / c = _____ * 3600 / _____ / _____ = ________
Meter 2: R * 3600 / t / c = _____ * 3600 / _____ / _____ = ________
Meter 3: R * 3600 / t / c = _____ * 3600 / _____ / _____ = ________
+
kW.h / hr = ________

Analogue Meter

Method 2 Record before and after readings on the meters whilst timing against a stopwatch.

Time Measured ____________ mins

H/D refers to High/Day tariff reading & L/N refers to Low/Night tariff reading

	Start (kW)	Finish (kW)		Total (kW)
Dial # 1 H / D				
L / N				
Dial # 2 H / D				
L / N				
Dial # 3 H / D				
L / N				
	Start (hr)	Finish (hr)	Sum of Total (kW)	
Time (hr)			Sum of Total (kW/hr)	

Digital Meter

Method 3 Use a stopwatch measure the time between 2 readings.

Start (kW) ____________ Time measured ____________ mins

Finish (kW) ____________ Total (kW) ____________

kW.h/hr = Sum of total / mins x 60 = ______ / ____________ x 60 = ____________

Tariff Code ________ Night ____________ c/kWh Day ____________ c/kWh

NOTE: For motor >100 kW, please look for the multiplier and multiply the final result by the multiplier.

Case Study - IPERT

A lychee grower on the Sunshine Coast in Queensland approached his local Water for Profit Growcom field officer to undertake both a system assessment and pump evaluation. The grower had a Kelly and Lewis pump connected to an 11.2 kW electric motor by a belt drive. The field officer printed off the IPERT field sheet which directed the collection of information including physical measurements (motor, suction, pump, discharge, electricity used) and other information (e.g. irrigation system, electricity tariffs). The field officer entered the data into the IPERT online tool. The efficiency of the pump was assessed at its usual duty point delivering 6.5 L/second at 62.3 m of head. The overall efficiency of the motor and pump was calculated to be 27.2% (motor efficiency 87.5% and pump efficiency 33.4%). Using the tariff information collected, the field officer calculated that irrigating using this pump (10.2 kWh/ML/m head) was costing the grower approximately $168/ML.

The grower then invested $6500 on a new direct drive pump, motor, filters, suction line and fittings to improve pumping efficiency and reduce costs. The field officer conducted a follow-up IPERT evaluation of the new equipment at a similar duty point as the initial evaluation (6.7 L/second at 62.8 m of head). The combined efficiency of the new system was calculated to be 40.7% (motor efficiency 87.5%, pump efficiency 49%). This increase in pumping efficiency produced $55/ML in pumping savings. The payback period for this investment would be approximately 2.7 years based on the grower’s average annual pumping hours.

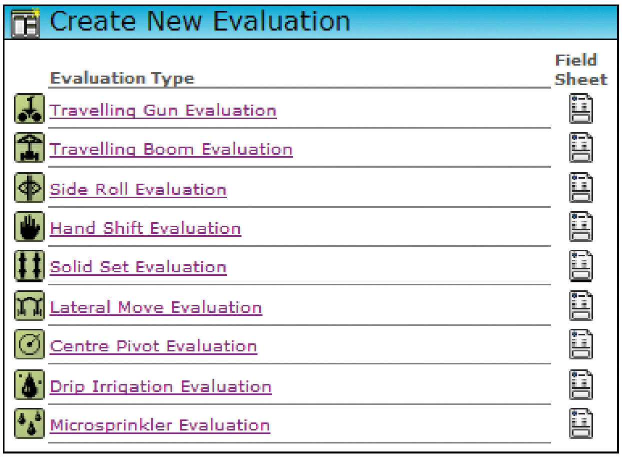
Irrigation Performance Audit and Reporting Tool (IPART)

The performance of a pressurised irrigation system is often dependant on both the design and operation of the system. One important parameter to consider when assessing the performance of an irrigation system is how uniformly water can be distributed across the field. The 'distribution uniformity' (DU) or 'coefficient of uniformity' (CU) are typically used to describe how evenly the water is distributed. These values are expressed as a percentage with 100% indicating a perfectly uniform application across the field.

However, achieving a perfect uniformity in the field is almost impossible as there may be malfunctioning or inappropriately placed sprinklers installed, poor or excessive pressure or flow rate, extra sprinklers added, later system expansion and aging components.

Catch can tests are the standard method for determining the uniformity of pressurised irrigation systems. This data is typically analysed manually and the quality of the outcome often depends on the skill of the person analysing the results and the presentation of the results.

The Irrigation Performance Audit and Reporting Tool (IPART) as part of KMSI is designed to assist extension staff, consultants and industry development officers in the evaluation and collation of infield irrigation application system performance data. The program consists of an online data entry interface linked to a database hosted on a centralised server. IPART provides a range of functions including standardisation of infield data record acquisition, calculation and presentation of infield irrigation performance evaluation indices, automated generation of grower recommendations and grower reports. The online tool is designed to accommodate a range of pressurised irrigation systems including those displayed below. IPART field evaluation data record sheets can be downloaded directly from the IPART home page. After saving the input data it is possible to include recommendations in the report that may assist the growers in improving their irrigation system.



Types of irrigation systems that can be evaluated in IPART

The data requirements vary for each of the irrigation systems but generally include:

- grower contact details
- field identification details
- generic pumping details
- conditions under which the evaluation was conducted
- irrigation system/machine details
- water usage
- field topography
- catch can data
- speed measurements for moving systems.

The data is saved in a secure database with restrictions on access to detailed information. This data can be interrogated at a crop, catchment or industry level to identify the development of any temporal or spatial trends.


IPART

Centre Pivot Evaluation

Field Sheet, Created on 24/5/2013 by Michael Scobie

Grower Details
Grower Name
Phone (Work)
Phone (Mobile)
Email
Business Name
Local Address
Postal Address

General
Organisation
Collection Date
Additional Comments

Farm Details
Farm Name
Field ID
Catchment
Description
Latitude
Longitude

Irrigation System
Machine ID
Machine Make
Sprinkler Height above Ground (m)
Sprinkler Make
Sprinkler Model
Design Flow Rate (L/s)
Design Pressure (kPa)
Wetted Radius of End Gun/Device (m)
Pressure Regulators Fitted? Y / N
Pressure Regulator Value (kPa)
Pressure at Pivot Point (kPa)
Pressure at End - Highest Point (kPa)
Pressure at End - Lowest Point (kPa)
Pressure at End - Other Point (kPa)
Elevation at End Relative to Pivot Point (m)
Speed Setting (%)
Speed Setting (m/hr)
Application Depth Setting (mm)

Hours of Operation per Day (hrs)
Days of Operation per Week (days)
Assumed Efficiency (%)

Soil/Crop
Crop
Soil Texture

Pumping Details
Total Dynamic Head (m)
Flow Rate (L/s)

Measurements for Flow Rate Calculator
Water Meter Reading at Start (ML)
Water Meter Reading at End (ML)
Time Elapsed (min)
OR
Water Measured (L)
Time Elapsed (s)
OR
Volume Pumped (ML)
Time Elapsed (hr)

Case study - IPART

A new six span, swing lateral move irrigator with wire guidance was installed in the Lockyer Valley in early 2011 to irrigate horticultural crops including sweet corn and broccoli.

The grower approached the local Water for Profit Officer to evaluate the performance of the new irrigation system. The initial evaluation was completed in early 2012 and incorporated a distribution uniformity and pump evaluation.

The irrigation system performance was undertaken by collecting flow and pressure measurements at various points in the irrigation system. Rows of catch cans were laid out across the field both parallel and perpendicular to the travel direction of the machine. These data were then entered into IPART (Irrigation Performance Audit and Reporting Tool) to calculate the irrigation distribution uniformity.

The figure below shows the data from two (perpendicular) rows of catch cans that were set across the length of the machine. The right hand side of the graph is the cart end of the machine. The arrows at the bottom represent the wheel tracks (towers). The target application was 30.8 mm whereas the actual average application was 35.1 mm ranging from 16.7 mm to 51.9 mm.

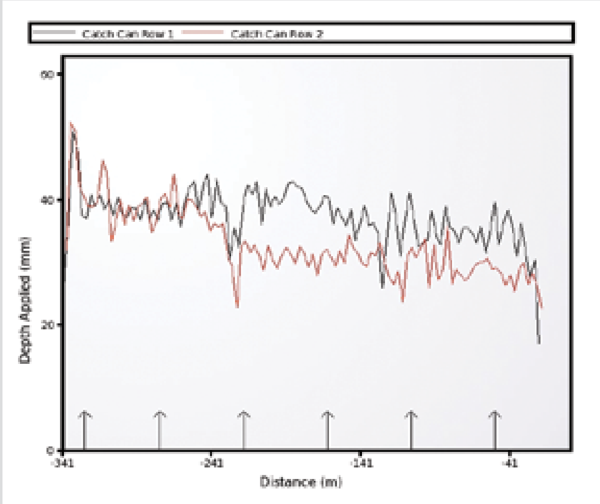
The table below highlights the variation in distribution uniformity and average depth applied.

Catch Can Row	Distribution Uniformity (%)	Average Depth Applied (mm)
Perpendicular 1	85.6	37.1
Perpendicular 2	82.0	32.8
Parallel 1	71.5	37.5
Parallel 2	73.6	35.2
Parallel 3	77.2	34.9
Target	>90	30.8

Pressure and flow data collected at the delivery pump was entered into IPERT (Irrigation Pump Evaluation and Reporting Tool) to evaluate the pump performance. The pump was found to be supplying insufficient pressure. According to the manufacturer pump curve, at a flow rate of 56 L/s, the Total Dynamic Head (TDH) produced should be approximately 55 m; however it was only 51 m.

The issues identified during the initial evaluation were:

- insufficient pressure at the machine
- poor uniformity, both across the length of the machine and in the direction of travel
- discrepancies between control panel and Percentage Timer Report
- alignment of towers
- significant pressure losses across the check valve
- discrepancies between inline water meter, ultrasonic flow meters and sprinkler chart
- delivery pump not generating the correct pressure.



Data from perpendicular catch can rows during the initial evaluation (arrows mark the towers)

A follow-up evaluation was completed in late 2012 after a series of recommended changes had been made. This evaluation showed improvements in uniformity bringing it to just within the target range. The target application was 22.5 mm, while the average application was 25.4 mm ranging from 9.5 mm to 34.2 mm. This shows an improvement between the target application and the actual application depths applied.

Catch Can Row	Distribution Uniformity (%)	Average Depth Applied (mm)
Perpendicular 1	88.3	26.4
Perpendicular 2	86.4	24.8
Parallel 1	94.3	26.8
Parallel 2	93.5	24.3
Parallel 3	91.7	25.7
Target	>90	22.5

The data presented above demonstrates the value of catch can and IPERT evaluations on irrigation system performance. However, further issues with this irrigation system need to be resolved. For example, further improvements to the distribution uniformity of the lateral move irrigator could be achieved by improving the performance of the pump and installing an in-line water meter to generate the correct pressure.

Measuring crop water demand / irrigation scheduling

Water Manager Tool

Irrigated agriculture relies on balancing the available irrigation water with the plant water requirements. This balancing act is restricted by the capacity of the irrigation infrastructure to deliver or apply the water to the right place at the right time. Irrigators can make better decisions on how and when to irrigate by having an understanding of all components of the system and plant water requirements.

The Water Manager Tool is a strategic decision support tool used to assess current irrigation management practices and the interactions between crop and irrigation system. The Water Manager tool also develops a personalised irrigation schedule and water budget for the grower based on the characteristics of the farm.

The Water Manager Tool: calculates the system capacity and crop irrigation requirements; compares actual practice with crop water requirements; and then determines an appropriate irrigation schedule.

System capacity assessment

The **System Capacity** is an important design parameter for irrigation systems and refers to the maximum volume of water that the system can apply to the field or block. If the system capacity is too low to keep up with peak crop water demand, the crop will never be fully irrigated which may lead to yield reductions. The **Operating System Capacity** is the system capacity considering the time when the pump is not running **Pump Utilisation Ratio** and the system **Application Efficiency** (ratio of water reaching the root zone)**.**

Crop irrigation requirements

The Water Manager Tool also calculates the crop water requirements using the long term average evapotranspiration from the nearest Bureau of Meteorology and crop coefficients. Part of the crop water requirement will be satisfied by effective rainfall but the remainder needs to be satisfied by irrigation water.

Irrigation requirements and actual irrigation practice

The Water Manager Tool uses irrigation data from growers to compare the crop irrigation water requirement with the amount of irrigation water being applied. This is important even for irrigation systems with the capacity to deliver the crop water requirements to ensure that the irrigation systems are being appropriately managed and the crop can reach its yield potential.

Irrigation system runtimes

The Water Manager Tool can calculate an irrigation schedule to better match the actual irrigation to the crop irrigation water requirements. This schedule informs the grower how much water needs to be applied and how often. Further, if the user enters the irrigation system application rate (mm/hr) the tool will calculate the system run times required to fulfil the irrigation requirement.

Benchmarking irrigation applied

An added feature of the Water Manager Tool is the ability to enter crop yield information to calculate water use efficiency indices. Through the next revision of the tool this data will be added to a database and used to benchmark the annual data against previous years or against other growers of the same crop.

System capacity:

$$\textbf{System Capacity}\ \text{(mm/d)} = \frac{\textit{pump flowrate}}{\textit{area irrigated}}$$

with mm/day = L/day/m^2

The maximum volume of water delivered to the irrigated area per day is called the **System Capacity**.

Pumping Utilisation Ratio:

$$\textit{PUR} = \frac{\textit{runtime per day (hours)}}{\text{24 hours}}$$

The amount of time that the pump is running is called the **Pumping Utilisation Ratio**.

Application Efficiency:

AE (%) = ***Applied water*** (%) – ***losses*** (%)

The **Application Efficiency** is the ratio of the water that actually makes it into the crop root zone.

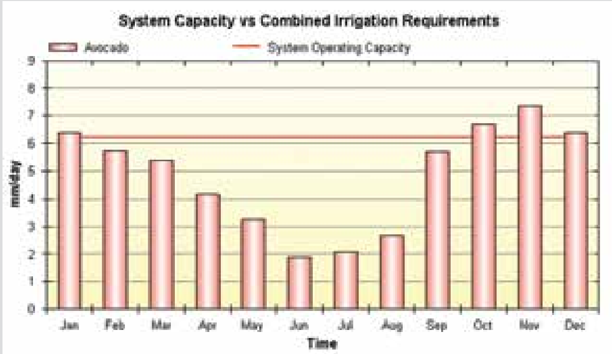
Operating System Capacity:

Operating System Capacity (mm/d) = ***System Capacity*** x ***PUR*** x ***AE***

The **Operating System Capacity** is the water that can be delivered to the root zone per day under normal operating conditions of the irrigation system.

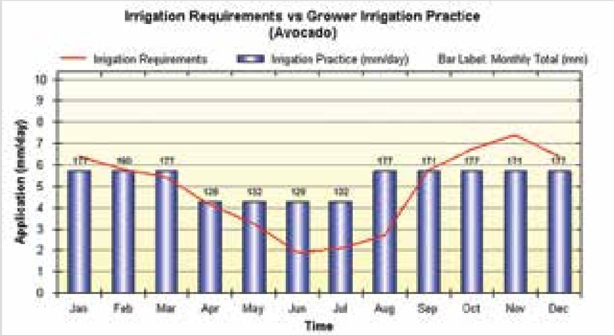
Case Study – Water manager

The figure to the right shows the daily irrigation requirements (vertical bars) for each month for an avocado crop at a specific location in Queensland. The graph shows that significantly less water is needed through the winter months and irrigation water requirement increases sharply when approaching spring. The horizontal line indicates the Operating System Capacity. It can be seen that the irrigation system has the capacity to satisfy the crop irrigation water requirement for the majority of the year, but the crop may begin drawing on soil water reserves in October and November.



The next step is to determine if the grower is managing the irrigation system appropriately. This requires the depths of irrigation water that are applied over the season. This data can be sourced from the grower's Scheduling Irrigation Diary Account or entered manually.

The second graph to the right shows the crop irrigation requirement as the red line that is lowest in June and reaches a peak during November. The blue bars are the actual monthly total of irrigation water applied. It can be seen that the grower is over-irrigating (blue bars are above the red line) from May to August but is under-irrigating (due to insufficient Operating System Capacity) from October to January.



Once the irrigation water requirement has been determined, the grower can use the tool to develop an irrigation schedule (how much water to apply and when). The tables to the right identify the daily irrigation requirements and calculate the amount and frequency of irrigation required. The Water Manager Tool also calculates the system run times required to meet the crop demand based on the irrigation system application rate.

Scheduling Irrigation Diary

The Scheduling Irrigation Diary is a tool in the KMSI (Knowledge Management System for Irrigation) suite of web-based software tools. It is a simple web tool that aims to replace the paper diary that growers use to record rainfall and irrigation amounts. The benefit of the Scheduling Irrigation Diary is that it can generate an irrigation schedule to show which fields require irrigation and when. Another benefit of the Scheduling Irrigation Diary is that it can generate summary data at any time throughout the season, including the total crop water requirement, in-season rainfall and irrigation applied at the push of a button. The tool takes the user through three simple steps: Set Up, Enter Data, and Reports.

Step 1 – Setting up (Farm, soil and crop information)

The user enters the farm name and address and the tool finds the closest Bureau of Meteorology (BoM) weather station to automatically collect default rainfall and evapotranspiration data. If the user has a rain gauge at the farm they can use this rainfall data as it is more accurate for the specific site. The user then enters the crop grown in each irrigation block and details on the soil type, harvest dates and the expected irrigation refill point (%).

Step 2 – Entering rainfall and irrigation data

The irrigation depth (mm) and any rainfall that may be collected on site are entered into the Scheduling Irrigation Diary. The tool displays the amount of evaporation each day. It also shows the grower how much in-season rainfall the crop had received and how much irrigation water has been applied to each block. There is a counter that shows the grower the number of days until irrigation is required (based on a grower-nominated refill threshold).

Step 3 – Producing reports

The Scheduling Irrigation Diary produces two reports: a Scheduling Report and a Complete Report. The Scheduling Report gives details of when each block needs irrigation and how much water (mm) is necessary to refill the profile. The Complete Report generates summary tables and graphs of total rainfall, irrigation and crop water use which can be used to compare individual blocks within a season or the same block over several seasons.

Case Study – Scheduling Irrigation Diary

A farmer grows stone fruit, persimmons and figs under micro sprinkler irrigation in the Lockyer Valley.

The grower currently keeps good records of when he irrigates to calculate fertiliser application rates and has used Scheduling Irrigation Diary on eight blocks of stone fruit crops to see how the tool can help him manage water. He had measured the application rate (mm/hr) of the microsprinklers and recorded how long each irrigation had lasted. Therefore, he was able to calculate the total depth of application in each irrigation. He used his own rainfall data and the evapotranspiration data was provided by the software from the BoM station at University of Queensland Gatton.

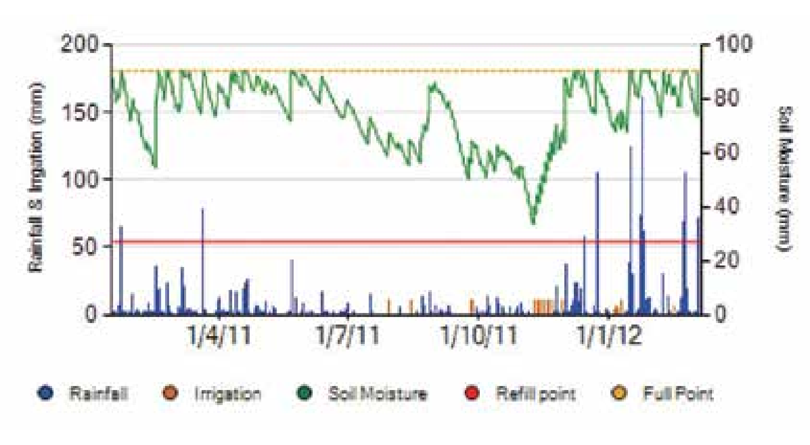
The grower used the Scheduling Irrigation Diary to increase his understanding of his existing irrigation schedule. The graphs presented are outputs from the Complete Report of one of the irrigation blocks.

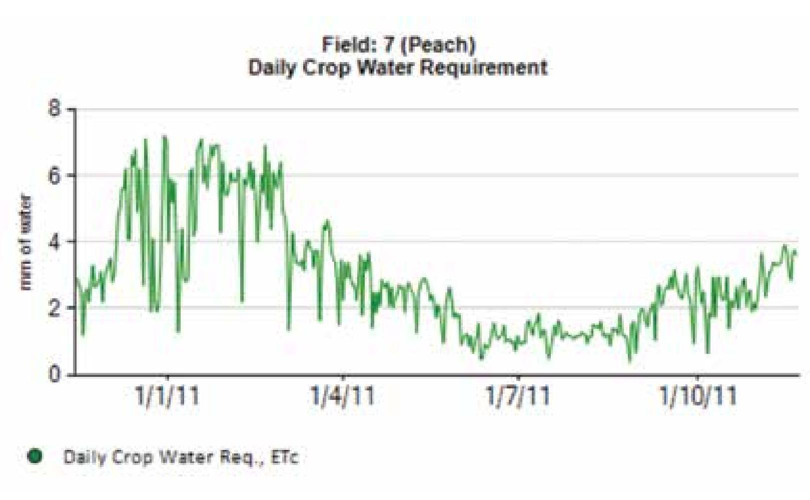
The first graph shows an estimate of the soil water (green line) changing over time with rainfall and each irrigation. As the plant consumes the soil water, the green line falls from the full point (orange line). The user nominates the refill point (red line) and aims to the keep the soil moisture between the full and refill points.

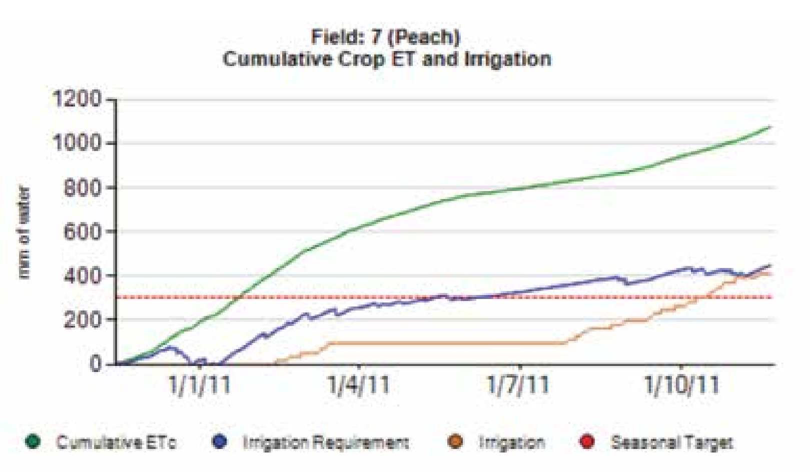
The second graph shows the daily crop water requirement throughout the season (green line) and rainfall (blue line).

The third graph shows a cumulative total for the crop water use (green line), irrigation requirements (blue line), how much irrigation water was applied (amber line) and how much water is budgeted for irrigation (red line).

The graph shows that the crop used approximately 1000 mm of water in the 2011 season. This consisted of approximately 440 mm of irrigation with the remainder rainfall. Ideally the timing and amount of irrigation applied should match the plant water requirements. This graph shows that the amount of irrigation applied matched the plant requirements but the timing of each irrigation event was lagging because no irrigation water was applied before February 2011.







Historical Data Analysis

FAO56 provides guidelines for estimating the water requirements for a range of agricultural crops. However, there is limited data available to estimate water requirements for speciality crops that cover a comparatively small area (e.g. cutflower and nursery industries) and to determine irrigation regimes that produce a profitable crop in these industries. Historical yield and climatic data are available for some industries and these can provide the basis for guidelines to estimate crop water requirement for different species and varieties in a cost effective and timely manner.

The analysis of the yield and climatic data requires consideration of the following factors:

1. What climatic data should be analysed?

- rainfall (total and average daily)
- percentage of positive water balance days.

2. What period of climatic data should be analysed with respect to each yield period?

- 12, 18 or 24 months prior to start of harvest
- monthly, quarterly prior to start of harvest
- end of previous harvest to start of harvest, during harvest, or end of previous harvest to end of harvest.

3. If the climatic data period of interest is reliant on harvest time, how should this be defined?

- full harvest (first harvest until last harvest)
- effective harvest (while harvested quantity gets and stays above a minimum).

4. How should yield be defined?

- number or length of stems, pots, bunches, flower buds, kg, m^3.

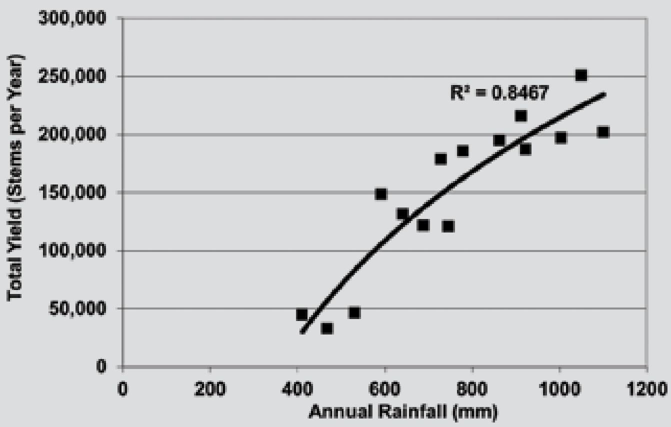
The computational complexity of the data analysis depends on the temporal scale and time period of the yield and climatic data. Large amounts of climatic data (e.g. daily rainfall and evaporation) can be collected from either on-farm automatic weather stations or the Bureau of Meteorology's recording stations. Smaller amounts of data can be analysed manually, whilst larger amounts of data require automated data analysis.

A water balance can be calculated daily by adding rainfall and subtracting evapotranspiration (ET_o). A number of simplifying assumptions can be made to minimise the data requirements, however, these simplifying assumptions can lead to errors in the water balance calculation. For example, for perennial dryland crops harvested once annually, the yield is compared with the total climate data of the 12 months prior to harvest. This is in contrast to field conditions where the yield will depend on the timing of the individual rainfall events and the growth stage. This leads to a more pronounced relationship between the total annual rainfall and the final yield in the desktop study rather than that in the field. Errors could also be caused by the seasonal maximum yield being reached and the rainfall having no further effect.

Case Study – Relationship between yield and rainfall for Protea cutflowers

Daily yield and climatic data were collected and analysed from a dryland protea farm between January 1992 and April 1997. The farm was situated near Crows Nest and produced Protea Pink Ice (hybrid of P. Neriifolia and P. Compacta) in a deep red ferrosol soil. Daily yield data involved the number of stems cut of each length, and climatic data included daily rainfall and pan evaporation values.

Previous studies and anecdotal evidence suggested that Protea Pink Ice experiences growth flushes in winter and/or early spring. However, a comparison of the available climate data and total yield in the subsequent harvest season (between January and April) found no relationship between climate and total yield. Further analysis was required to compare climate data with the stem length rather than total yield.



The strongest relationship between yield and climate was found during the period 12 months before harvest (above). Increased yields were caused by the increasing rainfall and percent of positive water balance days. This trend did not occur with total rainfall greater than 800 mm as the yield could not improve during the positive water balance days and/or more than 50% of days had a positive water balance. This indicates that yield could have reached a maximum (approximately 20 000 harvested stems) during these periods. The higher rainfall periods were also more likely to produce runoff and deep drainage. This would reduce the amount of effective rainfall and actual positive water balance days and potentially lead to a linear relationship between climate and yield.

Relationship between Turf Yield and Irrigation

Turf is primarily used as groundcover for lawns on house blocks. The majority of turf farms in Queensland are situated within 200 km of Brisbane to enable close proximity to customers. This has led to competition for potentially scarce water resources and the need to optimise turf yield and water productivity to sustain a profitable turf industry. This involves determining the minimum water required to sufficiently maintain turf yield.

Turf quality is a combination of turf colour and sod strength (which are closely correlated). Insufficient water supply affects the canopy and sod strength, and reduced sod strength may in turn result in turf losses at harvest. Over-watering in poorly drained soils can reduce turf quality by water logging and causing slowed plant development. However, over-watering often does not significantly reduce plant development in better draining soils, but is an inefficient use of the limited water resources.

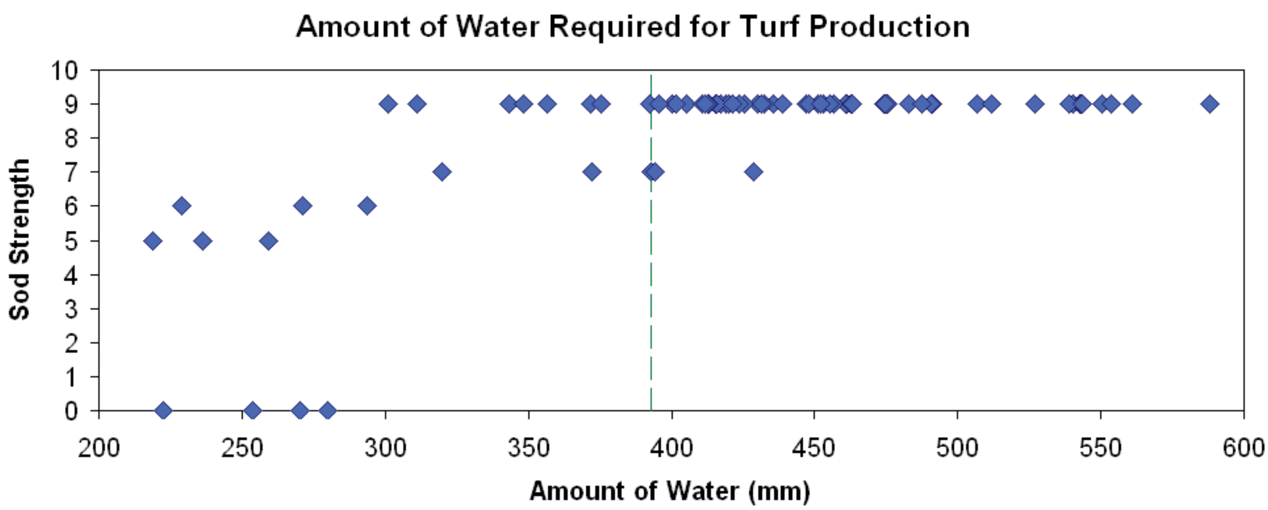
Experimental trials have found a strong relationship between water supply (rain and irrigation) and turf quality (figure below). The minimum water requirement for A grade turf production was found to be 300-400 mm over one production cycle (around six months) for Wintergreen couch *(Cynodan Dactylon)* on black medium clay on the Darling Downs.

Crop factors were derived from the trial to compare the influence of the growing conditions on the crop water needs (see table). The calculated factors are highest with bare soil after turf harvest. This indicates that evaporation from soil of newly cut turf is a major contributor to the overall water requirements and that recovery of the turf after harvest should be expedited to reduce irrigation requirements by up to 40%.

Production Stage	Crop Factor
Initiation/bare ground	0.8
50% ground cover	0.75
75% ground cover	0.6
Just reached 100% ground cover	0.55
Two weeks after reaching 100% ground cover	0.5
Two weeks after previous milestone, until cutting	0.45

Irrigation systems are used to supplement water supply to turf crops between rainfall events. However, poor uniformity of the water distribution from irrigation systems can lead to under- or over-watering of areas within the field. The non-uniformity of the irrigation system often leads to growers applying more water over the whole field to compensate for the areas that receive below average applications. Common issues include:

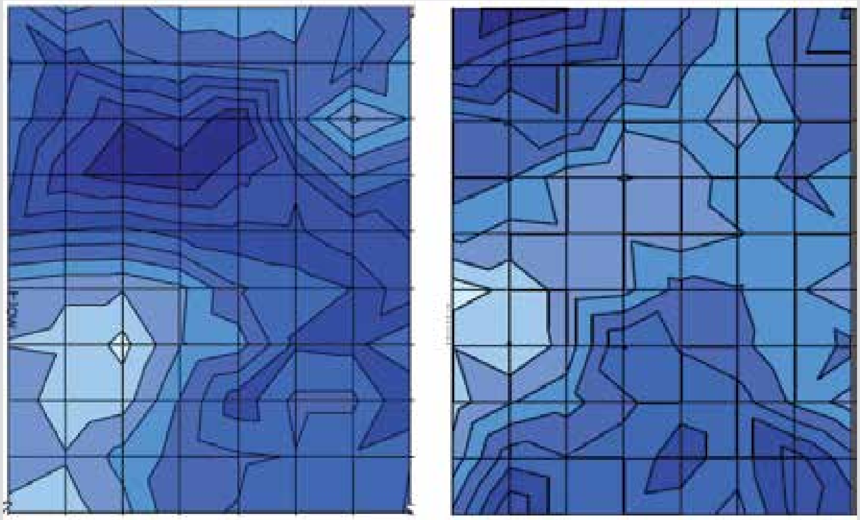
- wrong nozzle type
- sprinkler spacing inappropriate for sprinkler type
- water pressure at the sprinklers too high or low for nozzles.



Case study – Distribution uniformity of sprinkler irrigated turf

A pop up sprinkler system was assessed using catch cans (figure left). This testing showed a 52% distribution uniformity in the irrigation system. Within the turf field, some areas received 2.5 mm/hr while others received 16.4 mm/hr: this led to some areas in the field receiving six times more water than other areas.

The sprinkler nozzles were replaced and the irrigation system was re-evaluated (figure below, right). The distribution uniformity increased to approximately 60% which resulted in an increase in the amount of saleable turf. The increased yield enabled the purchase and installation cost of the new nozzles to be recovered within two production seasons.



Irrigation rate map using old sprinkler nozzles **Irrigation rate map using new sprinkler nozzles**

Each colour increment represents 1.5mm/hr with dark being the highest

Reference: Muller, B 2007, 'Irrigation performance and water use efficiency of turf production', Undergraduate dissertation, University of Southern Queensland, Toowoomba.

Case Study – Eddy Covariance (ECv)

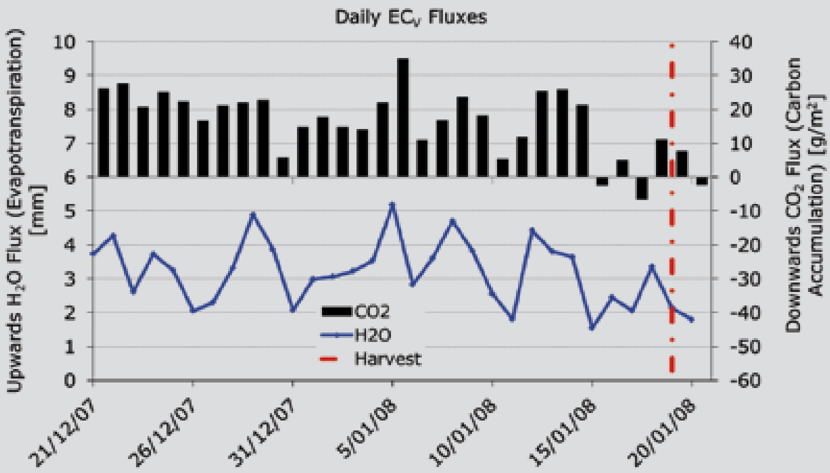
Daily water vapour and carbon dioxide fluxes over lucerne were measured using eddy covariance (ECv) at a dairy farm near Kalbar, Qld. The lucerne crop was harvested prematurely for silage after insect and leaf spot infestations.

The daily vertical water vapour flux from the crop varied between approximately 2 and 4 mm (figure below). The variation between consecutive days was up to 3 mm and corresponded with the weather conditions. The average value up to a week before harvest was ideally just above 3 mm per day. The declining flux level observed towards harvest is an indication of the deteriorating canopy structure due to leaf spot and the lack of soil water.

The CO_2 flux generally correlated with the water vapour flux with levels around 20 g/m^2 per day being assimilated by the crop. As CO_2 flux is primarily driven by the canopy activity it also reflects the vitality of the crop. Up to the end of December the CO_2 assimilation remained relatively constant between 20 and 30 g/m^2. During the days before harvest in January the trend became negative where the crop produced more CO_2 than it accumulated.

Over the evaluation period there was a correlation between water vapour flux and carbon dioxide flux. However, this correlation was less evident on a day to day basis. High evapotranspiration is usually associated with high CO_2 accumulation and vice versa but both components are not only driven by the activity of the plants.

There was a reasonably constant relationship between evapotranspiration measured with the ECv and regional weather records (SILO) with a ratio of 0.8. This ratio increased significantly when the regional weather station recorded high volumes of rain. This was likely caused by the ECv site experiencing different rainfall volumes to the regional weather station several kilometres away.



Eddy Covariance of Agricultural Crops

In irrigated agriculture evapotranspiration (ET) can be used to determine crop water requirements. ET must be estimated or measured accurately as inaccurate determination of ET can lead to over- or under-watering and suboptimal crop production. There are several methods that have been used to estimate or measure ET. The eddy covariance (ECv) method is considered a precise and direct micrometeorological method for estimating ET.

This technique quantifies the exchange of carbon dioxide, methane and various other gases between the earth surface (soil and plant canopy) and the atmosphere. The sensing hardware measures how much water vapour (or other gases) moves away from the soil surface. This method provides a very accurate record of the diurnal water requirements of agricultural crops because the measurements naturally integrate over a larger area than any of the traditional point measurements of soil water.

Possible applications of ECv in agriculture:

- Direct measurement of ET for irrigation scheduling and comparing cropping systems.
- Comparison with other sources of ET, eg. Silo, FAO56, E_{Pan}.
- Estimation of crop factors.
- Characterisation of different plant physical structures between cultivars.
- Impact of wind speed and direction plus other climatic factors on net ecosystem fluxes.
- Estimation of net exchange of carbon dioxide and other trace gases on agricultural land.

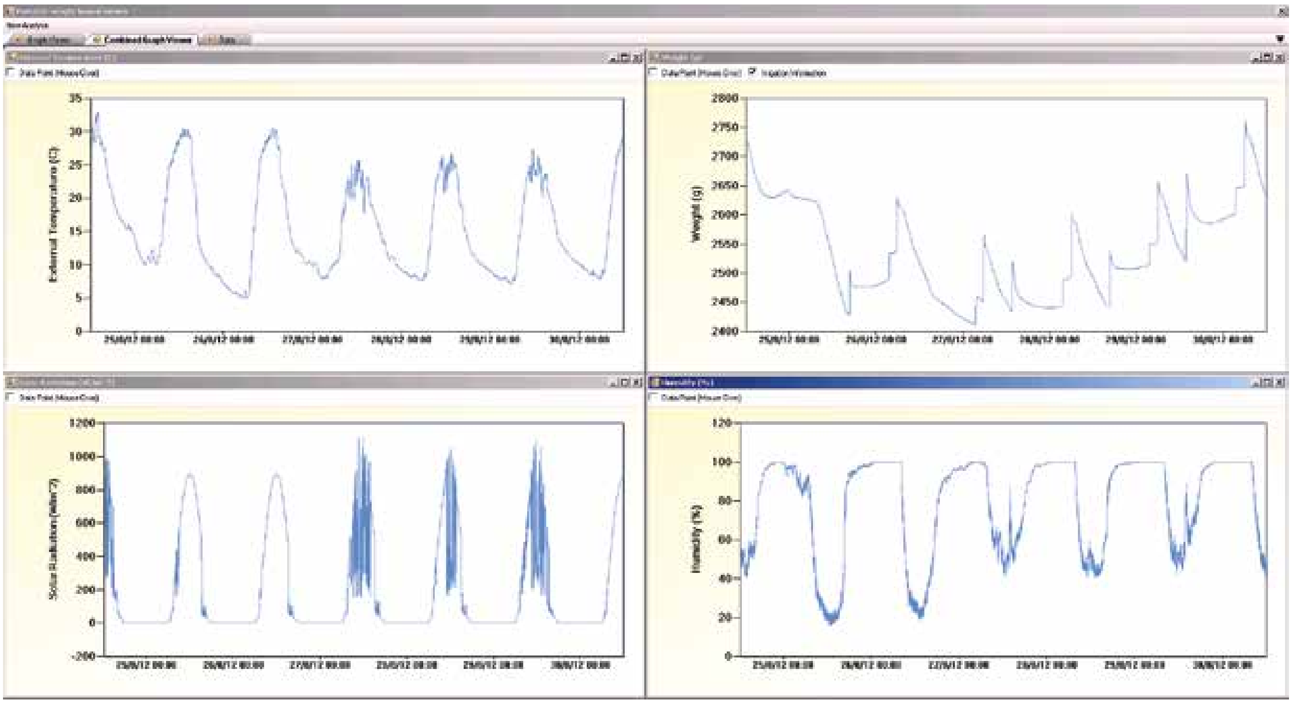
Weight Based Irrigation Scheduling for Potted Crops

The majority of commercial nurseries growing plants in containers currently use irrigation management practices that are fixed and time-based. These schedules are typically determined by individual grower experience with the irrigation fixed to apply water for a set duration and a particular time of the day. However, this strategy depends on the availability of an experienced operator but will be inflexible to respond to daily variations in climatic conditions and hence evaporation rates. In addition, plant growth and potting media water holding characteristics and an almost endless variety of propagation systems can alter watering requirements such that there is no static set of rules on how to irrigate. Hence, the plants may be over- or under-watered resulting in large environmental and economic impacts on business.

This highlighted a need within the nursery industry to develop an irrigation system that could supply the pot plants with the right amount of water at the right time to achieve optimal growth without causing stress and minimising water usage and labour cost. A portable weight-based scheduling system (PWBS) was therefore developed to demonstrate the concept.

The system records real-time pot weight readings from three load cells on a data logger. Radiation, temperature and humidity are also recorded to assist in the interpretation of the weight data. Specifically developed software supports data handling and presentation.

The PWBS can be used to view daily water use, peak demand (rate of change), and the effect of irrigation on micro-climate temperature and onset of plant stress. With this information irrigation timing and volume can be fine-tuned to meet water requirements of potted plants independently of the propagation system (e.g. open, shaded, indoors or ebb and flood, spray or sprinkler) and the plant species.



Start time	Duration (min)	Saturation after (min)	Pot weight full (g)	Pot weight gain (g)	Leached (g)	Max fill rate (g/min)	Average fill rate (g/min)
26/08/2012 5:44	15	11	2615	69	15	10.1	6
27/08/2012 6:00	15	12	2590	89	14	10.4	7
28/08/2012 6:00	15	12	2633	76	24	9.9	6
29/08/2012 13:45	15	15	2602	77	69	12.4	5

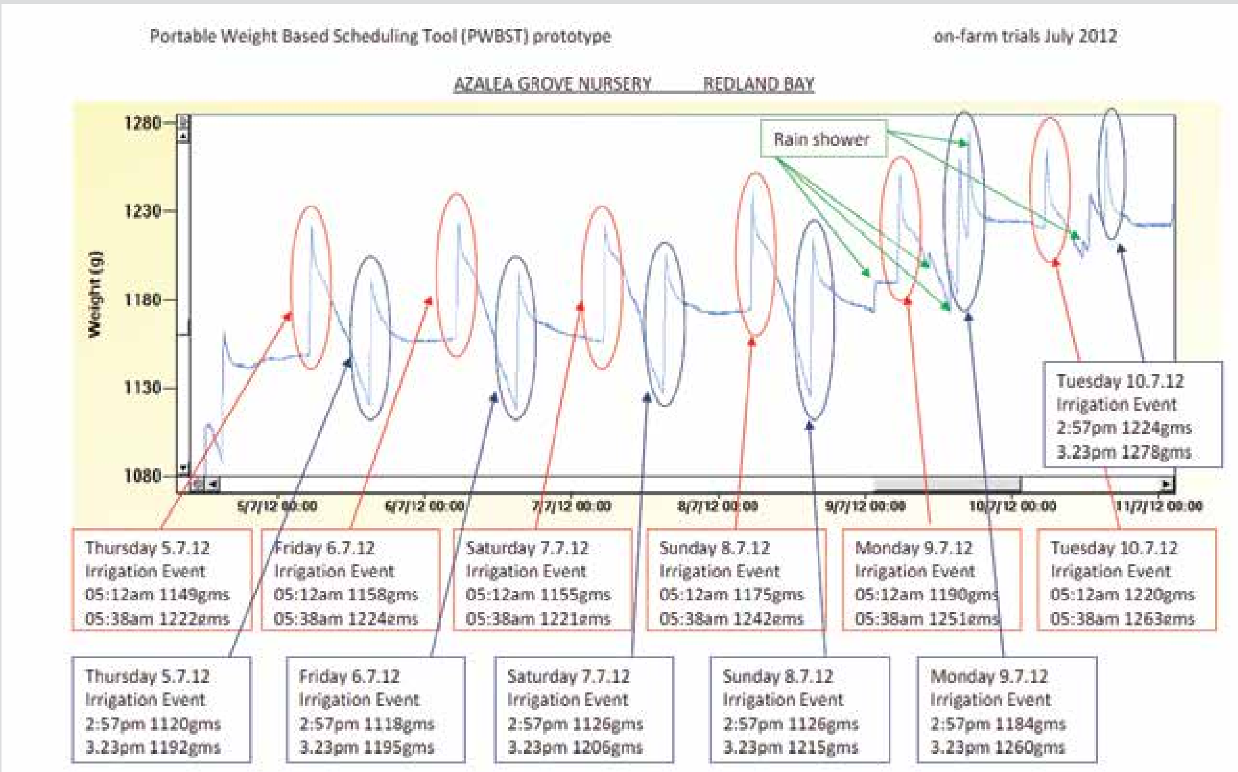
Automation of irrigation decision making using adaptive control strategies is the next logical progression for this technology. However, in the short term, reporting outputs of particular points on the plant weight curves will provide analytical capacity that has not previously been available.

Case Study – Portable weight bases scheduling tool

A nursery irrigates seedlings in medium sized pots twice a day in winter: once early in the morning before sunrise; and again in the afternoon. In summer an additional irrigation occurs late in the morning at around 11:00 am. The grower is confident in this irrigation management practice and the plants rarely show visible signs of water stress. An additional irrigation event would be triggered in the event of visible crop water stress.

Monitoring the seedlings with the PWBS tool revealed fluctuations in pot weights over time. In the graph below the two daily irrigations and some smaller rain events are displayed which on average lifted pot weight by around 50 g. This occurrence indicates that the irrigation regime in the days prior to the rain events maintained a consistent pot weight which indicates replenishment of daily water use. However, the maintained soil moisture conditions may not have optimised crop growth. From the graph, the maximum pot weight on the first three days after the first daily irrigation event was significantly less than the full point for the soil. This can be inferred by the increase in maximum daily pot weight (additional water holding capacity in the pot was available) due to the combination of a low evaporative demand day (9 July) and rain showers. Therefore, the full point on the days prior to the rainfall was not being reached by the irrigation regime imposed and plants soil moisture availability was being kept at a deficit, which is a suboptimal condition for maximum growth.

Use of the PWBS tool also showed that the grower occasionally turned off irrigation in the morning to do some spraying or maintenance. This resulted in one or more irrigation events being skipped which were not accounted for in subsequent irrigation events. The result of this practice is additional stress imposed on the plants as they are forced to grow under conditions of further reduced soil moisture in the pot. Even four days after the irrigation schedule was resumed, soil moisture conditions in the pot had only slightly recovered. This is because the standard irrigation volume was only just sufficient to meet daily water use and not increase net soil moisture. The PWBS tool enabled the visualisation of this situation and the grower to adjust his irrigation management to regularly check the potting media moisture and trigger extra irrigation events particularly if the irrigation system had to be switched off for crop maintenance. Although this change in irrigation practice might increase water usage, it most certainly will increase the productivity of the nursery as crops will become marketable earlier due to easier water accessibility.



Managing soil and media

Potting Media Water Retention and Degradation

A wide range of materials can be used to make nursery container media. Their composition is typically a function of the availability and price of local resources (e.g. pine bark, sawdust, sand and/or peat). Good growing media all have remarkably similar physical properties which are characterised by: large air-filled porosity to provide drainage and avoid water logging; and low water holding capacity or plant available water capacity. Soils with these properties therefore require frequent irrigation to prevent water stress. High frequency irrigation does however increase the risk of water wastage due to inefficiencies in the irrigation system that may be present. Previous studies have found up to 50% of irrigation water applied from sprinklers can be commonly wasted by missing the pot or through drainage. This is a substantial inefficiency in the irrigation system.

A simple and low-cost method of improving irrigation capture and reducing drainage in a sprinkler irrigated nursery is to reduce the irrigation frequency while still maintaining availability to the plant. This can be achieved by increasing the Water Retention Efficiency (WRE) of the growing media. WRE of a potting media is highest when the rate of application is equal to or less than the absorption rate of the media. Therefore, water savings can be achieved by either reducing the application rate of the irrigation system or increasing the absorption rate of the mixture. However, low application rate sprinkler systems have not been widely adopted in the industry due to fears the fine droplets from the sprinkler can lead to increased wind drift and evaporation. Converting irrigation systems can also be expensive because the existing spacing may not be appropriate for new heads.

The absorption rate of the mixture can be increased to improve the WRE of the growing media. For example, the maximum absorption rate of a sawdust, peat and sand mix under sprinkler irrigation is <15 mm/hr. As a general rule, the absorption rate will be lower for more open mixes. Closing the mix down will increase the absorption rate but also reduce drainage. The absorption rate can be increased by including coir in the formulation or by applying a wetting agent to overcome water repellence.

The addition of coir at 10 to 15% by volume of the mixture can significantly improve the water holding capacity. A greater percentage volume of coir in a mix significantly increases the water holding capacity, although there is no improvement in capacity between 50% coir and 100% coir. The increased water holding capacity using up to 50% coir by volume leads to improved available water and, hence water absorption rate and WRE. It also increases the saturated hydraulic conductivity which indicates that fully wetted material maintains good porosity and allows excess water to drain.

Wetting agents are an alternative material to coir to increase WRE, but care should be taken when incorporating them into a media, so that the required effect will be achieved. When water retention efficiency is a priority there is little difference between additions of coir or wetting agents. Coir is more effective in increasing water holding capacity than wetting agents which indicates that water absorption rate can be most effectively improved through the incorporation of coir.

An irrigation system with a high application rate would be suited to media with a high proportion of coir in the mix. The frequency of irrigation could also be reduced by incorporating coir in the media to enhance the water holding capacity and water retention efficiency. This would be valuable in situations where hand watering is required or the irrigation system is manually controlled.

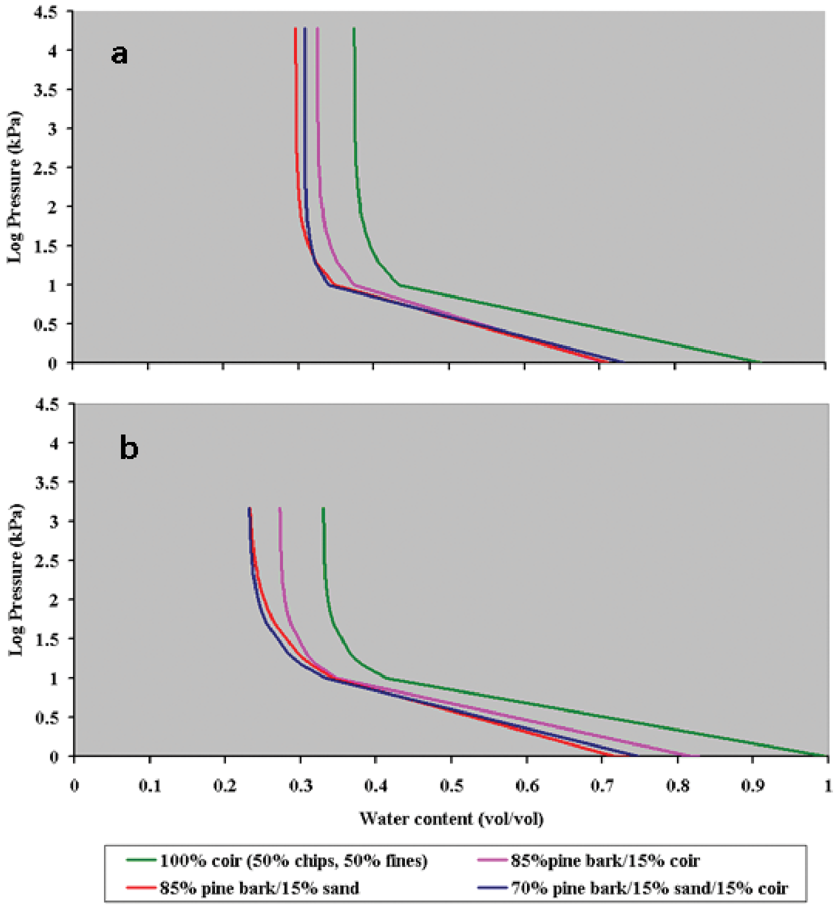
Where there is a specified requirement for sand in the media to provide weight for stability or bark to maintain air filled porosity an understanding of the physical properties allows informed choices to be made regarding the irrigation design, rate and frequency. As a general rule, the higher the irrigation rate the more the media should be dried down prior to irrigation. Irrigation should be triggered at 20 to 30% reduction in the total water held in the media, to achieve the greatest efficiency of absorption.

However, the aging of the media in pots during plant production leads to changes in the drainage characteristics and water retention of the media. For example, after seven months of cropping all standard media mixes maintain their bulk density. The saturated water content only increases in the bark – coir mix, indicating a reduced airspace near saturation. As the residual water content is reduced in all degraded media mixes, the calculated plant available soil moisture increases significantly. In conjunction with the dramatically reduced saturated hydraulic conductivity this indicates a shift to more medium sized pores, away from the dominant very large pores in the new media.

Irrigation management leads to less frequent irrigation to avoid potential water logging conditions. As media holds more plant available water (PAW) there is no need for frequent irrigations. Leaching of salts however could become more of a problem with the reduced hydraulic conductivity.

	85% pine bark / 15% sand mix		70% pine bark / 15% sand / 15% coir		85% pine bark / 15% coir		100% coir	
	NEW	DEGRADED	NEW	DEGRADED	NEW	DEGRADED	NEW	DEGRADED
Bulk density (g/ml)	0.41	0.36	0.39	0.41	0.23	0.22	0.08	0.08
Available soil moisture (g/ml)	0.41	0.51	0.43	0.52	0.38	0.56	0.52	0.66
Ksat[1] (mm/hr)	263	51	329	116	441	60	926	542

[1] Saturated Hydraulic Conductivity



Water retention characteristics for (a) new and (b) degraded potting media

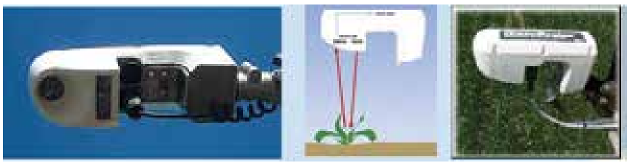
Assessing the effect of infield spatial variability

Measuring Variability of Crops and their Development in the Field

Crop growth is a direct response to the atmospheric and soil conditions imposed on individual plants. Changes in soil texture, soil nutrient levels, soil moisture levels and microclimate within fields can lead to spatial differences in crop growth and potentially yield. Measurement and analysis of the crop response can identify the spatial distribution and magnitude of this variability and potential underlying causes, and to lead to development of mitigation measures.

The spectral response of crops can be measured to determine the spatial variability of crop vigour (i.e. amount or volume of photosynthetically active plant material) as an indicator of infield conditions. The basis for spectral measurement of crops is that green plant canopies absorb red wavelengths for photosynthesis and reflect near infrared wavelengths much more than inorganic materials. Reflectance measurements in the near infrared and red wavelengths are typically compared to calculate vegetation indices. The most commonly used vegetation index is the Normalised Difference Vegetation Index (NDVI).

This methodology is used in earth science (satellites) to measure vegetation across large landscapes, but the resolution of these sensors is typically a minimum 30x30 metres which is insufficient to detect infield crop variability. NDVI sensors are commercially available and targeted for weed spot spraying but are applicable to on-ground crop measurement. These sensors could be combined with a GPS unit to measure the spatial development of a crop throughout the growing season. The output spatial maps would enable the measurement of individual crops at different growth stages and could be analysed to detect long term trends and support farming input recommendations. This implementation would improve knowledge of crop variability within fields and enable the potential underlying management practices that cause the variability to be identified.



Benefits

- Works in any weather (e.g. clouds blocking satellite view), day and night.
- Hand held use or vehicle mounted.
- Adjustable to suit row crops.
- No annual contracts or charges – cost effective alternative to aerial and satellite imagery.
- Significantly less post-processing than aerial and satellite imagery.
- Can be used throughout the season.
- Minimise destructive sampling.

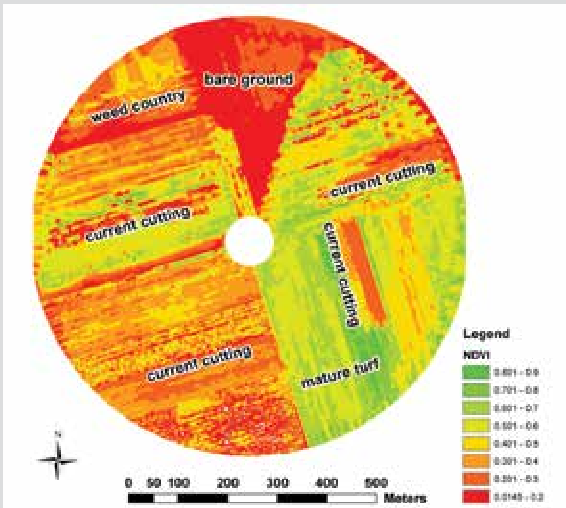
Applications

- Biomass and plant canopy measurement.
- Nutrient response, yield potential, pest and disease impact measurement.
- Real-time fertiliser, plant regulator and defoliant application.
- On-the-go, variable-rate application of inputs.
- Comparative analysis of data using dual index data outputs.
- Crop responses to irrigation performance and changes in topography.

Case Study – Visualising farm organisation

Large scale intensive production areas often have multiple crops at different stages of development. This is because the crops are harvested over smaller areas rather than across whole fields. This leads to additional labour and complexity in the maintenance of production records for the different cropped areas.

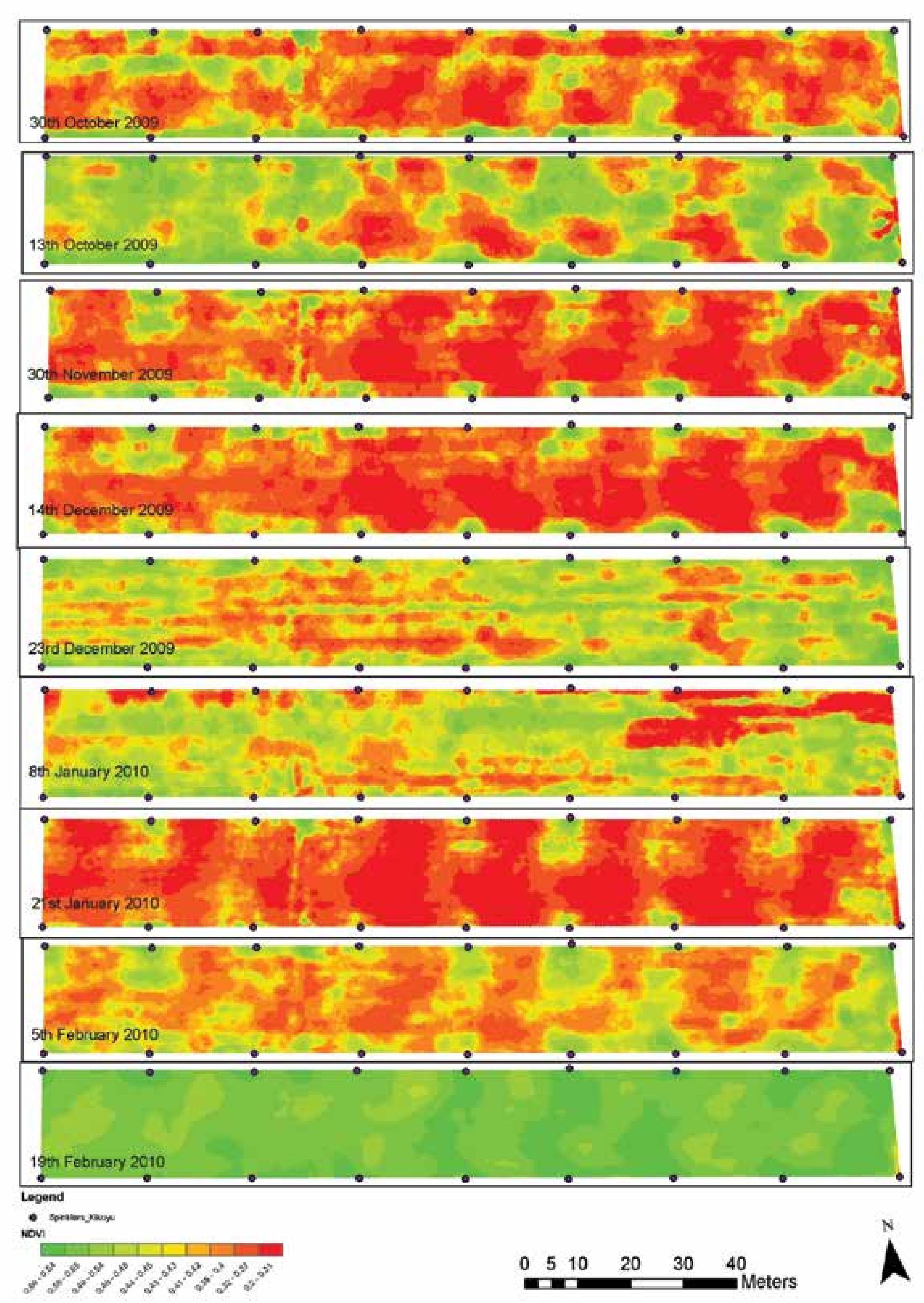
Regular NDVI surveys can be used to visualise the different crop growth stages and where crops have been harvested. For example, the figure below shows a field with crops at different growth stages where green areas are mature turf, dark red areas are bare soil, and the areas between indicate turf at various stage of regrowth.



Case Study – Assessment of irrigation system performance

NDVI measurements can be used to assess the uniformity of irrigation systems. A series of NDVI surveys was taken over a crop season for a commercial turf crop irrigated with pop up sprinklers. These surveys identified a pattern of non-uniform crop development throughout the crop season (figure, below). An overlay of the sprinkler locations on the NDVI surveys indicated that this variability was aligned with the location of the sprinklers, where the turf around the sprinklers and between opposite sprinklers better developed than in the centre of the sprinkler grids.

A catch can test was conducted on the irrigation system and found a Distribution Uniformity (DU) of 62%, which is low for a pop up sprinkler system. The spatial variability in irrigation application followed a similar pattern to the NDVI survey where more water was applied around the sprinklers and between sprinklers on adjacent laterals.



Measuring Soil Variability in the Field

Electromagnetic induction (EMI) techniques are regularly used to assess spatial variability in soil depth, soil type, salinity and the risk of deep drainage of water. EMI provides a measure of the apparent electrical conductivity (EC_a) of the soil profile, which is primarily affected by its clay, ion and water content. If two of these components remain constant across a paddock the EMI can be reliably calibrated to measure the third component.

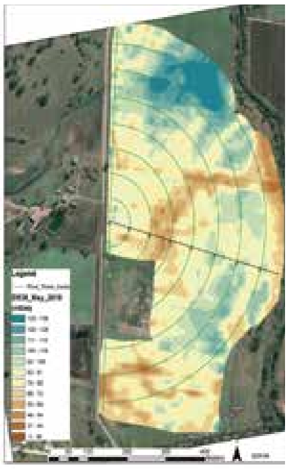
- EMI can be used to evaluate irrigation uniformity and irrigation performance.
- Traditional methods of soil moisture monitoring have been employed with some success but limitations in utilising them efficiently across both time and space have led to restrictions in their use.
- The chief value of the 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. This information can then be utilised to eliminate or at least manage the spatial variation.

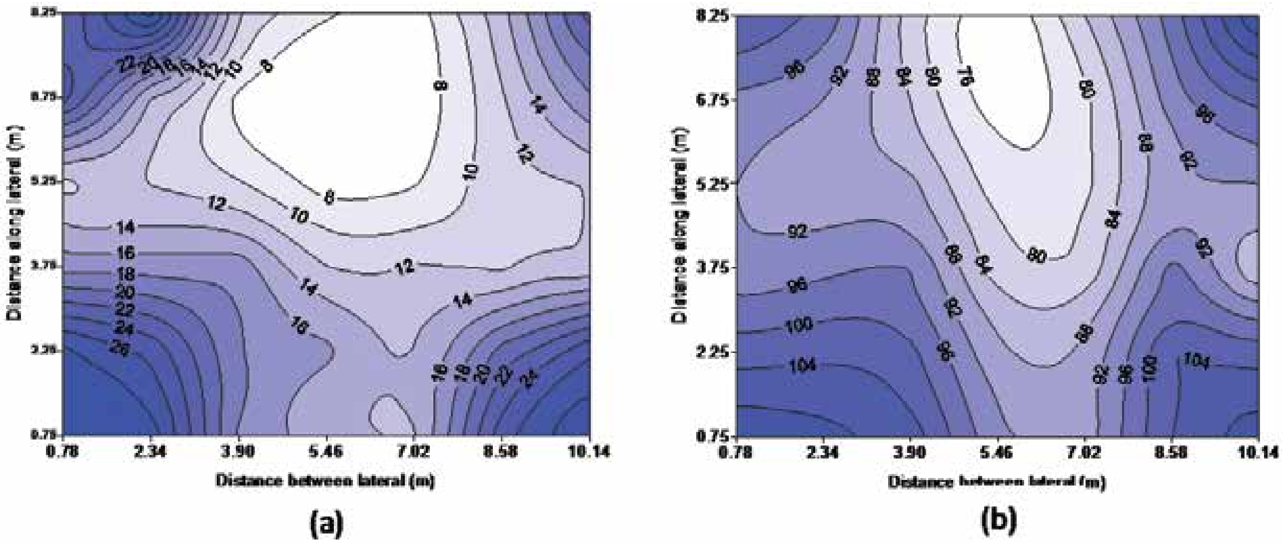
The typical smaller scale farming in South East Queensland is in contrast with the fairly rough scale of existing soil data. The Australian Soil Resource Information System (ASRIS) records two different soil textures for the shaded area in the picture (right), but is not sufficient to understand any variability in crop performance.

The variability in soil texture needs to be identified at a much higher resolution. This is not possible with conventional soil sampling methods thus proximal sensing with an electromagnetic induction sensor is an easy and rapid way to visualise the spatial variability of the soil texture within a paddock. The geo-referenced EMI survey of the same paddock gives a much more detailed picture indicating significant variability in soil texture.

Possible applications for EMI in agriculture include:

- precision agriculture
- identifying subsoil constraints
- measuring soil moisture deficit
- evaluating irrigation uniformity and crop water use.





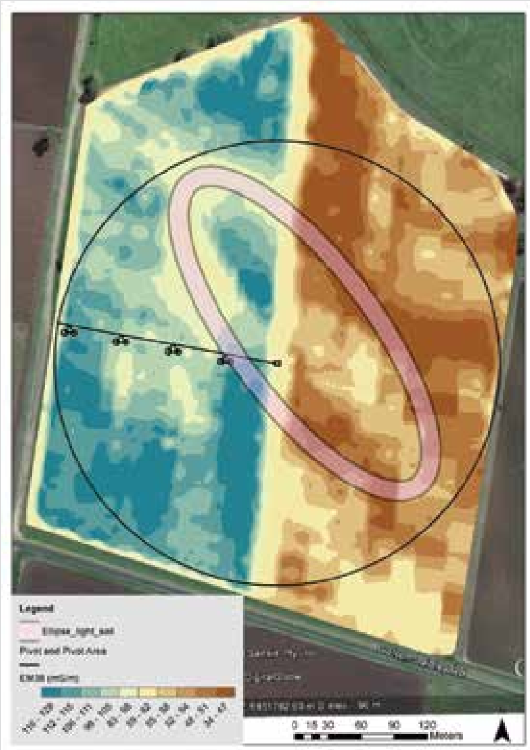
Example for relationship between pattern of (a) irrigation water application (mm) and (b) EC_a (mS/m) under solid set irrigation with poor distribution uniformity.

Case Study: EMI to aid with variable rate irrigation

A four span pivot irrigation machine was newly installed and the heterogeneity of the soil structure was required to aid trial layouts and design of a variable-rate application system.

An electromagnetic soil survey was conducted using an EMI instrument on 12 m transects in north-south direction (figure below). The data was geo-referenced with a differential GPS and presented using standard mapping software.

There was a distinct difference in the overall apparent electrical conductivity between the western and eastern halves of the paddock. This was caused by differences in soil moisture due to different cropping strategies: the western half was fallowed after a maize crop with a more shallow rooting system, whilst the eastern side was lucerne with a deeper rooting system and continuous soil moisture extraction.



The soil under the pivot was generally uniform with exception of lighter soil within an elliptical shaped band in the middle of the pivot area with a north west – south east orientation. A photograph of the field from a previous season showed poorer growth conditions where the lighter soil was identified.

The EMI surveys have provided a basis for designing a variable-rate irrigation system that can provide the identified spatial water requirements. These surveys can also be used to support infield crop management decisions during the growing season.

Predicting Spatial Variability of Produce Quality Mechanically before Harvest (assessing thatch quality of turf)

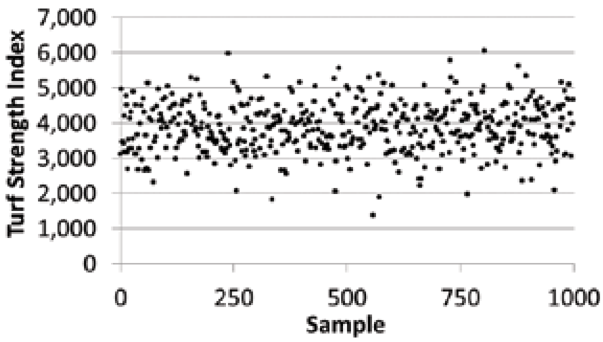
Methods for predicting the quality of a crop before harvest and determining the best time for harvest of an indeterminate crop is typically destructive and relies on grower experience. For example, for turf the colour (greenness) and subjective observations (e.g. sponginess) are used to establish the best harvest date with minimal losses. Spatial variability caused by non-uniform irrigation, fertiliser application, soil variation and general farm management introduces uncertainty into this process. An objective and repeatable method is required to integrate the physical and visual variables into a relationship and simplify and standardise the assessment of the crop development and crop quality.

A prototype on-the-go turf strength sensor was developed and evaluated for mounting behind an ATV. The sensor measures the shear force (labelled "Turf Strength Index") of two rollers running on a slight angle. It was assumed that this force would be proportional to the thickness (strength) of the thatch and root system.

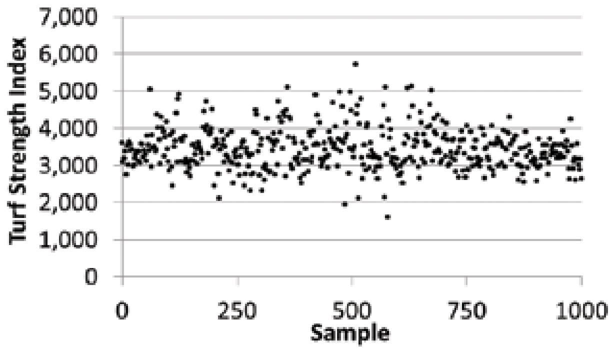
The graphs show some of the data that was collected from turf surfaces at different stages of regrowth. The first figure shows the shear index data from turf that had 95% ground cover and would need up to six more months to reach harvest quality. The following two graphs are from turf which was declared ready for harvest. The data was separated between areas that looked appealing and areas with little visual attraction. With increasing quality of the turf the shear index decreases and becomes more consistent which is supported through the descriptive statistics in the following table.

Descriptive statistics of Turf Strength Index data

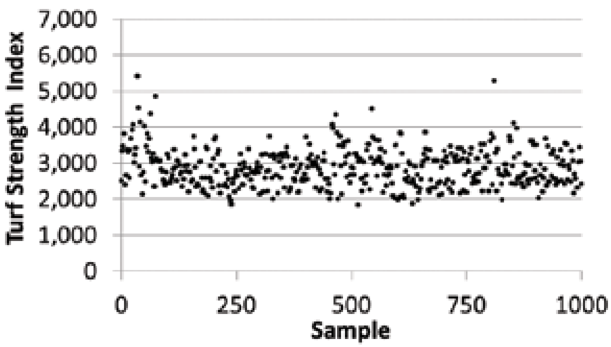
	Turf not ready for harvest (95% ground cover)	Turf ready for harvest	
Turf Strength Index		**"Poor"**	**"Good"**
Average	3876	3429	2865
Median	3871	3377	2811
Standard Deviation	734	545	525



Turf with 95% ground cover

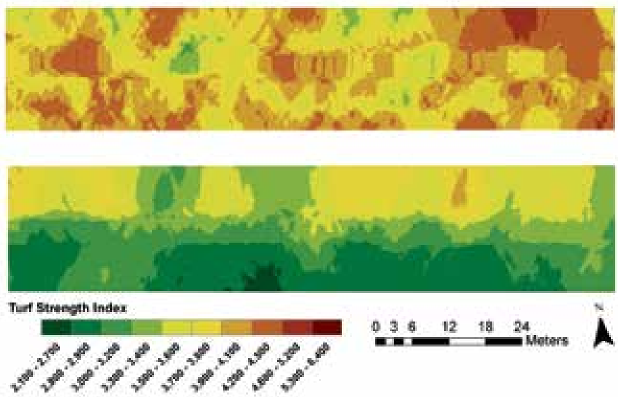


Turf ready for harvest with poor visual appeal



Turf ready for harvest with good visual appeal

Mapping the same data with its spatial reference can return valuable information for managing the crop. Block A is the turf about half way through its growing cycle with 95% ground cover, while Block B is ready to be harvested. The maps again show significant heterogeneity of turf growth while in the regrowth phase and increasing uniformity close to harvest. The sensor had low repeatability during drought conditions when the turf was under-irrigated.



Spatial mapping of turf strength index data

Monitoring and Evaluating Losses in Commercial Turf Production

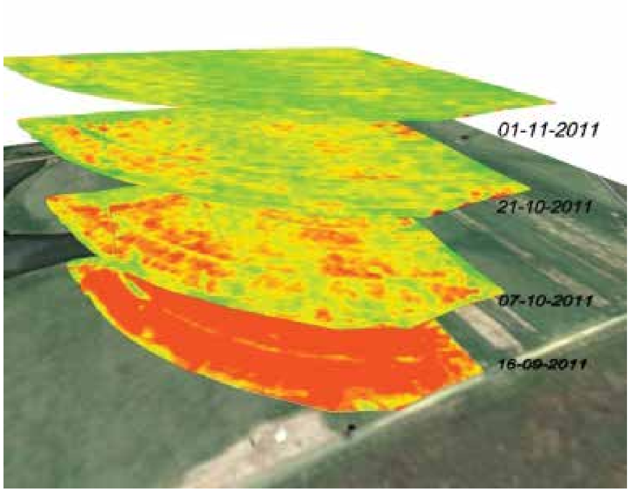
The process of establishing the readiness of turf for harvest typically relies on individual grower's experience and requires consideration of elapsed time since the last harvest and the time of the year (e.g. winter regrowth is slower). The regrowth of the turf can also be assessed visually to identify any abnormalities during the growing period that could delay harvest. This involves assessing colour of the grass, the evenness of the colouring across the area, the sponginess of the turf which is associated with the thatch thickness and a reliable indicator of how intensively the turf has been growing. At harvest each slab is assessed visually (on semi-automatic harvesters tactilely) and discarded if inadequate in quality. This current assessment method is both manual and difficult to automate, with no standardised assessments currently existing for turf readiness.

An approach has been taken to measure turf development during the growing period and use this information to estimate the quality of the turf across the field. This could enhance grower's ability to estimate losses and adjust harvest regimes according to the market situation.

The developed system estimates variable turf quality at harvest from deviations in the average grass development during the growth period. This was achieved by surveying the growth of the turf between harvests at a high spatial resolution and regular time interval using near infrared technology (and use of the Normalised Difference Vegetation Index, NDVI). With this technique, areas with above and below average turf development can be identified.

Areas that maintained below average growth characteristic (i.e. lower NDVI values) until harvest were expected to have poor quality turf. This assumption was used to calculate a Turf Growth Index that would indicate when turf had reached a certain threshold and would be ready for harvest.

Yield monitoring was required to develop and maintain this growth index. However, turf yield is typically only distinguished as marketable or waste. Therefore only the information (quantity and location) about the turf losses was required to correlate the Turf Growth Index with the turf quality at harvest. It was assumed that with the right timing of measurement, only a few NDVI surveys would be required to establish a highly accurate index of harvestable yield and inform the grower on the timing and economics of the harvest activities.



Stacked raster maps of consecutive NDVI surveys

A Turf Growth Index would also enable growers to investigate and possibly address the reasons for the detected losses and increase overall productivity of turf production. In addition, this new concept provides the basis for a crop production system generic enough to be applied for a variety of crops.

Case Study – Turf Growth Index

A trial site with a couch variety covered about a quarter section (4.15 ha) under a centre pivot irrigation machine with a significant slope towards the pivot point. NDVI surveys covered the entire trial area, with limited accessibility to lower lying areas in wet conditions.

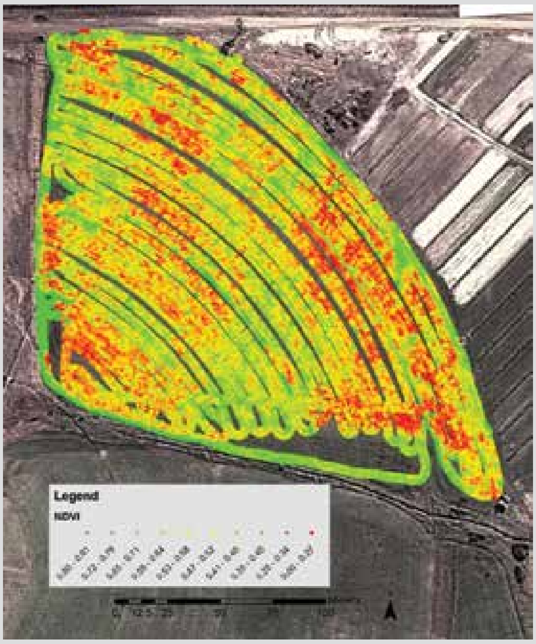
The surveys were conducted on roughly a fortnightly basis over a ten month period (September 2011 – June 2012) with a four sensor array (Greenseeker®, Trimble®) where the sensors were one metre apart. There was some variability in the spacing between transects as no guidance system was used for the surveys. A differential GPS provided the positioning which was simultaneously logged with the NDVI data. During post-processing each NDVI data point was geo-referenced and plotted with the ArcMap 10 software suite.

The statistical analysis of the individual data sets produced maps which categorised the NDVI data into areas with below, average and above average NDVI values. Reclassification of these categories into numbers then provides the basis to sum up multiple surveys and result in the Turf Growth Index (TGi). The derived seasonal TGi overlayed with the location of the rejected turf shows 64 slabs recorded as rejected randomly within this block, although not the entire block was monitored.

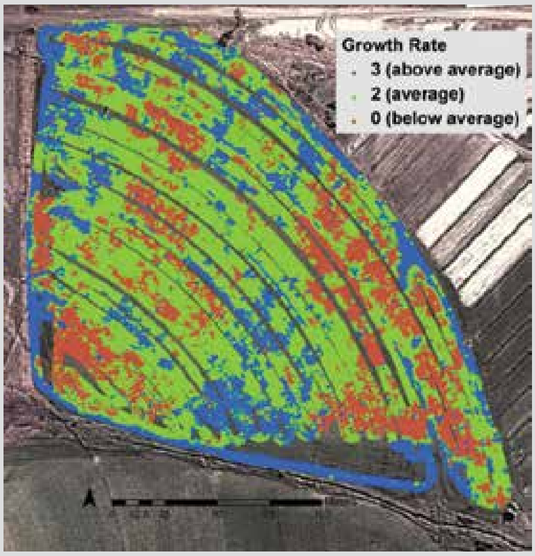
The corresponding statistics reveal little difference between the Turf Growth Index of the rejected slabs compared to the average values. Although the waste slabs have a slightly lower TGi, the minimum and maximum values are within the spread of values across the entire block, see table below.

	Average Growth Index	Standard Deviation	Minimum Value	Maximum Value
Losses	28.5	2.9	21.5	35.4
Total Growth Index	29.9	3.9	14.4	40.6

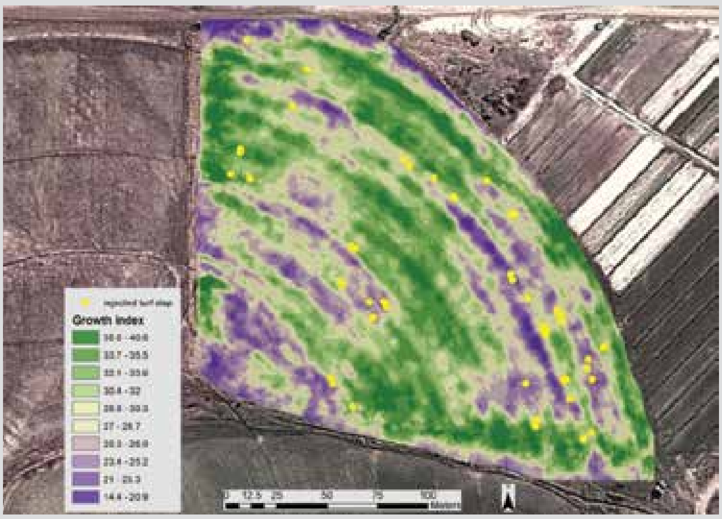
Total turf losses only accumulated to approximately 0.6% during the trial period because the harvest was delayed for six months. Hence, further evaluation is required to establish a significant correlation between turf waste and TGi.



Geo-referenced NDVI data (2011-10-07)



Reclassified Anselin Local Morans 1 statistics of NDVI data (2011-10-07)



Reduced data set to calculate correlation between Turf Growth Index and turf waste

Turf waste monitor

A turf waste monitor was developed for fully mechanised harvesters which are commonly used in the turf industry. This involved the electronic detection of the turf reject button status which inhibits the activity of the fork that picks up the turf slab from the conveyer belt and stacks the slab on the pallet (rather, the turf slab falls off the end of the conveyer belt down a chute). A beam breaker setup was first envisaged to monitor the slabs going down the chute, but lack of mounting points made it difficult to ensure reliable operation. Also a beam breaker would have produced "data noise" with dirt flying off the conveyer belt and slabs often being jammed in the chute and would lead to difficulties in separating individual slabs if more than one was jammed.

The electronic monitoring system was powered from the existing 24V control system of the harvester and considerable testing was conducted to guarantee no interference with the control system occurred.

A RTK GPS was attached to the tractor, a base station set up, and the GPS data were merged with the turf waste monitor output into a csv file. This file was later plotted with the ArcMap 10 software suite. The optical isolator of the turf waste monitor only detects when the reject button is pushed; hence, the length of time of the button push and the corresponding number of rejected slabs had to be extracted mathematically from the recorded data. Analysis showed that for individual slabs the button was pushed for between 1.5 to 2.5 seconds with a minimum of 0.5 seconds. This was consistent and supported by the fact that the conveyer belt ran at a constant speed. The individual waste slab was identified and the location marked for every recorded button push of more than 450 ms for the first rejected slab, and if the optical isolator status remained constant for 2.5 seconds it was assumed that the following slab was rejected. It was also assumed that the operator changed his mind and wanted the following slab to be ejected if the optical isolator status only briefly (less than 1.5 seconds) changed back to "button not pushed" before being pushed again. These assumptions and calculations were not reliable when the button was pushed for a prolonged time and for half-sized slabs at the onset or end of cutting. However, the calculated level of accuracy was deemed appropriate for the low level technical requirements for monitoring the turf waste production.

Turf Growth Index (TGI)

The Turf Growth Index (TGi) is based on NDVI surveys and requires analysis with the Anselin Local Morans 1 statistics. These statistics can test spatial information for clusters and outliers and return defined areas (clusters) with above and below average compared to average values. Outliers are neglected because of the uncertainty within their GPS location. The identified clusters are then labelled as "below average", "average" and "above average" and reclassified with numeric values of "0", "2" and "3" respectively, to allow for a numerical TGi.

This is because areas with below average NDVI values are developing slower than the average. If areas with below average growth at the start of the season change to above average growth levels later they might be able to catch up with the average turf development. The non-linear classifications of "0" for below average "2" for average and "3" for above average turf development were chosen to reflect the exponential function of the growth curve in a very simplistic way.

Remote Sensing of Variability

Site-specific irrigation enables the application of water where it is needed in the field according to the spatial variability of water requirements. This can be achieved by controlling individual valves on the outlets of centre pivot and lateral move irrigation machines. Commercial site-specific irrigation systems are available that provide variable-rate control hardware (e.g. Design Feats, Valley, Zimmatic), but do not provide a process for measuring or calculating the required irrigation amounts across the field.

Soil and weather sensors can be used to estimate crop water requirement, however they may not provide the most accurate indication of crop status; rather, the plant may be the best indicator of water availability. This is because the plants essentially integrate the atmospheric and soil factors that affect plant water status. Infield plant measurement for site-specific irrigation is time-consuming and not practical in commercial cropping situations. Automated, infield plant sensors could be used to indicate the spatial variability of plant response and crop water requirements. Existing plant sensors developed for agricultural systems have involved:

- Satellite imagery to determine multispectral properties and estimate vegetation indices, e.g. NDVI (Normalised Difference Vegetation Index) and RVI (Ratio Vegetation Index).
- Infrared thermometers that are permanently installed in the field or mounted on irrigation machines and collect measurements as the machine passes over the crop.

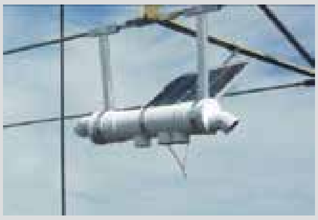
- Cameras mounted on infield vehicles (e.g. motorbikes, unmanned ground vehicles) that collect on-the-go images and analyse the images to extract plant growth parameters.
- Crop vigour and growth sensors on infield vehicles to measure plant height and stress.

Case Study – Estimation of vegetation indices using irrigation machine-mounted plant sensing system

A plant sensing system was developed to measure infield spatial variability for input to site-specific irrigation control systems. The sensing system could be mounted to an irrigation machine and provide data for a single circle in the irrigated area as the machine passed over the field (below). Multiple sensing systems along the irrigation machine or a motor-driven scanning system alone each span would increase the sensor spatial resolution.

Plant parameters widely used in the literature to estimate crop water requirement were plant temperature and vegetation indices, while plant height was used to determine growth stage. These parameters could be measured using off-the-shelf sensors as follows:

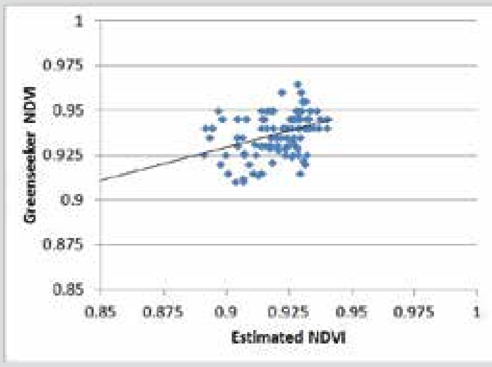
- camera with red and near infrared filters to determine reflectance of crop in red and infrared wavebands and calculate vegetation indices: Normalised Difference Vegetation Index (NDVI) and Ratio Vegetation Index (RVI)
- infrared thermometers that measure temperature of crop under and behind sensing system
- ultrasonic distance sensor to measure distance between sensing system and top of plant canopy to estimate plant height.

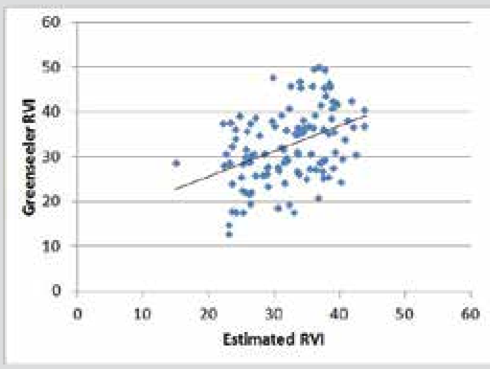


Each sensing system was self-contained, waterproof, solar-powered and Internet-enabled. The systems used a miniature PC that recorded images from connected cameras, and data from thermometers, an ultrasonic distance sensor, and a GPS module. When movement was detected by an on-board accelerometer, the sensing system captured camera images simultaneously at the red, near infrared and visible wavebands (below). These images were then uploaded to a web server with the corresponding temperature and height measurements. A web interface was developed for the sensing systems and is available at **http://hortplantsensor.nceaprd.usq.edu.au/.**

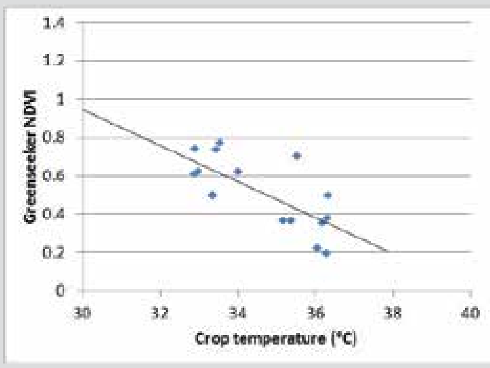
One sensing system was suspended from the supporting structure of an irrigation machine in Kalbar to collect data as the irrigation machine passed over the field. This case study compares the sensing system estimations of plant parameters with ground-based measurements. On 9 November 2012, the NDVI and RVI were measured using a Greenseeker mounted on motorbike and driven over a bean crop.

NDVI and RVI were estimated from the collected images and compared with the corresponding Greenseeker measurements (results below). Only the images taken of the crops under diffused lighting were included in the comparison. Visual inspection of graphs shows that NDVI could be estimated within ±5% of the actual NDVI for mature bean crops, whilst there is more variation in RVI estimation at ±20% accuracy. These comparisons indicate that a camera-based system could potentially be used to estimate NDVI for bean crops. Further evaluation of this technique with plants at different growth stages will enable the full range of NDVI and RVI values to be compared.





The temperature measurements taken of the crop canopy using the sensing system and NDVI measured using the Greenseeker were compared (below). This shows that the crop temperature increased as the crop NDVI reduced. Plant height was measured using the plant sensing system; however, no significant correlation was found between height and NDVI, RVI or temperature.



Managing infield spatial variability

Measuring Water and Nutrient/Salt Movement in the Soil

Nutrient movement through leaching of fertilisers such as nitrate from cropping systems can be a significant contributor to high nitrate concentrations being found in waterways and groundwater. The occurrence of these elevated nitrate levels is known to have deleterious health effects on aquatic life, livestock and humans.

Irrigation management practises can have a significant impact on the leaching of nutrients from the soil. Non-uniformity in irrigation can result in over-irrigation of some regions leading to excess nitrate leaching. Improvements in irrigation management can reduce the occurrence of leaching losses of fertilisers from the cropping system. This can be achieved by reducing the over-irrigation of crops, both at a field scale (matching the irrigation amount to the soil water deficit) and by improving irrigation uniformity within the field and thus reducing regions of over-irrigation which may be occurring.

However, higher water use efficiency can also result in reduced leaching fractions and hence promote the accumulation of salt within the rootzone. This can be further exacerbated by irrigation strategies such as deficit irrigation used to conserve water and the use of marginal quality irrigation water as irrigation supplies become limited.

It is important therefore to maintain irrigation uniformity, schedule irrigation timing and volume to match crop requirements, monitor the quality of irrigation water used and consider requirements for leaching to ensure accumulated levels of salt in the root zone don't reach yield limiting thresholds. It is also important to consider the impact that marginal irrigation water use may be having on the soils and the requirement for chemical amendments such as gypsum to address these imbalances.

Key points

- Management of the rootzone in irrigated soils is a trade off between two conflicting requirements - to minimise nutrient losses and to ensure salt levels don't reach yield limiting levels.
- Leaching is needed to control any build up of soluble salts in the rootzone from the use of marginal irrigation water.
- Non-uniformity of irrigation applications should be minimised, because of its effect on production and to minimise the leaching of nitrate from and the accumulation of salts in the rootzone.
- Consideration for leaching requirement must be made in the calculation of crop water requirements.

Toward Adaptive Irrigation Control of Pasture and Fodder Crops

Site-specific irrigation can potentially improve the productivity of fields with spatially variable crop water requirements. Commercial variable-rate hardware is available; however, the adoption of site-specific irrigation has been limited without the development of irrigation decision support and control systems to determine the irrigation requirements.

An irrigation control system has three components:

- infield sensors to measure weather, soil and/or plant status
- control strategies that determine the irrigation application and/or timing
- irrigation actuation hardware that adjusts the irrigation application.

This generic irrigation control system process can be applied to both constant and spatially varied irrigation management at a range of time scales. Similarly, the actuation of the irrigation application may be either manual or automated.

Case Study – Rootzone salinity with the use of marginal irrigation water

As a result of prolonged dry conditions across South East Queensland in the mid 2000s, horticultural growers with limiting groundwater supplies in the Lockyer Valley were improving the timing and volumes of irrigation based on crop water requirements in an effort to conserve water. In addition saline water sources previously considered unsuitable were being accessed to supplement supply. The combination of these practices highlighted the need to investigate if minimum leaching requirements were being met to maintain salt within the rootzone at acceptable levels.

In 2007 a field trial was conducted within a 4.4 hectare field of baby beets (beetroot) planted on a vertosol soil near Forest Hill. The beetroots were planted on 9 July 2007, with the trial beginning on 3 September 2007. The field was irrigated using two runs of a travelling boom, with water that had electrical conductivity (EC) > 2 dS/m. At two sites, solute samplers were installed at depths of 15, 30 and 60 cm below the soil surface. Solutes were extracted for salinity measurement after each irrigation event and after the one effective rainfall event.

The results showed an accumulation of salts in the rootzone over time, until leaching occurred as a result of the rainfall event. Significant differences in initial EC values, salt accumulation and rainfall leaching were measured between the two sites, presumably due to differences in the volume and timing of irrigation events. According to beetroot yield salinity thresholds (4 dS/m), slight yield reductions due to rootzone salinity were predicted for at least some sections of the field. Whilst a rainfall event near the conclusion of the trial caused substantial leaching, it did not return EC levels to those recorded at the beginning of the trial. Without increased leaching either before the next crop is planted or during the irrigation season, the increase in rootzone salinity from one season to the next would be expected to result in yield reductions over time for some areas of the field.

Further information on this work and the final report can be found at:

http://rads.nceastg.usq.edu.au/RADS/Case Study Root Zone Salinity.pdf

Case Study – Field evaluation of nitrate and salt movement in lettuce production and the effect of irrigation management

Lettuce as a crop has high nitrogen requirements and a need for high frequency, small volume irrigations to maintain soil moister levels in the shallow rootzone (15 cm maximum). As a result of this, high quality lettuce production requires the close management of both fertiliser and water inputs to prevent the loss of excess nutrients below the shallow rootzone and/or the buildup of yield limiting salts within the rootzone.

This work investigated the influence that irrigation and fertiliser management, as well as climatic conditions have on the movement of nitrogen and salts in the soil under lettuce production. Three field trials were conducted in commercial crops of lettuce grown under both drip irrigation and overhead irrigation systems and located across two different soils types (Ferrosol and Vertosol). Field soil solute samplers were installed at a range of depths to monitor soil water nitrate and electrical conductivity (EC) throughout the profile. In-crop irrigations, fertiliser applications and rainfall were also recorded through the trials.

In all three trials, regardless of irrigation system or soil type, varying levels of nitrate were found to be leaching below the rootzone and varying levels of salt found within the rootzone. A comparison of daily water and nitrogen balances calculated from two of the trials indicated 194 mm of water and 118 kg/ha of N were leached during the season in an early crop, but in a late season trial only 46 mm of water were leaching 16 kg/ha of N. In both cases the majority and difference in leaching occurred as a result of major rainfall events, however minor leaching also occurred as a result of excess irrigation, especially at the beginning and end of the irrigation periods. Throughout all trials measured levels of salt (EC) within the rootzone were found to be near or above the threshold level for yield decline of lettuce at some time during the season. There was also substantial variation in soil EC within the rootzone occurring both spatially and temporally as a consequence of irrigation and fertilizer application and rainfall inputs.

Further information on this work and the final reports can be found at:

http://rads.nceastg.usq.edu.au/RADS/Case Study Nitrate and Salt movement.pdf

http://search.informit.com.au/documentSummary;dn=575759793492400;res=IELENG

VARIwise control framework

The NCEA has developed a control strategy implementation and simulation framework 'VARIwise'.

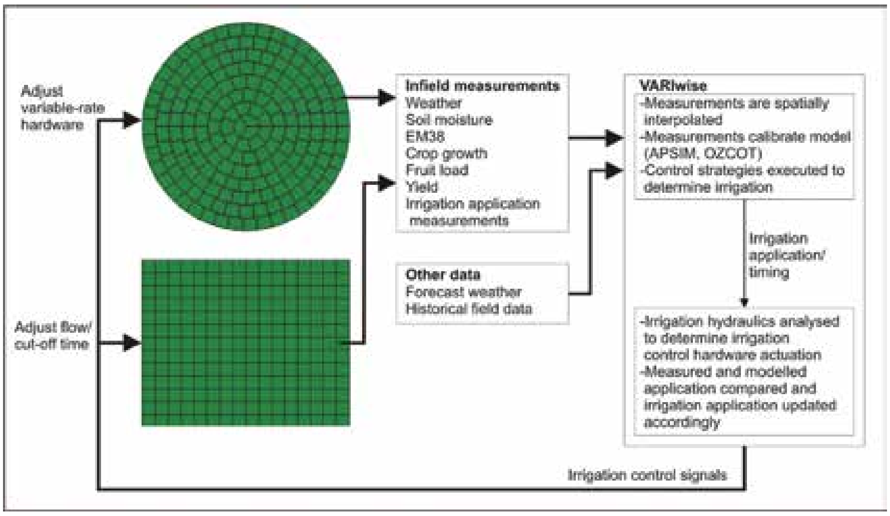
VARIwise that involves: (i) dividing the field into smaller, controllable sub-areas named 'cells'; (ii) assigning soil and plant parameters to each cell; (iii) calibrating the corresponding crop model for each cell; and (iv) executing a crop production model within in each cell.

VARIwise has the following features:

- enables data input at any spatial resolution or point in a field through maps (e.g. yield, satellite imagery) and georeferenced measurements (e.g. soil water)
- spatially interpolates sparse measurements to estimate measurements at unknown points using kriging and/or relating to underlying variability map (e.g. soil texture, moisture)
- incorporates irrigation hydraulics of surface and pressurised irrigation systems, irrigation system capacity, and irrigation uncertainty caused by wind (using sprinkler models)
- uses any APSIM crop model to provide simulated soil/crop response which is used to evaluate control strategies in simulation and/or to predict performance of control strategies.

The diagram below illustrates site-specific irrigation management of surface or pressurised irrigation systems that can be simulated and automated using: (i) infield measurements; (ii) VARIwise to interpret the spatial data, calibrate an external crop model and determine irrigation application by repeatedly executing the model; and (iii) variable-rate actuation hardware. This also enables real-time irrigation hardware adjustment if the measured application is not consistent with the calculated optimal application.

VARIwise utilises off-the-shelf crop models within APSIM to simulate the performance of irrigation strategies and to predict the performance of the irrigation control strategies. APSIM is a modular simulation framework for a range of farming systems and includes crop models for a range of agricultural systems, e.g. maize, corn, cotton and sorghum. APSIM incorporates soil, plant, fertiliser, organic matter and erosion modules.



Case Study: VARIwise uniform irrigation vs. site-specific irrigation

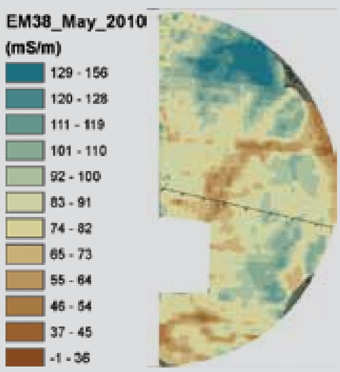
The VARIwise irrigation control framework was used to simulate the water productivity of a centre pivot-irrigated, grazed dairy field if variable-rate irrigation was implemented. This enabled a comparison of the instrumentation cost, input water and final yield for uniform and site-specific irrigation. This case study presents an evaluation of three control strategies in VARIwise:

- Strategy A irrigated according to an industry standard irrigation management strategy. Irrigation was applied uniformly when the soil water deficit of the soil with the lowest plant available water capacity in the field reached a set value (in this case, 30 mm).
- Strategy B applied site-specific irrigation based on EM38-measured soil variability and did not irrigate the non-cropping areas.
- Strategy C irrigated according to Strategy B but did not irrigate the crop within two days of harvest.

The strategies were implemented on a 426 m long centre pivot irrigation machine over a winter ryegrass crop sown on May 1. The spatially varied soil properties produced the underlying spatial variability used in this case study. The soil properties were determined by spatially interpolating results of four soil samples according to an EM38 map of the field (left diagram). Areas of the field that did not grow crops because of gullies, high ground, weeds and rocks were also mapped (right diagram, where blue areas were non-cropping areas).

The strategies were evaluated in simulation between May 1 and August 1 of three climate scenarios: La Niña (wet weather), El Niño (dry weather) and neutral. The weed module in APSIM was utilised to represent the ryegrass crop, where the weed type was a winter grass weed. Grazing was implemented every four weeks by harvesting the weed within the model.

Simulation results show that on average across the three types of weather patterns, the water productivity improved as the strategy complexity increased. Strategy B used 20% less water and produced 4% more yield than uniform irrigation, whilst Strategy C used 22% less water and produced 4% more yield than uniform irrigation.

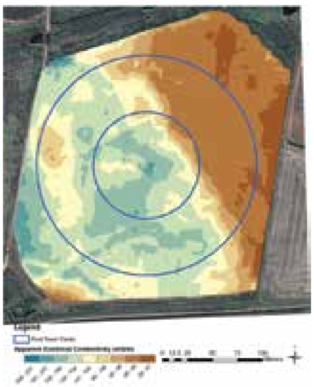


Information from In-Crop Spatial Variability to Improve Irrigation Efficiency

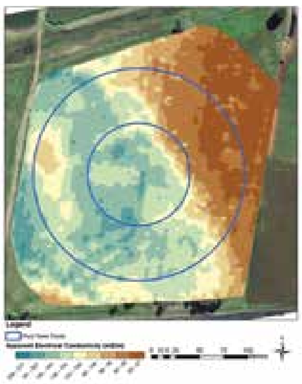
Profitable production in the horticultural industry, particularly when producing for the fresh market, requires crops with a very high degree of uniformity. The more uniform the crop, the more efficient the harvest will be, the higher the marketable yield, the better the visual qualities of the produce (evenness of display on shelf), and the easier the fertiliser and pest management regime (less inputs). A majority of horticultural crops are harvested at a (phenologically) premature stage. For example, lettuce and broccoli are harvested well before flowering and as a result the growing period is quite short. This poses a significant problem when differences in plant development (non-uniformity) across a field are noted, as the time availability to rectify the issues before harvest is limited. Early detection methods are paramount to enable timely intervention in short growth cycle crops.

The effect of the soil on variable plant development usually has a strong correlation with the soil texture, which can be determined anytime before planting and remains constant during the crop cycle. Variation in texture affects the soil water holding capacity and nutrient retention. Monitoring the plant/crop development throughout a crop cycle rapidly (in real-time) across the entire management unit to establish existing and developing variations provides time to apply measures to mitigate these variations. To address the variability of crop development at a suitable scale, the technology needs to be able to operate within smaller management units i.e. 1-3 m^2.

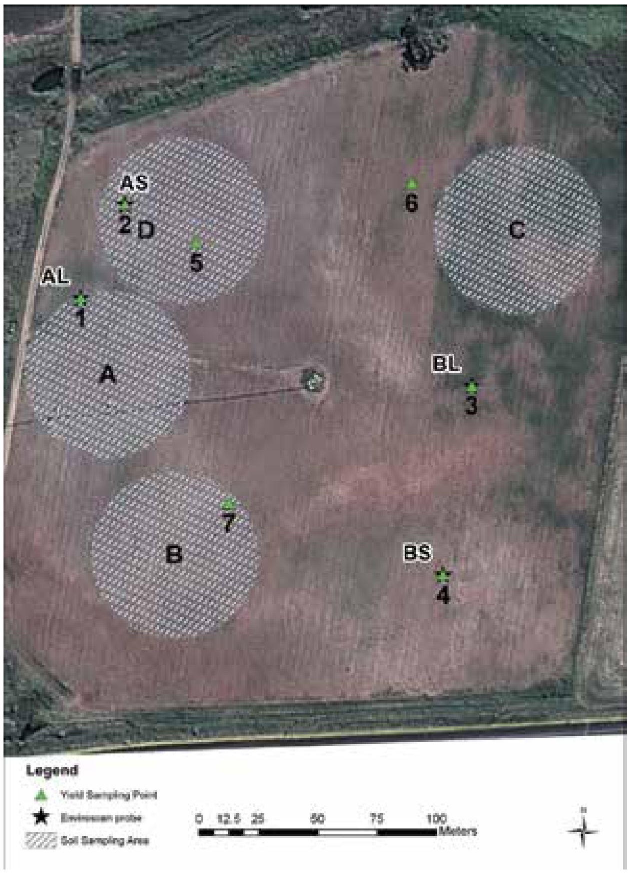
The field site selected to investigate measurement methods and factors influencing in-crop spatial variability was an irrigated green bean crop (planted August 2012) located under a 125 m long pivot irrigator. Using a previous EM38 survey (September 2011) as a guide, soil samples were taken in four distinct areas (areas A, B, C and D) within the paddock and four capacitance probes installed (each having sensors at 10 cm depth spacing). Crop vigour based on ratio vegetation index (RVI) and the normalised difference vegetation index (NDVI) was measured with four GreenSeeker® infrared sensors (covering four rows) two weeks before harvest with the assumption that variations mapped at this stage would carry through to harvest. A preliminary NDVI assessment was also conducted in the previous bean crop (September 2011). Yield mapping was conducted manually three days before commercial harvest at seven locations within the field (including the four locations with the soil moisture probes). Plant density, plant height, branch number, bean number and bean length were all recorded for a 300 mm subsample of row within the seven locations. Beans were also divided into four bean classes: Extra-Large Beans (=>140 mm), Large Beans (100-140 mm), Small Beans (80-100 mm) and Waste (<80 mm).



EM38 map November 2012



EM38 map September 2011

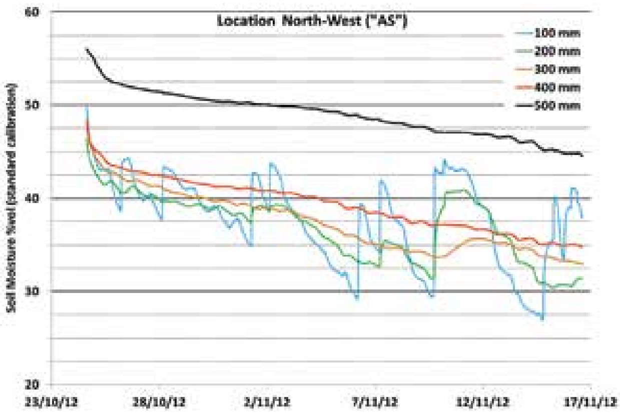


Location of soil moisture probes, yield and soil sampling, spring 2012

Comparison of EM38 (apparent electrical conductivity) of the soil measured twice with more than 12 months between is shown in the following figure. While individual levels are different the overall pattern remained the same over this time period, most likely caused by differences in soil texture (rather than changes in soil moisture and or salinity which may be present and influences EM38 readings).

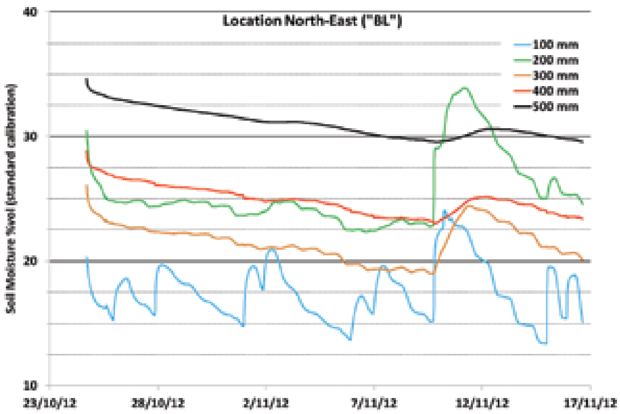
Comparison of soil moisture with depth and over time between these two different soil types revealed some interesting characteristics which support the notion for different management practices across this field. For example, soil sampling the north-west corner of the field around area D was found to have higher clay content, particularly at depth. Capacitance probes installed in the area showed the soil moisture in the top 10 cm changed rapidly. While the soil moisture at greater depths declined gradually over time, with the characteristic stepping of the curve only obvious down to 30 cm depth. At 40 cm depth appreciable daily drawdown occurred only 2½ weeks before harvest and at 50 cm depths, only for the last ten days of the cropping cycle.

More interesting is the rewetting after an irrigation event or rain. Normal irrigation events of 6–10 mm only affected the top 20 cm and even heavy rainfall (on 9 November) of close to 50 mm, only affected the soil moisture down to 30 cm. The intensity of the irrigation and rainfall had an effect on the efficiency of the water application, and influenced the irrigation scheduling. Depth of irrigation applications were limited by runoff issues and it was critical to maintain an irrigation schedule with frequent small applications to avoid too much water depletion with depth.



Soil moisture at different depths at location "AS"

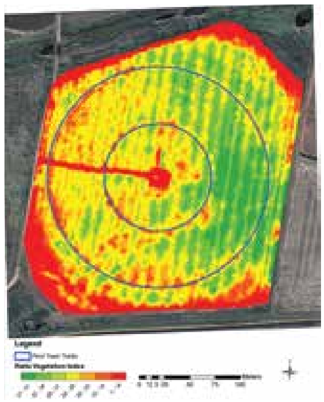
On the lighter soil in the north east corner of the block "BL" the situation was quite different. The soil moisture level was much lower at the start of the season, a clear indication of textural difference across the site (i.e. less clay). The water extraction pattern with depth was similar compared to the previous site but the water movement with depth from irrigation and rainfall events differed. The two irrigation events on 2 November influenced soil moisture levels down to 40 cm, while the large rainfall event clearly influenced soil moisture levels at all depths. The lighter textured soil had lower plant available water and greater infiltration capacity, hence this part of the field required lower applications more frequently.



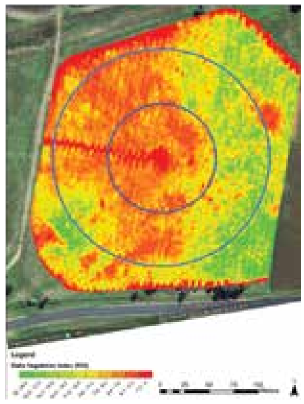
Soil moisture at different depths at location "BL"

Investigation of in-crop growth performance based on the RVI showed a similar pattern for both crops to that of underlying differences in soil texture as identified by EM38 surveys. In both years the lighter soil located to the north-east showed healthier more vigorous crop growth (green) compared to the crop located on the heavier clay soil to the north-west (red). Hand harvest results also reflected the same pattern in yield as found by EM38 and in-crop RVI survey.

Results from this trial indicate that information on spatial variability before the crop (EM38) and within crop (soil moisture, RVI) can be used as indicators of crop and yield variability supporting the argument for variable-rate management of irrigation and other



Ratio Vegetation Index (RVI) Nov. 2012



Ratio Vegetation Index (RVI) Sept. 2011

inputs. However, this needs to be considered in the context of factors that might have an influence. For example, the field in question had a considerable gradient falling from south-east to north-west, which resulted in surface runoff during modest irrigation events, and also some soil movement. Crop establishment differed across the distinct soil types, with germination rates lower on the heavier lower lying soils compared to the light soils that existed within the field. The ability of different crops to compensate for this will vary.

Key points

- Infield spatial variability in soil texture, water holding capacity, topography, irrigation, and crop establishment can all have a major influence on crop and yield uniformity.
- Monitoring of both these factors and crop growth spatially across the field and temporally over the season can enable strategies to be implemented to reduce, or avoid in-crop variability and consistency of quality in final yield.
- Options to reduce the effect of non-uniformity in soil texture, water holding capacity or irrigation include:
  - o Improved irrigation uniformity at a field scale
  - o Sub-field irrigation scheduling to better match irrigation requirements (frequency and depth of application) to demand where significant difference in soil type and/or crop growth performance is present
  - o Appropriate matching of irrigation application rate to infiltration capacity of the soil to reduce surface runoff.
- The monitoring and management employed to reduce spatial and temporal crop variability must be considered in light of the type of crop, length of season and desirable characteristics of final yield (quality, weight, maturity, consistency etc).
- Unknown and/or unmeasured influences (e.g. subsoil constraints, herbicides residue, soil borne diseases etc) can impact on the variability in crop growth and yield and might limit the effectiveness of variable-rate management of water and nutrients.

Further information on this work and the final report can be found at: **http://rads.nceastg.usq.edu.au/RADS**

Measuring energy utilisation

Irrigation and Energy Use in the Nursery Industry

On-farm energy costs are gaining significant attention from not only farmers but also those involved in other areas of agribusiness. Energy prices are rising and this is having substantial impacts on the sustainability of existing business models.

The NCEA is working with the NGIQ Farm Management Systems Officers to develop a methodology to undertake energy audits in the nursery industry. The methodology has been developed and refined (including tools for assessment) by conducting a series of audits in South East Queensland nurseries.

The general methodology follows the Australian/New Zealand Standards for Level 2 Energy Audits – AS/NZS 3598:2000. Level two energy audits *(Itemised Farm Approach)* generally involve breaking down the total energy usage on site into energy used in each process.

The energy audit process can be described in three main tasks:

1. **Desktop review and interviews:** Overview of the site's current energy performance from basic and detailed data supplied each nursery.
2. **Site inspection:** Assessment of the sites rated energy consumption and usage patterns aimed at disaggregation of energy use by area and process.
3. **Data analysis and report preparation:** Identification of areas of greatest consumption, reduction opportunities, recommendations and options including return on investment for infrastructure changes.

A complete inventory of all electrical equipment (e.g. pumps, motors, lights, computers, air conditioners) was collected along with the rated input energy for each item. Where this could not be found easily, photographs were taken to assist in identifying items at a later stage. The inventory was categorised by both the physical location of each item as well as the process in which the item is used.

The NCEA and FMSO then met with the site manager to determine the annual average usage of all items on the inventory. This data was combined with the rated input power data using the EnergyCalc software (figure below) to determine the estimated average annual consumption for each item. This was totalled for the all items on the inventory and compared against the actual billed electricity consumption. If the 'Estimate' was +/-10% of the 'Actual' then the assessment was accepted as sufficient. However, if there was a larger discrepancy a further interview (telephone or email) was undertaken with the site manager to refine the annual average usage data.

The data was disaggregated to show the site manager which processes were the most energy intensive and where on the site the most energy was being used.

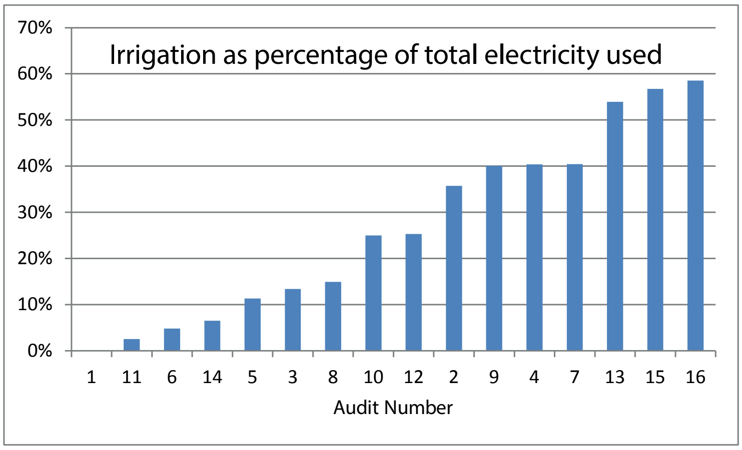
EnergyCalc

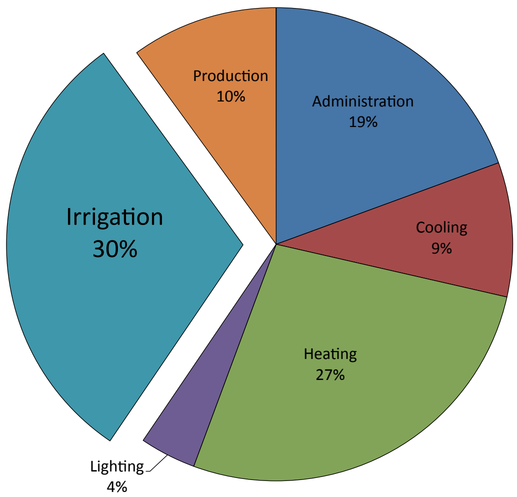
		Practice	Energy Source	Energy Used	Standard Energy (GJ)	%	Cost (A$)	%	Emission (Kg)	%
		Heating	Electricity	1140.00 (kwh)	4.10	4	250.80	4	1192.44	4
		Lighting	Electricity	160.00 (kwh)	0.58	1	35.20	1	167.36	1
		Air Circulation	Electricity	2808.00 (kwh)	10.11	9	617.76	9	2937.17	9
		Irrigation Pump	Electricity	6552.00 (kwh)	23.59	22	1441.44	22	6853.39	22
		Irrigation Pump	Electricity	8517.60 (kwh)	30.66	28	1873.87	28	8909.41	28
		Irrigation Pump	Electricity	1703.52 (kwh)	6.13	6	374.77	6	1781.88	6
		Irrigation Pump	Electricity	1703.52 (kwh)	6.13	6	374.77	6	1781.88	6
		Fertigation	Electricity	3276.00 (kwh)	11.79	11	720.72	11	3426.70	11
		Compressor	Electricity	3893.76 (kwh)	14.02	13	856.63	13	4072.87	13
		Bug Zapper	Electricity	582.40 (kwh)	2.10	2	128.13	2	609.19	2
Total	-	-	-	-	109.21	100	6674.10	100	31732.29	100

Irrigation and energy use

There are few diesel pumps used in the nursery industry. The most common pumps used for irrigation in the nursery are electric centrifugal pumps (both single and multistage) and are often run in excess of 12 hours per day. The results from the energy audit program show that an average 30% of the total electricity used on site was in pumping water and irrigation. This ranged from 6% (at a site where the heating dominated the usage) to 59%. Irrigation is the single largest electricity using process in 7 out of 16 audits conducted.

This series of audits identified that irrigation is a significant user of energy in the nursery industry. Further investigations could be undertaken to determine the efficiency of the existing pump systems. Once this is known, a cost benefit analysis can be undertaken to assess the viability of repair or replacement of poorly performing pumps. The IPERT tool (kmsi.usq.edu.au) can be used to calculate the efficiency of irrigation pumps.





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