
RWUE Project 18 Final Report Main Report

Quantifying high priority reasons for vegetable producers to adopt improved irrigation management strategies

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Executive summary

Introduction

The Rural Water Use Efficiency Initiative sought to encourage voluntary change in farm practices, with the objectives of making best use of Queensland's limited water resources to:

1. *Increase agricultural production by \$280M per annum*
2. *Create 1600 regional jobs*
3. *Improve profitability and viability of rural industries*
4. *Reduce agricultural contributions to nutrient and pesticide loads in waterways (fresh and marine)*

Actual practice change occurs when adopters decide the change is worth it to them as individuals, and they have the capacity (resources, knowledge, skills, psychological health) to implement change.

The focus of our project was to generate compelling reasons for vegetable producers to engage in the process of improving their on-farm water use efficiency. We thought this engagement was more likely if the proposed practice changes made producers' lives easier (less work time, easier decision making, more control of outcomes, less pesticide use), their production more consistent (higher and predictable yields), and their produce more marketable (increased uniformity, better quality, fewer defects).

We designed our project to investigate and demonstrate, for a range of vegetable crops, the potential for changes in irrigation practices (in combination with other agronomic inputs), to improve Economic Water Use Efficiency (\$ Profit per ML water use). We targeted improving yields and reducing water use, improving vegetable quality, and managing specific diseases and physiological disorders, such as pungency in onions, or tipburn in lettuce, to achieve the desired goals.

We also used economic analyses to determine the key components influencing profitability in vegetables, and investigated the potential for improved irrigation practices (e.g. those discovered in the detailed agronomic experiments described above) to drive improved profitability.

We evaluated our research findings by consulting with producers, and comparing our best practices with commercial scale conventional irrigation systems.

Drip irrigation strategies

We used drip irrigation to implement our experimental treatments. Conventional drip irrigation in vegetables strives to maintain a moist soil profile throughout the main crop root zone. It encourages the plant to transpire water freely, in order to maximise growth and yield potential, without any crop stress.

In the latter part of our project, we investigated a deficit irrigation technique. We deliberately only supplied a proportion of the vegetables' usual water demand from irrigation, forcing them to extract more water from deep in the root zone. Our intent was to slowly dry out the soil profile, but by irrigating regularly, to give the plant time to adjust to the increased effort required to extract the water, and thus reduce any stress the plants may experience. Our theory was that deficit irrigation should create a greater soil reserve for capturing rain, and improve water use efficiency. The risk was that vegetable yields or quality would be adversely affected.

Drip irrigation substantially improves Agronomic Water Use Efficiency in vegetable production

Across the range of crops we investigated (lettuce, onion, potato, sweet corn, sweetpotato), conventional drip and deficit drip irrigation strategies produced high yields of quality vegetables, demonstrating that drip irrigation is agronomically viable in these crops.

On average, conventional drip irrigation yielded 15% more marketable produce than sprinkler-based strategies, and used 10% less water, improving Agronomic Water Use Efficiency (tonnes of produce per ML of irrigation) by about 25%.

Vegetable crops that were deficit irrigated yielded nearly as well as the conventional drip irrigated crops (on average 96% of best yields, but varied with vegetable type and cultivar within vegetable type). However, the deficit drip irrigation reduced total irrigation by 17% on average, compared to conventional drip. This meant the Agronomic Water Use Efficiency of our deficit drip irrigated crops was 45% better than the comparable sprinkler irrigated vegetables.

Using our economic models, we calculated the potential economic value to Queensland vegetable producers of adopting drip irrigation, in circumstances where the availability of irrigation water was the factor limiting production (e.g. the current 2003 drought is such a scenario). In our analyses we modelled 30% of Queensland onion, potato, lettuce, sweet corn and sweetpotato producers switching to drip irrigation from sprinkler based strategies, and produce prices marginally higher than long-term averages (assumes produce shortages increased prices). In such a scenario, conventional drip irrigation increased profit (not revenue) to producers by \$2.2M per annum, whilst using the water efficient deficit drip system increased profit by an additional \$1.3 M per annum more than conventional drip irrigation.

Factors influencing adoption of new irrigation strategies

If drip irrigation can potentially have such a huge impact on Agronomic Water Use Efficiency, why isn't it universally and rapidly adopted? Our project clearly demonstrates that the economic viability of changing to a new irrigation strategy depends on its relative Agronomic Water Use Efficiency, its cost of implementation, and is very sensitive to produce price, and which factors are constraining production.

For example, at a standard district onion price of \$485/t at market, our research shows a sprinkler irrigated system gives the best profitability when the amount of produce required is the restricting influence, i.e. the market will not take any more produce. A conventional drip system is most profitable if the amount of land available is the constraining factor, whilst a deficit drip irrigation system is most profitable if the amount of water available is limiting production.

As a rule of thumb, irrigation systems and strategies that deliver superior Agronomic Water Use Efficiency, but are more expensive than current systems, are favoured by higher produce prices, restricted irrigation water supplies, and good opportunities for market expansion. Conversely, low produce prices, readily available irrigation water supplies, and restricted markets for produce, favour less investment in irrigation management, even at the expense of reduced water use efficiency.

This is precisely why we saw wholesale changes to drip systems in the Bowen district about 8 years ago when water became very restricted, and why we have seen massive increases in the use of drip in southeast Queensland in the last 18 months. At this point in time, there is significant opportunity to stimulate interest and adoption of new irrigation systems. As one method of improving water use efficiency, conventional drip systems can be currently adapted for most vegetable production systems, to produce high yields of quality produce. Adoption is probably influenced more by the economic and water policy environments than any major agronomic issues. Our project results can demonstrate the general utility of drip application systems, and also provide the tools to assess individual enterprise viability, to enhance the prospects of producers trying out new systems and techniques.

In contrast, although our deficit drip irrigation results demonstrate potential, they are from a limited set of experiments, on a single soil type, over fairly dry environmental conditions. Before any form of deficit irrigation can be strongly promoted as alternative strategies for vegetable production, their reliability of performance over season, soil and crop types needs to be assessed more rigorously. We believe there are significant opportunities to refine deficit irrigation by (a) Adjusting drip tape specifications and location in relation to crop rows and soil types and (b) Fine tuning the target irrigation deficit based on: soil type; crop type; drop growth stage; environmental conditions; short-term weather forecast; and irrigation water quality.

General recommendations for optimising irrigation and agronomy in current production systems

The agronomic results from our research helped refine best practice irrigation, nutrition, cultivar selection and other agronomic strategies for the vegetable crops we studied. We defined maximum irrigation intervals for various vegetable cultivars, and showed keeping soils constantly moist increased splitting and doubling in onions. We demonstrated that drip tape spaced between every second row of sweet corn (to reduce installation costs), and scheduled with tensiometers, could provide excellent yields, cob quality and water use efficiency. Our research emphasised that vigorous establishment of uniform planting material may be the key to consistent, high yields of quality sweetpotato. Once the cuttings were well established, **Beauregard** sweetpotatoes (90% of current Australian industry), yielded equally well when tensiometer values rose to 60-70 kPa between irrigations, compared to crops kept relatively moist during the storage root bulking period. These research results are already being incorporated into best-practice information and extension packages, and will become part of common vegetable production systems as appropriate.

We showed that maintaining moist soils increased the pungency in onion, and recommend that producers use the least irrigation that gives them an economic return if pungency is a concern.

Limited impact of irrigation on specific vegetable diseases and physiological disorders

For most of the other diseases and disorders, we were unable to demonstrate improved management through irrigation practice change. We could not ameliorate cracking in the **Northern Star** sweetpotato cultivar, by optimising irrigation. Although there was some relationship between irrigation and brown fleck incidence in potato, we could not demonstrate a commercially acceptable irrigation solution to this disorder. Similarly, we did not discover any relationships between irrigation strategies and levels of tipburn in lettuce, or cob quality in sweet corn. We did develop best-practice guidelines for managing tipburn in lettuce by other agronomic practices, and showed that supplementary calcium did not consistently assist in managing tipburn or brown fleck, which may prevent wasted efforts by producers in potato and lettuce. Although we did define optimum irrigation conditions for establishing beetroot (estimated value \$50/ha or \$15,000 per annum to the industry), we did not establish any capacity to manage white-rot in onions, or soil borne diseases in beetroot, through irrigation management.

Extension activities

During the project we had excellent links with the Horticulture Adoption program, with our research results included in their information resource materials. We conducted collaborative activities assisting individual producers and producer groups. We organised or significantly participated in 21 group extension activities during the project, involving over 500 individuals (producers, agribusiness, irrigation industry suppliers, consultants and scientists).

Future research

As previously indicated, we believe deficit drip irrigation has the potential to offer a quantum leap in Agronomic Water Use Efficiency for vegetable producers. By capturing more rain in the crop root zone, it also offers the possibility of reducing nutrient leaching off-site, improving environmental sustainability. However, it is definitely a more risky approach to irrigation with fewer margins for error. It clearly requires much more evaluation and refinement before it could become a recommended practice.

Apart from the field work previously mentioned, we also believe there is a real opportunity to link field studies on deficit irrigation with a range of modelling, forecasting and precision system activities

Example areas of research that would be productive include: (a) Improving deficit irrigation outcomes by using weather/climate forecasting systems; (b) Using irrigation simulation models to develop the best deficit irrigation strategies for different soil/crop type combinations and drip tape specifications; (c) Use of models to determine the potential environmental and productivity benefits of deficit irrigation over a long term run of seasonal conditions, at both farm and catchment scales.

Another area of research that would be very topical is the specific evaluation (field and model based) of deficit irrigation as a mechanism for vegetable producers to cope with drought.

Apart from research into deficit irrigation, we also believe that a review of the assumptions used in water policy decision making, and the companion economic analytical tools is required, to make certain that the key elements discovered in our economic modelling are incorporated.

We suggest any analyses that do not explicitly enunciate assumptions on constraining factors, and include sensitivity analyses about market price, are fundamentally flawed. Analytical tools must include the capacity to factor in resource availability (land, water, capital etc.) and/or market capacity (i.e. what volume of product can be profitably sold) as constraints to the level of practice change. Most economic studies we have seen relating to practice change in vegetable production have assumed any increased production can be absorbed by the market at current prices, and/or that all the resources required for that practice change are available.

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Background

The rationale for the research component of the Rural Water Use Efficiency Initiative is to ‘... *support adoption programs to improve water use efficiency on farms.*’ The improvement is to come about through voluntary change in farm practices (as opposed to legislated or forced change through punitive mechanisms). The program is funded by the Queensland Government to achieve outcomes for the Queensland community. To paraphrase the booklet produced at the start of the program:

Making best use of Queensland’s limited water resources to

5. *Increase agricultural production by \$280M per annum*
6. *Create 1600 regional jobs*
7. *Improve profitability and viability of rural industries*
8. *Reduce agricultural contributions to nutrient and pesticide loads in waterways (fresh and marine)*

Queensland communities obviously recognise the outcomes as laudable and desirable, and that changes leading to those outcomes as highly worthwhile. However, the actual practice change is undertaken by individual producers, voluntarily. Research all around the world has clearly demonstrated that voluntary practice change comes through the adopters deciding that the change is worth it to them as individuals, and having the capacity to change. This is excellently summarised by Marsh (2001), where she states:

‘...There is stress, learning and risk associated with changing farm practices.

Although the economic profitability of practices is the most decisive influence on whether or not a practice is adopted by farmers, social factors also influence the adoption of new management practices and technologies, and their speed of uptake (Lindner, 1987; Rogers, 1995). There is a wealth of empirical evidence about the factors that influence uptake of new technologies and sustainable management practices.

Basically it comes down to the fact that no two farms are identical and no two people are the same. People tend to act in their "best interest", but this is determined both by objective factors and by perceptions. When a producer considers a new innovation or management system they take into account:

The objective profitability of the change that is dependent on the quality and quantity of resources at their disposal (e.g. land, labour, machinery, credit), the land use elsewhere on the farm, and the level of skills/expertise they possess;

A subjective perception of profitability, which may be affected by the farmer's age, experience, education, future plans, proximity to relevant information, circumstances, etc.; and

Their attitude to profit, risk, leisure, the environment, land acquisition, etc. due to age, life stage, ethnicity, gender, wealth, experience, education, family size and composition, health, psychological make-up, etc.

The above factors relate mainly to the worth of the change to the individual and the capacity of the individual to change – both from an objective and subjective point of view – not to the actual worth of the change itself.

Furthermore, social factors at a regional level can affect management changes. There can be differences in rates and levels of change between different groups or regions because of differences in the nature of information channels, the credibility of information sources, and regional or group cohesiveness.

It is not helpful or appropriate to expect people to respond to a situation in the same or even similar ways. They will respond in a diversity of ways, dependent on their individual situation.

In his paper 'Understanding the elements and adoption of environmental best practice in horticulture – A guide to implementation' Leigh Sparrow from Horticulture Australia concludes 'where voluntary adoption is sought, some form of incentive is usually required (for example increased market access or price premiums).'

In developing our project idea, we felt an effective way for a vegetable research project to assist the Horticulture Adoption Program was to provide a suite of reasons for producers to engage in the process of improving their on-farm water use efficiency. The primary focus needed to be on developing farming systems and system components that significantly improved individual enterprise profitability, whilst essentially delivering the RWUE outcomes detailed previously. Apart from the primary financial incentives of new technologies, it was also important that they appealed to a range of other producer objectives, including:

- Ease of implementation, testing and evaluation
- Flexibility and robustness to changing external influences
- Low risks associated with failure
- Positive impacts on lifestyle, peer status
- Positive impacts on product quality and marketability (pride as well as potential economic payoff)

From previous research and experience in extending new irrigation technologies with vegetable producers in southern Queensland, we recognised that simply advocating practice change on the basis of saving water and associated water changes was unlikely to be successful. We hypothesised that practice change was more likely when new systems made producers' lives easier (less time at work, fewer problems, less pesticide use, easier decision making, more control of outcomes), their production more consistent (fewer pest or disease incursions, higher and predictable yields), and their produce more marketable (higher quality, less variable, fewer defects, closer to retailer and consumer specifications).

As will be reiterated later in this report, the profitability of vegetable production is extremely sensitive to marketable yields and fluctuations in prices received, and much less sensitive to changes in production cost components. The most effective way to deliver financial benefits from a practice change is if the practice change improves crop yields or crop price. Product quality, integrity, uniformity, match to specification, and reliability of supply, all affect the price received for vegetables, although price is also certainly heavily influenced by many factors beyond the farm gate.

Research and local anecdotal evidence suggested several examples where improving irrigation management could positively influence vegetable yields, as well as ameliorate specific agronomic and quality issues, to give significant, attractive outcomes for producers. These agronomic and quality issues included:

- Internal physiological disorders in harvested lettuce (tipburn) and potatoes (brown fleck and hollow heart)
- Distortion and cracking in sweetpotatoes
- Pungency, sweetness levels, multiple shoot initiation (doubling), and cracking in onions
- Cob size, tip fill and kernel uniformity in sweet corn
- Incidence of soil borne diseases and subsequent establishment and crop performance issues in onions and beetroot

These issues can determine price premiums or penalties associated with harvested products, whether produce is accepted or completely rejected by markets at any price, and initially the levels of total and potentially marketable yields achieved in the field, all of which substantially affect profitability.

If we could clearly demonstrate irrigation impact on these issues, we reasoned this would stimulate producers to look closer at improving their water management.

An increased intensity of irrigation management to achieve agronomic goals almost inevitably raises consciousness of water application, local redistribution and potential losses. By focussing on where and when water is needed (to maximise crop benefits), there is a concomitant concern for water going where it is not wanted, i.e. over and under-irrigation due to lack of application system uniformity, significant drainage below crop root zones, or increased evaporative losses through poor application and timing.

If we broadly model the Economic Water Use Efficiency (EWUE) indicator as \$ profit per ML water use, we based our project on the following hypothesis -

Focus our irrigation goals on driving the profitability numerator up, and simply removing glaring inefficiencies in the water use denominator, would give the best scope for major improvements in Economic Water Use Efficiency.

A very simple example using the template lettuce crop gross from the DPI Agrilink series shows Economic Water Use Efficiency of \$775/ML. Suppose that by irrigation scheduling using tensiometers (total costs \$105/ha) we improve lettuce quality to the extent that we receive a 5% increase in on-farm price. If total water use stayed the same, Economic Water Use Efficiency still increases to \$1015/ML. A 10% reduction in water use lifts the value to \$1130/ML, however even a 10% increase in water use only reduces the EWUE to \$920/ML, still well above the original starting value.

Specific details on the agronomic issues listed earlier in this section can be found in the introductory sections of each of the individual experimental reports.

Objectives

This project sought to provide information that would enhance the prospect of significant practice change in vegetable production, through encouraging adoption of improved irrigation management. To generate this information, we set the following project objectives.

1. To investigate and demonstrate the potential for changes in irrigation practices, alone, or in combination with other agronomic inputs, to improve Economic Water Use Efficiency, whilst at the same time:
 - (i) Making producers' lives easier (less time at work, fewer problems, less pesticide use, easier decision making, more control of outcomes);
 - (ii) Ensuring their production is more consistent (fewer pest or disease incursions, higher and predictable yields), and;
 - (iii) Enhancing the marketability of their produce (higher quality, less variable, fewer defects, closer to retailer and consumer specifications).
2. Use economic analyses to determine which are the key components influencing profitability in vegetable enterprises, and investigate the potential for improved irrigation practices (e.g. those discovered in the agronomic experiments above) to drive improved profitability.
3. Verify that potential key improvements in irrigation practices can be realised at commercial production scales, by field testing in large research plots, as well as consultations and collaborative demonstrations with commercial vegetable producers.

Achievement of objectives

The economic analyses, scenario modelling and experiment evaluations we conducted during our project clearly demonstrated the key components influencing the profitability of irrigation investment and practice change. Our experimental work demonstrated that drip irrigation could increase Agronomic Water Use Efficiency (volumes of marketable produce per ML of water use) compared to standard commercial irrigation practice, and consistently provide high yields of uniform quality produce. We showed that the relative profitability of various drip irrigation strategies were very sensitive to produce market price, but were also influenced by water policy and resource constraints. We found irrigation strategies could optimise yields and influence general quality parameters (size, uniformity), and have a minor effect on some specific quality issues such as pungency, splitting and doubling in onion, and flesh colour in sweetpotato.

Despite our endeavours, we could not develop irrigation strategies capable of having significant impact on tipburn in lettuce, brown fleck in potato, cracking in **Northern Star** sweetpotato, or contributing to white-rot disease management in onion.

Our capacity to field test our irrigation strategies at commercial scales was seriously limited for the following reasons.

Because of contractual delays, the project did not actually get underway until March 2001. There were limited experimental outcomes in year, with no standout research results that we felt confident of taking to commercial scales. It was not until our deficit irrigation experiments and accompanying field evaluations in 2002 that we felt we had some new ideas that would be useful in having a look at on commercial scales.

Unfortunately, by 2002, drought conditions were seriously affecting horticultural producers throughout southern Queensland. These conditions still persist to this point in time, except in the Bundaberg area. Most producers are focussed on trying to make ends meet under difficult circumstances, and most of the growers we spoke to were ambivalent about committing scarce time and resources to experimental work. We did not feel it was appropriate to push them; rather we simply discussed their best irrigation options for coping with the current situation. In early 2003 we were able to organise some collaborative experiments with sweetpotato growers in the Bundaberg area, however ironically heavy rain delayed their planting by several months. As described in later sections, a field evaluation in Bundaberg sweetpotato is currently underway, but is not due for harvesting until September 2003. Similarly, a field evaluation in a Lockyer potato crop is due for harvesting later this month. We will continue these activities beyond the current project, to retain continuity and good relationships with these producers.

Gatton Research Station is currently suffering the worst irrigation water deficit in its history, with bores at historically low levels, and water of moderate-poor quality. It was not feasible to run additional significant evaluations at commercial scales at this site, apart from those we implemented in conjunction with our detailed experimental areas.

When the project was initiated, we planned to involve a horticulture economist to conduct the bulk of the economic analyses, and a dedicated information officer to assist with our extension materials and activities. Incumbents in both positions left before the project actually commenced, and DPI made a budget-based decision not to replace the economist. Casual and inexperienced temporary employees have occasionally filled the information position, for specific tasks not related to our project. We were unable to find suitable people in other sections of DPI with the necessary skills and time available to commit to the project. As a result, the Principle Investigator had to take on those work activities, and although I increased my time commitment to the project, still needed to reprioritise other activities. Because of the factors mentioned above, we decided to concentrate our reduced resources on achieving significant research results that could be evaluated and extended by the Adoption Program. Thus there has been a limited amount of commercial scale testing of the deficit drip irrigation strategies.

Methodology

Detailed experimentation

All the detailed experiments were conducted at the Department of Primary Industries Gatton Research Station (lat. 27°33'S. long. 152°20'E). The soil type is mainly a black earth (*Ug5.15*, Northcote *et al.* 1979), clay loam at the surface grading to light-medium clays at depth. Apart from specific irrigation and nutrition treatments, standard agronomic practices (land preparation, nutrition, pest management) were applied by either the research team, or GRS operational staff.

In this project we completed 11 intensive agronomic experiments. For detailed descriptions of the methodology for individual experiments, refer to the detailed experiment reports or the experiment preschedules in the attached documents, or contact the authors.

To summarise the objectives of each experiment, we have categorised their prime targets of investigation as:

1. Pest or disease management (white rot in onion, *Fusarium* / *Pythium* / *Aphanomyces* in beetroot)
2. Produce disorders (brown fleck in potato, tipburn in lettuce)
3. Produce quality (cracking and shape in sweetpotato, cob fill in sweet corn, pungency, doubling and bulb integrity in onion)
4. Evaluation of deficit irrigation

In all experiments we analysed the total and marketable yields, product specifications and uniformity, and the water use efficiency from the range of treatments. In the later experiments, we specifically investigated the potential for deficit irrigation to maximise water use efficiency whilst maintaining or improving product yields and quality.

The objectives of the detailed experiments are summarised in Table 1. Each experiment comprised 12 irrigation treatments, replicated twice, in a complete block design. In some experiments the irrigation treatments were further split by cultivar sub-treatments (Table 2). Irrigation frequencies varied from daily to fortnightly; the most common comparisons being every 1-3 days, every 5-7 days, and every 10-14 days. In the initial experiments we attempted to refill the crop root zone every irrigation. However, in the experiments evaluating deficit irrigation, we implemented treatments where we applied a percentage of Class A pan evaporation at each irrigation, commonly 120%, 90%, 60% or 30% of pan evaporation for individual treatments.

Table 1. Specific objectives of detailed irrigation experiments.

Experiment number	Crop	Specific objectives
1	Beetroot	Soil borne disease management, improved crop establishment
2	Lettuce	Tipburn management
3	Lettuce	Tipburn management
4	Lettuce	Tipburn management, deficit irrigation evaluation
5	Onion	White-rot management, crop uniformity
6	Onion	Pungency levels, crop uniformity
7	Onion	Pungency levels, crop uniformity, deficit irrigation evaluation
8	Potato	Brown fleck management, crop uniformity
9	Potato	Brown fleck management, crop uniformity, deficit irrigation evaluation
10	Sweet corn	Tip fill, crop uniformity
11	Sweetpotato	Cracking, storage root shape, crop uniformity

Table 2. Primary treatments in detailed irrigation experiments.

Experiment number	Crop	Cultivars	Irrigation treatments	Other treatments
1	Beetroot	Pablo, Detroit Dark Red, Garnet, New Globe	Irrigation frequency, pre- and post plant moisture strategies	Seed priming
2	Lettuce	Greenway, Titanic	Irrigation frequency, diurnal application timing	Nitrogen nutrition, calcium nutrition
3	Lettuce	Oxford, Raider	Irrigation frequency	Nitrogen nutrition, calcium nutrition
4	Lettuce	Oxford, Raider	Irrigation frequency, deficit strategy (% of pan evaporation)	Calcium nutrition
5	Onion	Golden Brown	Irrigation frequency	Fungicide drenching
6	Onion	Wallon Brown, Predator	Irrigation frequency	Sulphur nutrition
7	Onion	Colossus, K5156, Rio Zena	Irrigation frequency, deficit strategy (% of pan evaporation)	Sulphur nutrition
8	Potato	Sebago, Atlantic	Irrigation frequency	Nitrogen nutrition, calcium nutrition
9	Potato	Sebago	Irrigation frequency, deficit strategy (% of pan evaporation)	Calcium nutrition
10	Sweet corn	Pacific H ₅	Irrigation frequency, drip tape spacing	
11	Sweetpotato	Beauregard, Northern Star	Pre and post-bulking soil water stress	

Experimental plots were 3 m wide and 10 m long. Only the central 1.5 m of plot width was used for experimental purposes, with the outer 0.75 m on either side employed as irrigation buffer zones. To keep the experiments a manageable size, we used drip irrigation for watering the plots, to minimise the areas of buffer zones required. This was particularly important during the latter part of the project, when the drought seriously curtailed the amount of irrigation water available at Gatton Research Station.

All irrigation was via T-Tape[®] drip tape (Model No. 508-20-500); specifications 500 L/hr per 100 m @ 55 kPa pressure, emitters every 20 cm. Drip lines were spaced 0.75 m apart in both treatment and buffer areas. Drip lines were connected via 16 mm polyethylene tubing (four drip lines per 16 mm tube outlet) and tap to a 75 mm layflat main line. Each drip tube had a flushing outlet at the far end to enable flushing every four weeks. An example of a typical plot layout is shown in Plate 1.



Plate 1. Plot layout, demonstrating central experimental zone with buffer areas on either side, irrigated with a surface drip system.

Experimental measurement

Weather, irrigation and water balances

We accessed weather data from the adjacent Gatton Research Station weather station.

We measured quantities and rates of irrigation by recording water meter and pressure gauge values before, during, and after each irrigation. We crosschecked these with water meter readings from the main irrigation pump, and specified drip tape outputs for irrigation intervals and pressures. We used an Excel[®] spreadsheet that accounted for irrigation leakages in calculating daily water additions to individual treatments.

In each experiment we installed tensiometers Shallow (10-20 cm below the soil surface, depending on crop type) and Deep (45-60 cm), in all plots. We used SoilSpec[®] tensiometers, which consist of a standard ceramic tip and tube, but no vacuum gauge. To obtain soil water potential readings, a hollow syringe is forced through a rubber septum at the top of the tensiometer, and an electronic vacuum gauge senses the vacuum in the small air gap below the septum. Tensiometer readings were recorded around 8-9 am daily.

In analysing the experiments, we used the tensiometer, weather and irrigation data to construct period water balances, deriving crop water use, drainage and evapotranspiration values for all the treatments.

For each of the experiments, we assessed crop growth, yield, quality and agronomic performance using the indicators detailed in Table 3. The specifics of the methods used can be found in the individual experiment summaries and reports.

Table 3. Agronomic performance parameters measured in detailed irrigation experiments.

Experiment number	Crop	Agronomic performance parameters
1	Beetroot	Emergence rates, seedling densities, seedling weight, root system health
2	Lettuce	Total and marketable yield, disease, head deformity, maturity rating, tipburn (incidence and severity), dry matter
3	Lettuce	Total and marketable yield, disease, head deformity, maturity rating, tipburn (incidence and severity), dry matter
4	Lettuce	Total and marketable yield, disease, head deformity, maturity rating, tipburn (incidence and severity)
5	Onion	Plant establishment, white rot incidence and severity, total and marketable yield, size grade distributions
6	Onion	Plant establishment, total and marketable yield, size grade distributions, doubles, pyruvic acid levels (pungency)
7	Onion	Plant establishment, total and marketable yield, size grade distributions, doubles, split onions, pyruvic acid levels (pungency)
8	Potato	Total and marketable yields, size grade distributions, brown fleck (incidence and severity), dry matter percentage
9	Potato	Total and marketable yields, size grade distributions, brown fleck (incidence and severity), dry matter percentage
10	Sweet corn	Total and marketable yields, insect damage, cob quality
11	Sweetpotato	Plant establishment, storage root development, total storage root yield, marketable yield, size grade distributions, insect damage, cracking (incidence and severity), root deformities, flesh colour, dry matter percentage

Data analysis

We used Genstat5[®] or Genstat6[®] to run standard analysis of variance procedures for the agronomic measurements recorded. We used standard F-tests at the 5% probability level to determine whether there were significant differences between treatments, and protected LSDs for examining differences between individual treatments.

Economic analyses

We used the Excel[®]-based gross margins for vegetable crops, developed by our local financial counselling service, as the basic information for our economic analyses. In many instances we changed some of the input and cost data after consulting with extension officers and commercial vegetable producers. Generally, these input changes had only minimal influence on the overall conclusions from our sensitivity analyses.

In our first analyses we compared the costs of irrigation inputs to other production, harvesting and marketing costs for both vegetable and field crop production enterprises. The intention was to give an overall context to the discussion of investing in irrigation practice change, compared to potential investments of time and money in other areas such as pest management, harvesting practices, and marketing. We used the simple spreadsheets to analyse the sensitivity of enterprise and whole farm profitability to changes in irrigation costs (from such influences as increased water charges, or implementation of irrigation scheduling systems).

We then investigated what outcomes producers would need to achieve to cover increased investments in irrigation, comparing the benefits of water savings, increased yields or increased prices. We initially did this for a range of vegetable and field crops, using the individual gross margins for each crop.

To refine our sensitivity analyses, we constructed seasonal modelling spreadsheets that linked with the gross margin spreadsheets, and provided a platform to interact changes in irrigation management costs, water use, crop yields and price, and provide a seasonally profitability outcome.

As a first step in providing realistic assumptions about irrigation scheduling costs, we developed a spreadsheet to calculate costs of irrigation scheduling using two different methods. These were based on a proportion of time that equipment is used per annum, or based on a planting schedule and the levels of equipment and operating time to service that planting schedule. The levels of equipment and intensity of monitoring were input factors into both models.

In the project we used two examples to demonstrate the principles of using the spreadsheets. In the lettuce enterprise example, we used the models to determine the effects on profitability from improving prices, yields, or saving water, in scenarios that were land limited (i.e. no more land available for cropping), market limited (no profitable market for additional produce grown) or water limited (water savings could be used by the producer to increase cropping area). We investigated the impacts of changing tipburn likelihood and severity on profitability under several price penalty regimes.

Following feedback from RWUEI Adoption Program staff, we modified the models to determine the breakeven points for recouping investments in changing irrigation practices, under a range of operating environments. In the example presented in the report, we used the spreadsheet models to determine what percentage of water savings were required to recoup increasing investments in irrigation management. Our model crop was sweetpotatoes, grown in circumstances where water was in limited supply, and water savings could be used to increase planting area. We modelled the breakeven points for various sweetpotato pricing levels, to enable risk assessments of the likelihood of getting a return on irrigation investment.

Field evaluation

In conjunction with 4 of the detailed agronomic investigations (sweet corn, onions, potato and lettuce), we grew commercial sized (100 m by 10 m) plots of sprinkler-irrigated crops, to compare with the intensively managed drip treatments. The irrigation inputs into the large plantings were principally managed by the Research Station staff, using commercial decision making processes (e.g. fitting in with other plantings, availability of irrigation equipment, interaction with pest management schedules, levels of water in the drought-affected bores). In comparison with the optimal treatments in our intensive plots, these large plantings provided a baseline for determining where irrigation improvements could potentially be made, and the potential agronomic and water use efficiency benefits from implementing such improvements.

As previously mentioned, we consulted with several producers to benchmark the assumptions and actual input values in our economic analyses. We also facilitated changes in irrigation systems and practice with commercial producers, particularly switching to drip irrigation, and optimising those new systems (drip tape output specifications, irrigation frequencies and quantities).

We initiated an experiment where we measured the variability in onion plant growth within a sprinkler-irrigated paddock, attempting to correlate that agronomic variability with irrigation variability. The intent was to use this data to plug into economic analyses, justifying improvements in irrigation uniformity. At each of 56 points in a 7*8 grid between sprinkler lines, we measured onion bulb diameter at the soil surface for onion plants 25 cm either side of a irrigation/rainfall catch can, within a crop row. We made these measurements at fortnightly intervals. Unfortunately the grower harvested the onions before we could collect yield data. The results of this experiment are still being analysed by Adoption Program staff at USQ.

We currently have 2 demonstration experiments still underway on vegetable producers properties. The irrigation treatments involve us putting in drip tape specifications with emitters 20 or 30 cm apart, putting out 1.7-5 L/m/hr, and comparing to the commercial drip tape the producer is using. Our tape sequences are plugged directly into the producer's system, so that every time he irrigates, our plots receive different proportions of his crop's water, based on the relative outputs of each tape. Our intention is to assess the agronomic performance and water use efficiencies of different deficit irrigation strategies, using the differences in tape specifications to automatically assign different deficits. In each experiment we are recording all the agronomic treatments applied by the producer, their irrigation and nutrition programs, and their rainfall. We are using flowmeters to record total volumes of water into each irrigation line, and pressure sensors to measure pressure drops down the line during sample irrigations. From this data we can get a good estimate of actual water applied to each plot. We are using tensiometers to monitor soil water status, with these instruments read at least weekly, and before and after each irrigation or rainfall event where possible. We are rating crop health in each plot several times during the growing period.

A potato demonstration near Atkinson's Dam is due for harvesting in early July, whilst a Bundaberg sweetpotato demonstration was only successfully planted in early May (due to disruptive rainfall in March and April that prevented the collaborating producer from planting). This experiment will not be harvested until September/October 2003.

Experimental plans for these demonstrations are detailed in attached documentation.