

Field evaluations

In conjunction with several of the detailed experiments during 2002, we grew blocks of sprinkler-irrigated crops generally 100 m * 10-12 m. These blocks were of a similar size to a single commercial producer planting as part of their weekly schedule. Apart from the irrigation management, the agronomic treatments on these blocks were as similar as possible to the detailed experimental areas, in terms of nutrition, pest management, and harvesting methods. The irrigation was controlled by the Research Station Manager, to fit in with his farm operations (as would happen in a commercial enterprise). Given the severe drought we are currently experiencing, these crops generally received less water than they would in a normal season, however this was again replicating what was happening in commercial production areas.

The following analyses evaluate the performance of the different irrigation systems investigated in the detailed experiments and these commercial scale blocks. We used our economic models to scale up each of the systems to a commercial production unit.

In these evaluations, we applied the following assumptions.

1. The producer is in an operating environment where water is the restricting factor.
2. They have a total of 60 ML to allocate across their 50 ha cropping area, and can sell all the product they grow.
3. Any excess land that is not cropped, they can lease out to a neighbour at \$1,000/ha.
4. Using a drip system costs them an additional \$0.10 per metre of drip tape installed, in irrigation costs.
5. All yields from the detailed experiments were discounted by 15%, to account for any perceived 'small plot' factor.

Lettuce

Table 15. Comparison of physical and economic performance of conventional and deficit drip irrigation, with a sprinkler-irrigated block and a standard district gross margin.

	Water use (ML/ha)	Yield (cartons/ha)	Area planted (ha)	Cartons produced	Return/ha (\$)		Economic Water Use Efficiency (\$Return/ML)		Seasonal return (\$)	
Market price (\$/carton)					7.00	7.50	7.00	7.50	7.00	7.50
Standard gross margin	3.0	3,350	20	67,000	2,325	3,799	775	1,266	76,501	105,981
Farm block	2.05	3,160	29	92,488	1,965	3,356	959	1,637	78,255	118,950
Best conventional drip	2.20	3,728	27	101,673	1,861	3,501	846	1,591	73,468	118,204
Best deficit irrigated drip	1.75	3,728	34	127,817	1,886	3,526	1,078	2,015	80,380	136,620

This evaluation demonstrated that the irrigation strategy adopted by the Research Station manager used much less water than the standard budgeted for lettuce, with a yield slightly below average. Because the water saving was used to increase cropping area, the total seasonal production was greater, and the total seasonal return was greater as well.

The conventional drip strategy of refilling the root zone with each irrigation, we achieved a substantial increase in lettuce yields (including the small plot discount), and did save water compared to the normal budgeted amount for lettuce. At a market price of \$7.00 per carton, the water saving and increased yield was insufficient to recoup the investment in the drip system. However, if the lettuce price was \$7.50 per carton, the investment in conventional drip irrigation (compared to under watering using sprinklers) was recouped.

Our best deficit irrigation treatments achieved the same yields as the conventional drip treatments, but used much less water. Although this only had a very small impact on the return/ha compared to the conventional drip treatment, because of the marked reduction in water use, it meant the Economic Water Use Efficiency, and the total area able to be cropped was much increased. It also meant the lettuce price needed to recoup the investment in drip (compared to under watering using sprinklers) was lower, or alternatively the return on investment at higher prices was greater.

This result confirms many of the assumptions and conclusions outlined in our economic modelling. In an operational environment of water shortage, it may be acceptable to sacrifice some yield for large water savings, if no other irrigation investments are required. Alternatively, significant investments in irrigation improvement can be recouped if water savings can be used to increase cropped area (assuming no market limitations). Water savings required to recoup the irrigation investments fall dramatically as the price of produce increases. If a deficit irrigation strategy can deliver large water savings and comparable yields to conventional drip irrigation, it has real potential to maximise economic benefits to producers, as well as potentially deliver environmental outcomes, in terms of reduced runoff and leaching.

Onion (assuming a market price of \$485/tonne)

Table 16. Comparison of physical and economic performance of conventional and deficit drip irrigation, with a sprinkler-irrigated block and a standard district gross margin.

	Water use (ML/ha)	Yield (t/ha)	Area planted (ha)	Tonnes produced	Return \$/ha	Economic Water Use Efficiency (\$Return/ML)	Seasonal return (\$)
Standard gross margin	4	40	15	600	8,302	2,076	159,530
Farm block	6.82	50.6	9	445	10,907	1,599	137,158
Best conventional drip	7.08	51.5	9	436	9,794	1,383	124,525
Best deficit irrigated drip	5.24	51.7	11	592	9,951	1,899	152,489

This evaluation was conducted in a very warm, windy growing period, with a very limited amount of rain. Hence the total irrigation required was much greater than normally budgeted for in a late onion crop, and comparisons with the standard gross margins are not particularly relevant.

The sprinkler irrigation strategy adopted by the Research Station manager was very efficient, running a deficit during the last 5 weeks before harvesting. He achieved total irrigation requirement and marketable onion yields equivalent to our best conventional drip treatments, meaning that his economic returns were superior (due to not having the additional costs of the drip irrigation compared to sprinkler application systems). The total returns were poorer than the standard gross margin because of the reduced cropping area.

Our best deficit irrigation treatments achieved the same yields as the sprinkler and conventional drip treatments, but used much less water. Because of the marked reduction in water use, it meant the Economic Water Use Efficiency, and the total area able to be cropped in this season of high evaporative demand was increased. As a consequence, overall onion production and seasonal return approached that of the onion budget under a more equitable growing season.

Potato (assuming a market price of \$360/tonne)

Table 17. Comparison of physical and economic performance of conventional and deficit drip irrigation, with a sprinkler-irrigated block and a standard district gross margin.

	Water use (ML/ha)	Yield (t/ha)	Area planted (ha)	Tonnes produced	Return \$/ha	Economic Water Use Efficiency (\$Return/ML)	Seasonal return (\$)
Standard gross margin	3	25	20	500	1,835	612	66,701
Farm block	3.0	19.9	20	398	1,012	337	50,244
Best conventional drip	3.3	34.0	18	618	1,936	587	67,017
Best deficit irrigated drip	2.6	30.9	23	713	1,478	569	61,039

As for the onions, this evaluation was conducted in a very warm, windy growing period, with a very limited amount of rain. The total irrigation required for best yields was substantially more than normally budgeted for in a Spring potato, hence the poor yield performance of the Farm block. One of the benefits of drip irrigation is that all of the applied water ends up in the hill, compared to sprinklers where at least some of the water penetrates through the furrow, and is less accessible to the potato plant. The increased yields under the drip irrigation recouped the extra expense of the drip tape, whilst the reduction in yields from deficit irrigation could not be compensated for by the increased total production available from reduced water use.

Fresh market sweet corn (assuming a market price of \$7.50/carton)

Table 18. Comparison of physical and economic performance of conventional and deficit drip irrigation, with a sprinkler-irrigated block and a standard district gross margin.

	Water use (ML/ha)	Yield (cartons/ha)	Area planted (ha)	Cartons produced	Return \$/ha	Economic Water Use Efficiency (Return/ML)	Seasonal return (\$)
Standard gross margin	4	1,000	15	15,000	305	76	39,574
Farm block	3.1	1,520	19	29,419	1,464	472	58,974
Best scheduled treatment (75 cm drip row spacing)	2.5	1,808	24	43,392	778	311	44,677
Best 1.5 m drip row spacing	2.4	1,612	25	40,300	1,032	430	50,810
Least water use drip (Fortnightly, through 1.5 m drip spacing)	1.7	1,424	35	50,259	672	395	38,415

Because sweet corn inherently has a low gross margin (relative to other vegetables), it becomes more difficult to recoup the additional costs of drip irrigation, unless there is a large yield improvement compared to sprinklers, and or a price well above average. At this stage, most producers elect to have a wide drip row spacing (1.5 m) to reduce their installation costs. In this evaluation, that proved to be the most economic drip system, although it still did not perform as well economically as the sprinkler system.

However, note that if the price for sweet corn increased beyond \$8.50 per carton, the drip strategies became more profitable than the sprinkler crop. Which strategy is most profitable (highest yields, best yields at 1.5 m spacing, or lowest water use) depends on the price received, and the yield sacrificed by limiting water use. For example, total seasonal return for a range of prices from the above field evaluation is shown in Table 19, with the best-performed strategy highlighted.

Table 19. Market price influences the best performing irrigation strategy in sweet corn production. Values are total seasonal return in (\$'000).

Market price (\$/carton)	\$7.50	\$8.00	\$8.50	\$9.00	\$10.00	\$11.00	\$12.00
Farm block	59	74	88	103	133	162	191
Best scheduled treatment (75 cm drip row spacing)	45	66	88	110	153	197	240
Best 1.5 m drip row spacing	51	71	91	113	152	192	232
Least water use drip (Fortnightly, through 1.5 m drip spacing)	38	64	89	114	164	214	265

Potato producer evaluation of deficit irrigation

Using drip tapes of various specifications, the collaborating producer has differentially watered potato plots. The experiment is not due to be harvested until late June 2003, however we do have some information on irrigation quantities applied, soil moisture levels during the growing period, and a general rating of crop health 9 weeks after planting (Table 20). The crop has so far received rainfall of 180 mm, consisting of four major rainfall events 1, 2, 4 and 5 weeks after planting, as well as a several minor events.

Table 20. Impact of irrigation quantities on soil moisture fluctuations and potato crop health.

Treatment	Drip emitter spacing (cm)	Tape output (L/m/hr)	Total irrigation applied (mm)	Peak shallow tensiometer in first 9 weeks (kPa)	Peak shallow tensiometer value 9-11 weeks (kPa)	Crop health rating 0=death, 3=acceptable 5=good, 7=excellent
1	20	5.0	245	17	39-46	3.37
2	30	3.4	166	17	39-46	4.62
3	20	2.5	122	26	39-46	4.75
4	30	2.5	122	17	39-46	4.38
5	30	1.7	83	29	62	4.00

The producer's crop is being watered with tape equivalent to Treatment 3. In none of the treatments or the producer's paddock have deep tensiometers 60 cm below the top of the hill registered values above 13 kPa, suggesting no substantial uptake of water from depth to this point in time. There has certainly been deep drainage from Treatment 1 and possibly Treatment 2.

The differences in crop health rating are not significant, however the wettest treatments may be suffering from excessive nutrient leaching. To this point in time, the least watered potatoes (Plate 4) appear to be performing as well as the standard crop (Plate 5).



Plate 4. Potato plot watered with 78% of intensity of producer's crop.



Plate 5. Potato crop watered identically to producer's crop.

Sweetpotato producer evaluation of deficit irrigation

As outlined in other sections, we also have a sweetpotato evaluation currently underway, however due to late planting and rain, there are no substantial irrigation or crop performance results to report at this stage. A summary of this activity is included in the attached document including experiment summaries and preschedules.

Conclusions

- Lettuce, onion, potato, sweetpotato and sweet corn were successfully grown with drip irrigation.
- Taking into account a discount for 'small plot' effects, conventional drip systems provided average yield increases of 15%, and average water savings of 10%, compared to standard sprinkler irrigated district practices.
- Our deficit-irrigated drip treatments provided a lesser average yield increase of 10%, but a greater water saving of 25%, compared to standard sprinkler irrigated district practices.
- In terms of agronomic water use efficiency, the conventional drip thus increased agronomic water use efficiency (tonnes product per ML of irrigation) by about 28%, whilst deficit irrigation increased it by nearly 47%.
- The best performing irrigation system and strategy is very sensitive to market price for produce, and which factors are constraining returns (access to land, water or other input resources, or capacity of market to absorb produce). For example, at an onion price of \$485/t, our models show a sprinkler-irrigated system gives the best profitability if the amount of produce required is the restricting influence. 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.

Project Impact Assessment

Water use efficiency

The economic modelling, scenario testing and analyses of experiments and field evaluations demonstrated that price improvement in produce or cost-effective yield increases are the primary economic drivers of practice change that could lead to improvements in Economic Water Use Efficiency (\$ Returns per ML of water used).

The analyses also clearly demonstrated that in operational environments when water is scarce, i.e. drought, or restricted water allocations due to policy changes, reducing water use per unit produce can also be a substantial incentive to change irrigation practices.

In analysing potential impact of project findings, we have assumed 30% adoption across Queensland industry, and used the basic district gross margins as the starting point for comparisons. These figures are only indicative, as actual returns will depend on spot market prices that can fluctuate enormously across and between seasons.

Capacity to increase price through improved quality

This project demonstrated that optimising irrigation management could reduce doubling and splitting in some onion cultivars, reducing wastage, or potential contamination of moderately graded produce. There was a tendency for lower pungency in onions grown with reduced irrigation, although pungency was more influenced by cultivar selection.

To try and estimate the potential value of these improvements, we assumed a modest price increase of 2%, from producing uniform, high quality, lower pungency onions compared to current product. This is worth \$390/ha, equivalent to \$90,000 per annum increased profit to the Queensland onion industry. We also demonstrated that using the minimum amount of sulphur fertiliser would reduce pungency.

Although there was a trend for superior flesh colour in **Beauregard** sweetpotatoes under optimal irrigation strategies, the market is apparently not currently sufficiently discerning to pay a price premium for that at this time. We could not ameliorate cracking in the **Northern Star** cultivar, by optimising irrigation, whilst **Beauregard** produced excellent quality irrespective of our range of irrigation treatments. Therefore, we cannot assume any price improvement in this crop from our project results.

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 show that supplementary calcium did not assist in managing these disorders in the respective crops, which may prevent wasted efforts by producers in potatoes and lettuce. This may have a minor effect on industry productivity.

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.

Improving Economic Water Use Efficiency through increasing yields by better irrigation and/or reduced water use

In many of our experiments and field evaluations, we achieved superior yields through conventional drip irrigation, compared to standard district averages, or more fairly, against companion farm scale sprinkler plantings. The farm scale plantings were treated similarly to commercial crops at the time, however it must be remembered that drought conditions in the Lockyer Valley at present may slightly skew the results.

To reiterate our findings from the field evaluations, we estimate our best conventional drip irrigation treatments provided average yield increases of 15%, and average water savings of 10%, compared to standard sprinkler irrigated district practices. Our deficit-irrigated drip treatments provided a lesser average yield increase of 10%, but a greater water saving of 25%, compared to standard sprinkler irrigated district practices. In terms of agronomic water use efficiency, the conventional drip thus increased agronomic water use efficiency (tonnes product per ML of irrigation) by about 28%, whilst deficit irrigation increased it by nearly 47%.

However, the economic impact of these potential agronomic improvements depends on the operational irrigation environment at the time. If we assume 30 % of producers in the 5 crops mentioned might change practices in the first instance, this equates to an area of about 3,000 ha per annum in Queensland, using nearly 10,000 ML of irrigation per annum.

Scenario 1

If that group of growers wishes to produce the same volume of product to retain profitable markets, using a conventional drip system, they could reduce their area cropped by 390 ha, and the amount of water used by 2150 ML. Using a deficit drip irrigation system, the land and water savings are 270 ha and 3,100 ML respectively.

Scenario 2

If instead, those producers have a market for more produce, but are restricted to using the same amount of cropped land, under the conventional drip system they can grow 15% more product and still reduce water use by 300 ML/annum. By deficit irrigating, they produce 10% more product with 750 ML less irrigation per year.

Scenario 3

In circumstances where the availability of water is the restricting factor (e.g. through drought or reduced water allocations), to only 70% of previous quantities i.e. only 7000 ML/annum, our growers using the conventional district system would be restricted to planting only 2100 ha, and delivering 70% of original production. By using the conventional drip system, they could increase their cropped area to 2300 ha and deliver nearly 90% of original production. In the same scenario, using deficit irrigation could enable cropped area to increase back to 2800 ha and deliver 100% of the original production.

If drip irrigation can potentially have such huge impact on agronomic water use efficiency, why isn't it universally and rapidly adopted? As demonstrated throughout this project, the economic viability of changing to any new irrigation strategy depends on its cost, and the price received for the produce. At standard gross margin prices, the economic benefits of switching to drip systems, even given these significant agronomic and water use efficiency outcomes, are marginal. Our project results suggest economics is most likely to stimulate increased investment in irrigation management when prices are above long-term averages, and water is in restricted supply.

Potential state-wide impact of project outcomes

To demonstrate potential state-wide impact of adopting the techniques described in this project, the following analysis assumes only 70% of irrigation water previously available (Scenario 3 above), can currently be accessed by producers of the five crops we investigated. We assume that 30% of producers adopt drip irrigation strategies, and that the prices are slightly above long-term averages (generally a reasonable assumption in times of drought and likely product shortages). Note that the figures provided are increases in annual industry profit, not revenue.

Table 21. Increase in industry profit to producers (\$ per annum) from adopting improved irrigation strategies.

	Assumed market price	30% of producers adopt conventional drip irrigation	30% of producers adopt deficit drip irrigation
QLD Onion industry	\$500 per tonne	\$216,000	\$431,000
QLD Potato industry	\$400 per tonne	\$1,282,000	\$1,831,000
QLD lettuce industry	\$9 per carton	\$610,000	\$1,028,000
QLD sweetpotato industry	\$15 per carton	\$64,000	\$129,000
QLD sweet corn industry	\$9 per carton	\$38,000	\$114,000
TOTAL		\$2,210,000	\$3,533,000

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. Our project results can demonstrate their general application, and also provide the tools to assess individual enterprise viability to enhance the prospects of producers trying out new systems and techniques.

Whole farm systems

The results of our detailed experimentation, economic analyses and field evaluations demonstrated the linkages between changing irrigation systems, yields, and water use. In our extension activities, we always communicated our irrigation information in conjunction with other system information. Refer to the extension leaflets on our lettuce, onion or sweetpotato work. In lettuce for example, we outlined the importance of cultivar selection in relation to season, appropriate harvest scheduling, nitrogen and calcium nutrition, and timing of drip irrigation, in relation to optimising lettuce yields and quality. In sweetpotato we discussed improving establishment through quality of cuttings and planting techniques, irrigation scheduling sequences, and differences in cultivar performance.

We analysed experimental results using parameters that indexed product quality, and assessed the contributions of irrigation treatments interacting with other factors such as nutrition and cultivar.

Our economic analyses and the spreadsheets we have developed have improved our capacity to analyse the key contributors to the performance of whole farm systems. We used these spreadsheets to analyse the potential impacts of irrigation techniques on farm profitability. They could be easily adapted to analyse the impacts of other potential practice changes.

In real life examples of producers who have recently switched to conventional drip irrigation systems, this has led to a range of changes not immediately obvious. These subtle but important outcomes specifically mentioned to us by producers have included:

- Ease of irrigation at short notice in adverse weather– doesn't take time to move winches or pipes
- Capacity to irrigate during extended periods of wind
- Ability to pre-program irrigation, enabling focus on other activities at important times. This was not just a work issue, but also related to work/family balance, and personal health (e.g. sleeping at night rather than shifting irrigators)
- Reliability of irrigation – not concerned about travelling irrigators 'escaping' from paddocks at night
- Ease of modifying nutrient status of crops by additional fertigation

Several producers have mentioned that they will persist with drip irrigation because of all these benefits, even if water supplies become more readily available. We are relatively confident that once producers have successfully implemented the new irrigation systems we investigated in our project, that adoption will be relatively robust and resistant to small fluctuations in operating environments.

Sustainability

The project demonstrated irrigation systems that could deliver substantial improvements in Agronomic Water Use Efficiency (tonnes or cartons of marketable produce per ML of irrigation water), ranging from 25% increases for conventional drip systems, up to 45% for deficit drip systems. These systems still need to be economic to be adopted, and the project demonstrated the circumstances under which the investments to adopt drip irrigation for example, could be recouped.

This project demonstrated agronomic techniques to markedly reduce the amount of irrigation water required to grow a specific volume of vegetable produce. The actual process to convert that capacity into environmental sustainability outcomes is actually determined by the underlying water policy framework, i.e. water regulation, distribution and pricing mechanisms. Vegetable marketing and pricing constraints also determine impact and adoption.

For example, suppose a vegetable producer grows from 50 ha of produce per annum, using 150 ML of irrigation water. They adopt a conventional drip irrigation strategy, which improves their agronomic water use efficiency by 25%. They may have adopted that strategy because government policy has reduced their water allocation by 40 ML/annum, to return water to environmental flows. They may voluntarily produce the same amount of vegetables to meet a market, and leave the 40 ML in the creek, or alternatively sell that water to their neighbour (depending on water trading regimes). They may simply produce 25% more vegetables and hope they can sell them.

Thus, this project has developed a capability to improve environmental sustainability by reducing water use. However, achieving environmental outcomes from that capability requires economic and policy settings that encourage sustainable practices.

Our preliminary investigations of deficit irrigation suggest a capacity to irrigate vegetables in such a way as to increase the proportional contribution of rain to the total crop water requirements, and thus reduce the average amount of irrigation required in the long term. We believe that deficit irrigation may also increase the ability of some vegetable crops to expand their root systems, and tolerate mild water stress, whilst still producing economically viable yields and quality. We believe that deficit irrigation has the potential to dramatically improve the Agronomic Water Use Efficiency of certain vegetable crops, with the environmental benefits described above.

Although we did not have the opportunity to prove our hypothesis in the drought conditions we are currently experiencing, we believe that deficit irrigation could reduce the potential for off-site contamination of water resources and environments through reduced risk of leaching and runoff. This is certainly an area of research that we would like to pursue, through both modelling and field investigations.

Adoption of precision irrigation systems, that also have the capacity to supply nutrients during the cropping period have the potential to reduce nutrient movement off site, by delivering nutrients in small quantities as crops require them. By demonstrating that drip systems can be economically viable for a range of vegetable crops, we have improved the potential for vegetable production to contribute less to off site nutrient loads.

During this project we have shown that both conventional and deficit irrigated drip systems can produce high yields of quality vegetables. When linked with encouraging water policy and vegetable marketing settings, this could deliver economic and environment outcomes more sustainable than current systems. We were not able to demonstrate an increased capacity to reduce specific disease or quality disorders by manipulating irrigation, with some of those issues still remaining problematic.

Model development and use

The spreadsheets we used to determine the costs of irrigation practice change, analyse the contribution of outcomes to enterprise profitability, and the return on irrigation investments under different operational environments, can all be used to generate data for other economic models.

The project demonstrated that any economic evaluation models need to be able to factor in the operating constraints to determine economic outcomes, e.g. are market limitations, resource limitations, or policy/legislative limitations, determining the optimum outcomes from proposed practice changes?

For example, at an onion price of \$485/t, our models show a sprinkler irrigated system gives the best profitability when the amount of produce required is the restricting influence. 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. I am not aware of economic models that explicitly include or even consider those constraints in their design or application.

Our detailed irrigation/output production functions provide initial data for vegetable crops to be included in current biophysical crop modelling. These types of experiments will need to be repeated across a range of environments, particularly soil types and weather. As we fine tune drip systems, we expect there will be further opportunities to flatten out the production function curves toward the low end of irrigation requirements.

We would like to further investigate interactions between use of precision irrigation systems, deficit irrigation strategies and weather/climate forecasting models. We hypothesise that there will be opportunities in some vegetable crops to further improve agronomic and economic water use efficiency by manipulating irrigation based on weather prediction. We perceive a significant role to combine models such as WetUp[®] to provide information on soil water characteristic under deficit irrigation, with APSIM[®] based production models. It would be useful to generate a multitude of data runs, testing the capacity of deficit irrigation to generate consistent and significant water savings.

Links to Adoption Programs

Throughout the project we provided research results and extension materials to Adoption Program staff. These materials have been included in their Resource CD, and apparently provided on demand to interested producers.

Findings from current and previous research have been included in most of the Adoption Program Factsheets relating to vegetable crops, and we reviewed the relevant Factsheets prior to their release.

Early in the Adoption Program we supported the Southern Queensland Officer in developing strategies for working with key producers.

As noted in the section on extension activities, we held specific field days and seminars for Adoption Program staff throughout the project, detailing research activities and findings to that point in time. Adoption Program staff also attended general field days and seminars.

We worked with Adoption Program officers Scott Barber and Evan Howard in South Queensland, and Callum Rowe in Bundaberg with specific activities helping producers adapt drip systems for their vegetable crops.

As the Adoption Program continues for several months after this project officially concludes, there is an opportunity to continue working with extension staff. The likely focus is assisting producers cope with severe water shortages, as well as evaluate the potential benefits of drip systems, and specific adaptation of irrigation systems to producer environmental and operational circumstances.

Use by farmers and in training programmes

Following excellent attendances at presentations, field days and seminars, we answered many inquiries about application of research results and general irrigation issues in a range of vegetable crops.

In conjunction with advice from local agribusiness, irrigation suppliers and Adoption Program staff, as well as active learning by producers, there has been a substantial increase in drip irrigation of vegetables such as lettuce, potatoes, sweet corn, brassicas and sweetpotato in major production centres in southern Queensland (Lockyer, Granite Belt and Bundaberg districts) during the last 18 months. We have actively supported that uptake by regular discussions with agribusiness, irrigation suppliers and local Adoption program staff in particular. We have assisted several potato, sweetpotato, lettuce and onion producers develop appropriate drip irrigation and irrigation scheduling systems.

Working with our DPI sweetpotato team, we are changing the way those producers manage their watering and irrigation scheduling in that crop. Producers are reducing their irrigation intensity and overall water use during the bulking up period as a direct consequence of our research and advice.

A national lettuce agronomy project is using our lettuce information to reinforce their strategies for managing tipburn and optimising lettuce yields.

We have initiated some introductory evaluations of deficit irrigation on 2 producers' properties, although most growers are seeking more evidence that the risks to yields and quality do not outweigh the potential savings in water use.

Given the critical water shortages in southern Queensland, the opportunities to encourage further adoption of drip irrigation still exist. Unfortunately the generally pessimistic outlook, stressful operating environment and lack of cash flow and market certainty for many producers means it is still a complicated process to encourage such significant practice change and investment as a switch from sprinkler to drip irrigation. It is as much about building long-term relationships as it is about presenting the latest technology or research results.

Project Intellectual Property

There are no clearly identified intellectual property issues arising from the conduct of this project. All information generated by this project has been freely shared amongst the Research Program and Adoption teams, and specific outcomes targeted at producers, producer groups and relevant agribusiness free of charge.

If further work shows deficit irrigation to be a reliably successful strategy in reducing water use in vegetable production, we do not foresee that the technique could be sufficiently described and differentiated to become intellectual property. Each producer who adopted some form of deficit irrigation would probably need to substantially alter any particular 'recipe' to suit their specific production systems.

Our intention is to develop our simple economic models to the point where they can be readily used and modified by irrigation extension workers in the field. Because of their level of simplicity, and the potential benefits from making them available for more general use sooner rather than later, we believe that the time, effort, funding and delays associated with developing them to protected IP status would not be cost-effective.

Publications List

Conference posters (reviewed)

Gilbert A and Henderson C (2002). Management of Irrigation Frequency and Sulphur Nutrition in Fresh Mild Onions- Impacts on Crop Water Use, Quality and Yield. Poster, Australian Onions 2002 Conference, 3-5 June 2003, YANCO Australia

Project reports

RWUE Milestone 1 report (RWUE website) August 2001

RWUE Milestone 2 report June 2002

Other extension materials

RWUE experiment summaries – Managing yields and quality of lettuce cultivars (circulated to lettuce industry and RWUE personnel 15 March 2002).

RWUE experiment summaries – Irrigation and sulphur nutrition impacts on onion production and water use (circulated to onion producers and RWUE personnel 22 November 2002).

RWUE experiment summaries – Irrigation impacts on sweetpotato production and water use (circulated to onion producers and RWUE personnel 19 February 2003).

Workshop reports

Henderson CWL (2003). Could deficit irrigation improve water use efficiency, profitability and environmental outcomes in vegetable production? Proceedings RWUE workshop II, 8-9 April 2003.

DPI Notes

Henderson CWL (2002 update). Managing yield and quality of lettuce cultivars: Research results from the 2001 growing season. DPI Note HTML File H0230

Henderson CWL (2003 update). Producing vegetables for a market or (are vegetables an appropriate enterprise?). 4. Sensible use of irrigation resources during drought periods. Web File H0169.

Industry journal papers, magazine, and newspaper articles

Henderson CWL (2002). Drip irrigation put to good use in projects at Gatton Research Station. *General Press Release to Gatton Star*

Field walk and seminar notes

RWUE project Lettuce Quality Field Walk Notes 21 September 2001

RWUE project Onion Quality Field Walk Notes 15 November 2001

RWUE project Beetroot Establishment Seminar Notes 23 November 2001

RWUE project Sweetpotato Field Walk Notes 7 May 2002

Multiple Water Use Posters 8 May 2002

Presentations

Alternative mulches and irrigation for quality	17 May 2001
RWUE Project 18 highlights (RWUE workshop)	10 July 2001
Irrigation costs in producing vegetables (City to Soil)	26 July 2001
Managing irrigation in beetroot	23 November 2001
Managing irrigation in beetroot	25 May 2002
New water, new thinking	18 August 2002
RWUE Project 18 highlights (Adoption program workshop)	17 February 2003
Irrigation strategies, water use efficiency, potato yields & quality	26 March 2003
Deficit irrigation impacts in vegetable production	8 April 2003

Detailed experimental reports

- RWUE Project 18 Experiment Report. Irrigation management and seed priming affect the establishment of four beetroot cultivars. 7 September 2001.
- RWUE Project 18 Experiment Report. The impacts of irrigation frequency and timing, and calcium and nitrogen nutrition, on yield and quality of four lettuce cultivars. 15 January 2002.
- RWUE Project 18 Experiment Report. Management of irrigation frequency and sulphur nutrition in fresh, mild onions – impacts on crop water use, onion quality and yield. 31 July 2002.
- RWUE Project 18 Experiment Report. Irrigation impacts on water use, quality and yields of sweetpotato cultivars. 30 January 2003.

Committed publications

- Henderson CWL and Gilbert A (2003) Drip irrigating potatoes when water is scarce. *Potato Australia* **14**
- Henderson CWL and Gilbert A (2003) Drip irrigating onions when water is scarce. *Onions Australia* **20**
- Henderson CWL and Gilbert A (2003) The economics of irrigation depends on environment and market conditions. *Good Fruit and Vegetables (October edition)*
- Henderson CWL and Gilbert A (2003) Can deficit irrigation improve water use efficiency in vegetables? *Good Fruit and Vegetables (October edition)*

Extension and networking activities

On 17 May 2001, I presented the project concept to the Atkinson-Buaraba Landcare Group (Inc.), as part of a broader presentation and discussion on vegetable crop mulching and irrigation management. There was genuine interest on optimising irrigation by the use of the most appropriate application systems, and the interaction between irrigation and other agronomic practices. The group expressed an interest in being kept updated on project progress.

On 22 May 2001, I discussed concepts of irrigation management for vegetables with a group of potential vegetable growers from the eastern Downs area, as part of a broader activity by Gatton Research Station scientists, the RWUE Horticulture Adoption Program (Scott Barber), and various agribusinesses, on vegetable production and irrigation. We visited the lettuce tipburn experiment to illustrate the concepts of maximising quality outturn by irrigation management. This group was appreciative of the demonstration and discussion, and certainly appeared to take on board the importance of getting irrigation right to maximise the probability of enterprise success.

On 25 May 2001, I presented the initial results from our beetroot experiment to the beetroot project team, processing company representatives, and their contracted producers. This presentation was part of a bigger field walk and discussion afternoon, which was arranged in some haste by the beetroot project team, in response to an urgent request by the processing company and producers. The soil-borne diseases referred to earlier have caused serious crop losses this season, and the industry was vitally concerned to:

- a) Make sure they were doing everything possible to minimise the impact in the current season,
- b) To see what they could do to scale up project activities before and into next season.

On 10 July 2001, we presented the initial project ideas and results at the Queensland Irrigation Technology Workshop.

On 26 July 2001, I presented ideas on the relative importance of irrigation costs and outcomes to the local City to Soil group. This community organisation of farmers and agribusiness is attempting to encourage the development and application of the scheme to take water wastes from Brisbane and surrounding urban areas, and recycle them as irrigation sources for the Lockyer, Bremer and Fassifern Valleys. I presented some of our initial economic modelling, at the behest of the City to Soil executive, who wanted to enhance producers' awareness of how they may be able to afford the potential water charges associated with the renewed water. The audience recognised and agreed with the scenarios that in field crops and lucerne, saving irrigation applications as water charges increased was the priority, whereas with high value vegetable crops, the focus was on achieving yield and prices received to pay for increased water costs.

On 21 September 2001, we displayed our intensive lettuce irrigation/nutrition experiment to about 40 lettuce producers, agribusiness representatives, scientists and other government officers, discussing our objectives, methods and initial findings. We had a hands-on exercise looking at the tipburn as it had developed under the various cultivar and nutrition treatments.

Most of the major lettuce growers in southern Queensland attended (Lockyer, Eastern Downs, Granite Belt), and expressed an interest in being informed of the final results and the progress of any further work. We sent all the attendees (and other industry stakeholders) a copy of the lettuce experiment summary (see accompanying extension leaflets). The summary was adapted to a DPI Note for incorporation in the suite of lettuce agronomic material.

On 15 November 2001, Angelina presented the objectives, methods and initial findings from the experiment she conducted, investigating the influence of irrigation and nutrition on onion yields, quality, and sweetness/pungency. The short summary of her talk, which was one of several given by Gatton staff to onion agribusiness reps, on various aspects of onion production and marketing, was expanded into a poster presented to the Australian Onion Industry annual conference (see onion poster in presentation attachment).

The general impressions of the reps present was that the yields over all were very good, and probably the treatment range did not stress the onion plants to the extent of reducing yields.

On 23 November 2001, under the auspices of the major project assisting the beetroot industry overcome some production/quality/consistency issues, we provided a final update on our experiment investigating beetroot establishment under different irrigation regimes. We also had some discussion of general irrigation issues, as well as any potential further work they felt might be required. Eric Coleman discussed the outcomes of some on-farm work he and Evan Howard from Water for Profit had conducted (focussed on distribution uniformity and implications for disease incidence and yields).

The meeting was attended by 90% of the QLD beetroot industry (producers and processors). Although there was some limited discussion about irrigation issues during the meeting, there was no call for further irrigation work by the group - they were certainly more focussed on other issues such as cultivar portfolios and immediate disease control practices.

The experiment report (see attached experiment report) was sent to interested stakeholders, and a copy of the PowerPoint slides from the November presentation is available (probably only of medium use, given it doesn't include the context of ensuing discussions).

On 4-6 March 2002, I visited 8 sweetpotato producers, as one of the members of the group doing research and extension on sweet potatoes at Gatton Research Station. Our visits included producers at Bundaberg and Rockhampton, and we discussed linkages between production inputs and practices, sweetpotato performance and marketing issues. We described our project work, and specifically issues such as drip irrigation, quality outcomes, collaborative work and ground truthed some of our assumptions in economic modelling of sweetpotato production and marketing. These visits helped build the relationships which was very advantageous at the later field walk and on-farm producer experimentation of drip systems.

On 18 March 2002, we presented our project work to the Water for Profit Adoption Program officers, including field walks through the sweet corn and sweetpotato experiments, and presentations on findings from the previous experiments and the economic analyses. Several officers in the program asked to be kept apprised of the experimental outcomes and discussed the implications of the economic work. Some of them were interested in plugging data from their field observations and measurements into the models, to give another evaluation of potential impacts from system improvements, e.g. better distribution uniformities.

On 7 May 2002, we walked attendees at a regional sweetpotato forum through our detailed sweetpotato experiment. The group included sweetpotato producers, scientists, wholesalers and retailers from Queensland (Atherton Tableland, Central Queensland, Bundaberg, South-east Queensland and Northern New South Wales), and encompassed almost all the major stakeholders in the sweetpotato industry. There was real interest in how we were using drip to irrigate sweetpotatoes, and the potential to reduce cracking, particularly in the purple-skinned cultivar Northern Star. Several producers were in digging around the experimental plots (fortunately mostly in the buffer rows). This was a very forward thinking and enthusiastic group to work with, following on from the initial awareness visit to the main production areas as detailed earlier.

On 19 August 2002, I presented a seminar entitled 'New water, new thinking' to an audience of producers, agribusiness and government scientists at Toowoomba DPI. The afternoon involved several speakers talking about the potential use of recycled water in horticulture and agriculture, in the light of the proposed schemes to pump recycled Brisbane urban water to the Lockyer Valley and Darling Downs. The theme of my talk included outcomes from our economic analyses, investigating the outcomes producers would need to achieve (improvements in water saving, yields or prices), to pay the potential charges for recycled water. The talk was well received, and caused many people to rethink their simple answer to increased water charges was to 'switch to high value horticultural crops'.

On 22 August 2002, I conducted a field walk of our experimental sites and gave a brief presentation of results to date, to a group of Tasmanian scientists visiting Gatton Research Station. Their principle interests were in sustainability issues, and improving water use efficiency was certainly an important agenda item.

On 28 August 2002, I presented the preliminary outcomes of our intensive sweetpotato experiment to sweetpotato producers at the property of Duane Joyce in North Bundaberg. Around 20 people attended, as part of the 'Understanding your soils' workshop series conducted by the Horticulture Adoption program. There was ongoing interest in the use of drip tape to produce sweetpotatoes, which led to the collaborative work discussed elsewhere in this report.

On 13 February 2003, I took part in an internal DPI workshop, developing a 'Managing for drought' information service for vegetable production. I presented our preliminary results on the potential for deficit irrigation using drip tape to substantially reduce crop water use with limited impact on production for some crops. I also discussed the good performance of all our drip-irrigated vegetables, indicating that it was a viable option for producers looking at that method of reducing their overall water use. As a consequence of the workshop, I updated our DPI Note on 'Producing vegetables for a market or (are vegetables an appropriate enterprise?). 4. Sensible use of irrigation resources during drought periods.'

On 17 February 2003, I presented highlights of our research program to the Horticulture Adoption program workshop in Mooloolaba. I discussed our economic analyses and the relativity of potential benefits of reducing water use, improving yields, or chasing higher prices by improving product quality, uniformity or reliability. I also presented initial data on the potential of deficit irrigation in vegetable production. On the basis of comments from some of the Adoption team, I re-jigged the economic models to present the data as breakeven points to recoup costs of irrigation investments under different price scenarios.

On 26 February 2003, we presented our findings on potato irrigation to staff from a Japanese potato processing company and some accompanying producers. Although the talk was necessarily simple because of language difficulties, we received very useful feedback on some of our ideas, which we then incorporated in our presentation to local potato producers a few weeks later.

On 3 March 2003, I held discussions with staff at T-Systems (a major drip tape supplier), about coordinated activities in the Lockyer and Bundaberg. As a consequence, they provided supplies of different specification drip tape to use in our demonstration sites, and we jointly keep each other informed of research and demonstration activities in vegetables.

On 5 March 2003, I discussed our lettuce irrigation findings with Craig Murdoch from the Victorian Department of Agriculture, who has a major project on managing tipburn. His recent results match ours, with findings being incorporated into lettuce best-practice guidelines that are being circulated to producers in industry newsletters.

On 26 March 2003, I presented the results of our intensive potato experiments to a group of about 60 producers and agribusiness people at Gatton Research Station. The presentation was one of several during the afternoon, discussing research on managing brown fleck and dry matter in potatoes, pest management (melon thrips and root aphids), as well as my talk on 'Irrigation strategies, water use efficiency, potato yields & quality'. As a result, of the talk, several producers approached me for advice on managing drip systems in their potatoes, and we negotiated a demonstration on David Keller's property, which is currently underway.

On 8 April 2003, I presented some of the significant research results from our Project 18 to the Rural Water Use Efficiency Workshop, which included most of the people involved in both the R&D and Adoption components of the program. The presentation and paper are reproduced in accompanying documentation.

Other networking activities include, but are not limited to:

- Visits to collaborating producers (including significant discussions and advice to Geoff Story, Lester Hamblin, Ian French; Dave Fisher, Dean Acres, Troy Qualischefski and David Keller); individual presentations to Ian Bell and Ken Smith (RWUE management); Terry Johnston (Deputy Director-General DPI).
 - Mid-term project review by Don Yule, Ian Bell and David Clarke
 - Discussions at the Irrigation Association of Australia National Conference, and Researching the Future Irrigation Workshop
 - Various water innovation and natural resource management workshops
 - Local catchment management and producer group meetings
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Recommendations for further research

We believe the most significant outcome from this project was the potential for deficit irrigation to improve water use efficiency and sustainability outcomes in vegetable production. We strongly recommend that further investigations into deficit irrigation of vegetables be conducted in the following areas.

Field confirmation of the practicality and reliability of deficit irrigation as a strategy in vegetables

In this project we only conducted a limited number 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
- Crop growth stage
- Current evaporative demand and soil moisture content
- Short-term weather forecast, and
- Irrigation water quality

The performance of deficit irrigation would be compared with conventional drip irrigation, and measured on the basis of:

- Impacts on marketable crop yield and quality
- Impacts on total irrigation requirement and agronomic water use efficiency
- Impacts on deep drainage and nutrient movement
- Consistency and reliability of system performance

We believe this work clearly fits within program objectives of various state and national programs to increase irrigation efficiency, and reduce overall water use. An example is the CRC for Irrigation Futures, which has a specific program looking at making better use of natural rainfall; a key rationale for deficit irrigation.

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:

- Improving deficit irrigation outcomes by using weather/climate forecasting systems (use of APSIM[®] type models)
- Use of WetUp[®] type models to develop the best deficit irrigation strategies for different soil/crop type combinations and drip tape specifications. This may require significant model upgrading to cope with non-uniform starting conditions for soil water status in a 2-dimensional profile.
- 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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Finally, a very sincere and special thanks to the other members of our project team, Angelina Gilbert and Greg Finlay. Through a steep learning curve, a mountain of detailed experimental activities, data collection and analysis, and unsupportive environmental and resourcing conditions, we still managed to get things done without too many arguments. Well done team, and I hope we can continue to build on this in the future.

Attached documents

- Individual detailed experiment reports
- Extension leaflet summaries
- Minor experiment summaries and selected experiment preschedules
- Miscellaneous additional publications and presentations