Intensive agronomic experiments

Although not explicitly considered in the original research agenda, we believe that our initial serendipitous discovery of the potential for deficit irrigation, and subsequent results in specifically designed experiments evaluating deficit irrigation, are the most important positive irrigation research outcomes of our project. Therefore we started this section considering the ideas, research results and conclusions relating specifically to this topic.

The potential for deficit irrigation to substantially increase Economic Water Use Efficiency and producer returns, in a water restricted operational environment

Due to changing regulatory environments, and ongoing dry weather, there is a consistent trend of less irrigation water per hectare available for individual vegetable producers. They are reacting by purchasing water allocations, moving to areas where water is more readily available, or changing irrigation hardware to improve application efficiency. For example, there has been a major increase in the use of drip irrigation in the Lockyer Valley during the past 6 months.

Even if the water supply situation improves, there is increasing community consideration for environmental issues associated with water utilisation and subsequent off-site impacts, including increased environmental flows in rivers and tributaries, less deep drainage and nutrient exports into groundwater, and less runoff containing sediments, nutrients, and occasionally pesticides into waterways (freshwater and marine).

Maintaining productivity levels in the face of reduced irrigation water availability and increasing environmental considerations will be a significant challenge, but one that we must engage enthusiastically. There is much recent research on irrigation allocation in circumstances where water is a restricted resource (Kipkorir *et al.* 2001, Pereira *et al.* 2002, Pitts and Obreza 1999).

The shift toward more intense irrigation management (e.g. drip systems, electronic scheduling tools) **is an opportunity to re-invent our irrigation strategies**. Deficit irrigation, where only part of a crop's water requirement is supplied by irrigation, promotes use of stored soil water. It is particularly easy with drip irrigation, where localised water application leaves a substantial proportion of the crop root zone unwatered. Deficit irrigation can change the physiology and morphology of the crop plant, by inducing mild water stress (Fabiero *et al.* 2002, Kipkorir *et al.* 2002, Kirnak *et al.* 2002), or encouraging different root systems, compared to crops that are fully irrigated at each watering. Deficit irrigation may deplete soil water in an extended volume of the crop root zone, creating a reservoir more capable of retaining rain during the cropping period. Not only does this improve the irrigation efficiency, by substituting rain for irrigation, it should theoretically reduce the amounts of deep drainage and runoff. The trick is to manage the deficit strategy so as not to adversely affect crop performance.

Depending on the season, deficit irrigation can increase the amount of rain captured and used by the crop, which can then substitute for irrigation. We planted a sweetpotato experiment in January 2002, irrigated entirely using drip tape. Five weeks after planting, we implemented irrigation treatments, four of which are shown here, to simplify interpretation. 'Moist' treatments were irrigated when tensiometers 20 cm below the hill surface reached 40 kPa, 'Dry' treatments when tensiometers reached 80 kPa. Treatment combinations (e.g. 'Moist/Dry') refer to scheduling before/during bulking respectively. Although unintentional, the irrigation quantities in the 'Dry' schedules created a deficit irrigation scenario, which gives a good demonstration of rain capture. In the 'Dry' treatment, from about 6 weeks after planting the crop was creating a substantial soil moisture deficit in the hill (values for tensiometers 60 cm deep are shown in Figure 4). When 45 mm of rain fell around 56 days after planting, the bulk of this rain was stored in the crop root zone, rather than draining through the profile or running off. In the 'Moist' treatments, about 15 mm drained beyond the root zone after this event.

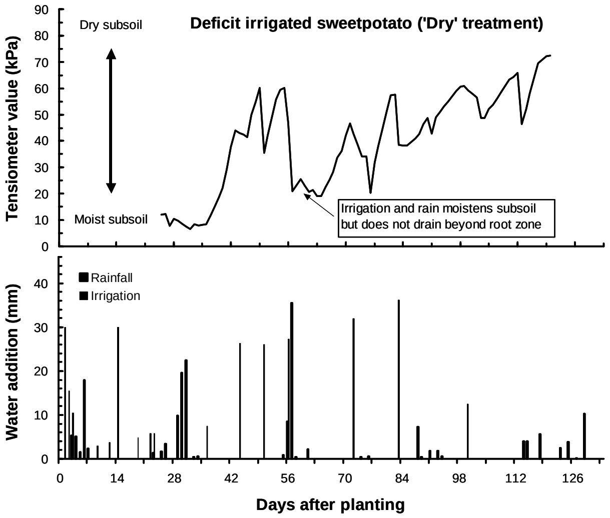


Figure 4. Deficit irrigation dries out root zone and increases capture and storage of rain in a sweetpotato crop.

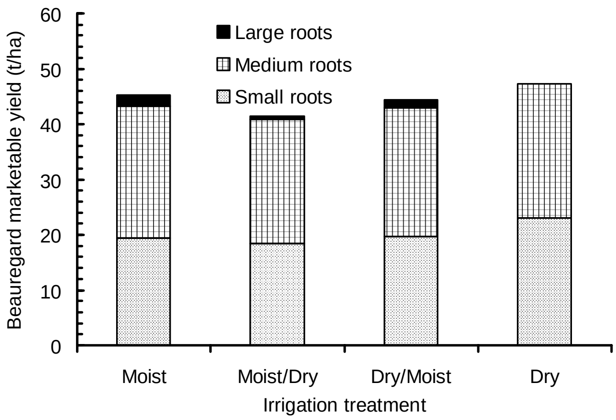


Figure 5. Yields of **Beauregard** sweetpotatoes under different irrigation regimes.

There was no significant sweetpotato yield nor quality penalty (Figure 5) from stressing the root zone to 70-80 kPa between irrigations, or from substantially drying out the subsoil in a deficit irrigation strategy (Figure 4). Contrast the amount of irrigation supplied to the 'Moist' crop irrigated 35 times, (400 mm), and the 'Dry' crop, irrigated 16 times (276 mm). Note that because of the dry season, there was very little additional drainage from the 'Moist' treatment (only about 25 mm), so most of the water saving was from reduced evapotranspiration. There is ample evidence that deficit irrigation and subsequent mild stress can induce physiological changes in vegetables (Al-Jamal *et al.* 2001, Fabiero *et al.* 2002, Fabiero *et al.* 2001, Panigrahi *et al.* 2001, Pitts and Obreza 1999), including reductions in transpiration. In crops such as sweetpotato, soil evaporation is probably negligible after the first 5-6 weeks, due to massive leaf area and ground cover.

In our first onion experiment, with our unintentional deficit irrigation of the **Daily** and **Five** day irrigation interval treatments (see later sections for more detail), there were obviously significant areas within the rooting zone of soil that were never saturated. However it seems the wet zone at the immediate surface (from the deficit irrigation) was sufficient to avoid yield-limiting stress in these treatments. Although in this experiment we had no comparisons with treatments where the root zone was refilled at each irrigation, nevertheless the marketable yields in this experiment were exceptional (50 t/ha for the cultivar **Wallon Brown** and 70 t/ha for **Predator**) using only 3 ML/ha of irrigation (and less than 50 mm of rain during the growing period). Combined with the sweetpotato results, this onion experiment encouraged us to more explicitly investigate deficit irrigation as a mechanism for maximising Economic Water Use Efficiency and returns to producers during periods of restricted water availability.

In the following discussions of the experiments that focus on deficit irrigation, we determine the ‘best conventionally drip irrigated treatments’ as those that refill the root zone at each irrigation, whilst using the least amount of water. Refilling the root zone is assumed if the deep tensiometers in the experiment maintain a consistent moist status during the growing period, without significant dips to indicate substantial deep drainage, or alternately consistently rise to indicate extraction of water at depth.

In the three experiments specifically investigating deficit irrigation in lettuce, onion and potato, we used drip tape to irrigate plots 3 m wide by 10-20 m long. We investigated different intensities of irrigation (0.9 pan evaporation, 0.6 pan evaporation, 0.3 pan evaporation), supplied at 3 irrigation intervals (every 2 days, every 5 days, every 10-12 days). We had a ‘Wet’ treatment (1.2 pan evaporation every 2 days), and 2 other treatments with additional nutrition components. We measured irrigation, rainfall, evaporation, and soil moisture status (using tensiometers). We measured total and marketable crop yields, size grades, defects, and quality parameters.

Lettuce

In our lettuce deficit irrigation experiment, our treatments watered every 2 or 5 days at 60% of pan evaporation were our best conventionally irrigated treatments, achieving experimental yields of 41 t/ha of marketable heads from 2.2-2.4 ML/ha of irrigation (Fig. 6). That these treatments refilled the root zone is confirmed by the deep tensiometer values in Fig. 7.

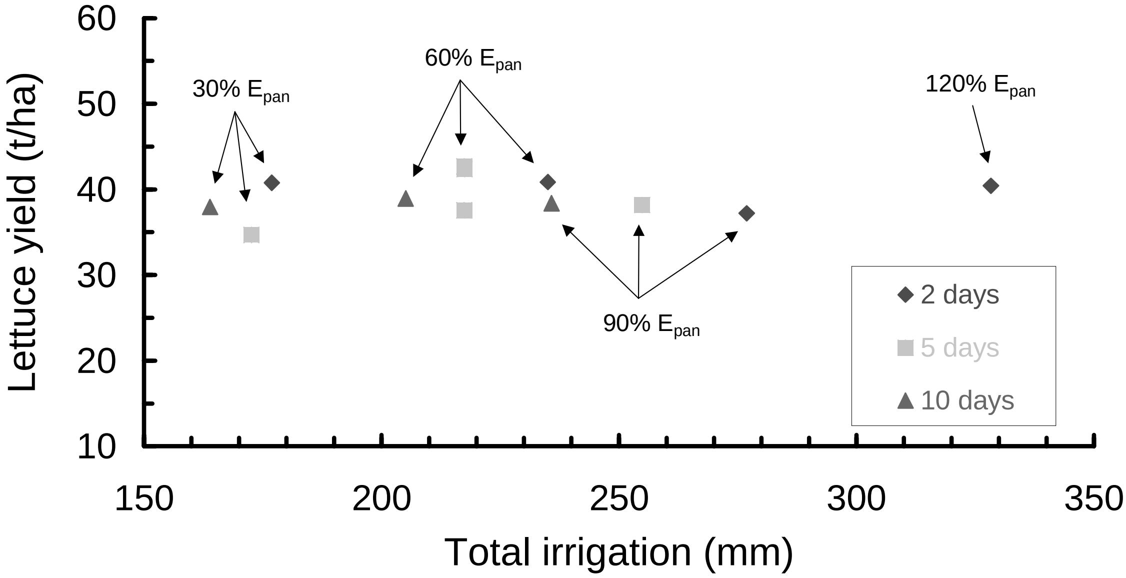


Figure 6. Impacts of irrigation deficit and irrigation frequency on yields of lettuce.

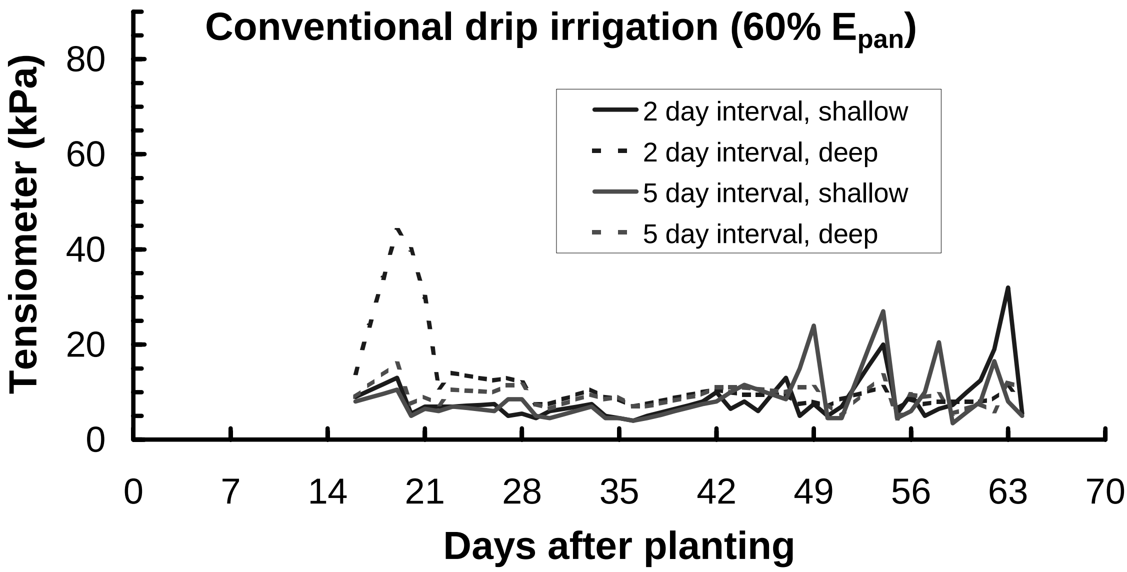


Figure 7. Changes in tensiometer values under a lettuce crop conventionally irrigated with a drip system.

By only supplying 30% of pan evaporation, we encouraged the lettuce crop to extract more water from the root zone, shown by the gradual increase in deep tensiometer values during the growing period, particularly during the later stages (Fig. 8).

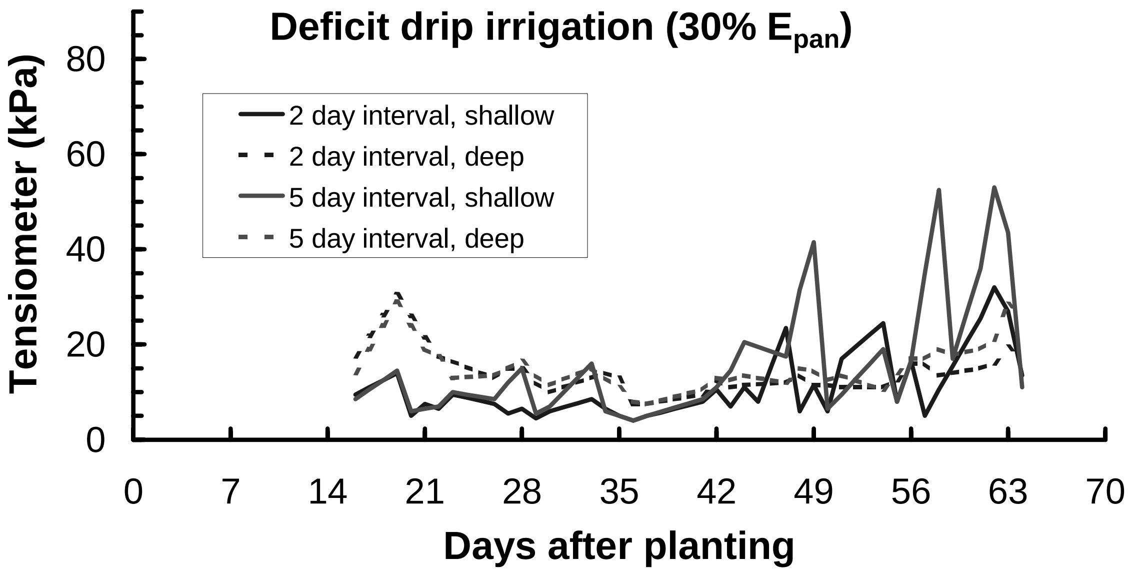


Figure 8. Changes in tensiometer values under a lettuce crop deficit irrigated with a drip system.

Although the shallow tensiometers in the treatment deficit irrigated every 2 days remained below 30 kPa until close to harvest, the 5 day interval lettuce reached values of 40-60 kPa between irrigations. Combined with the slight (though not significant) reduction in marketable yields associated with that 5 day treatment, we are recommending that deficit irrigation be implemented using a frequent irrigation strategy, until we investigate the technique further.

Onion

In our onion deficit irrigation experiment, supplying 90% of pan evaporation every 2 days (Fig. 9), or every 5 days (Fig. 10), provided our best conventional drip irrigation treatments, whilst supplying 60% of pan evaporation (Fig. 11, 12) were our moderate deficit treatments. Supplying only 30% of pan evaporation, or irrigating at 12 day intervals, markedly reduced yields, and is not further dealt with in this section.

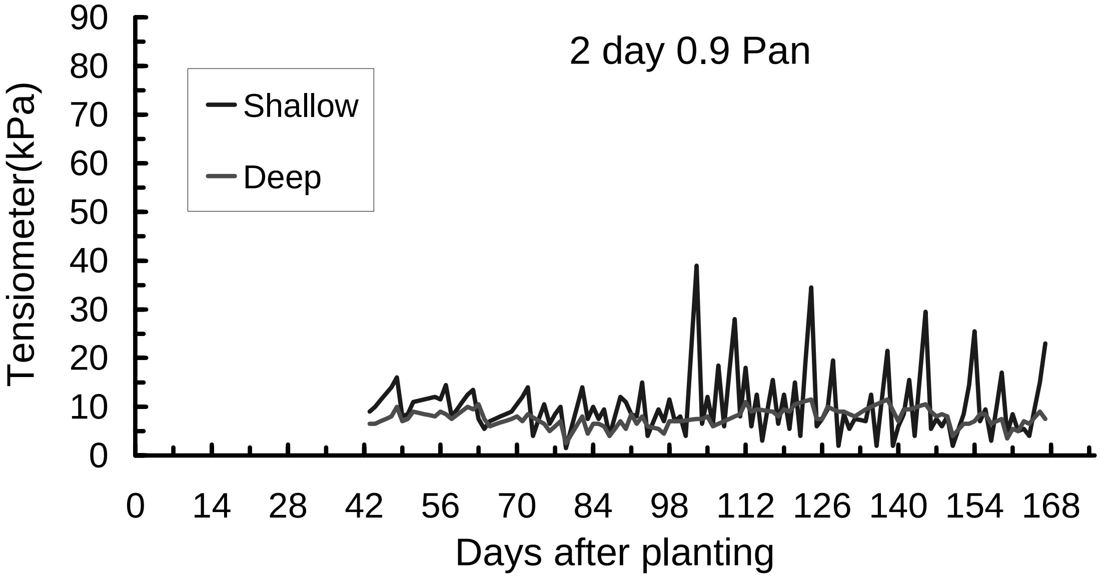


Figure 9. Changes in tensiometer values under an onion crop conventionally irrigated with a drip system every 2 days.

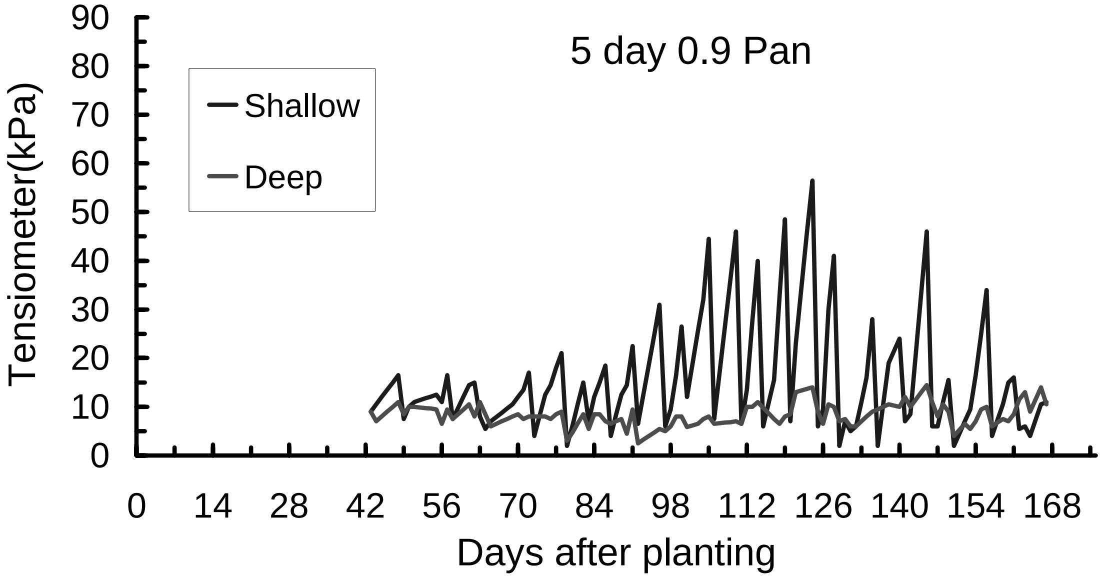


Figure 10. Changes in tensiometer values under an onion crop conventionally irrigated with a drip system every 5 days.

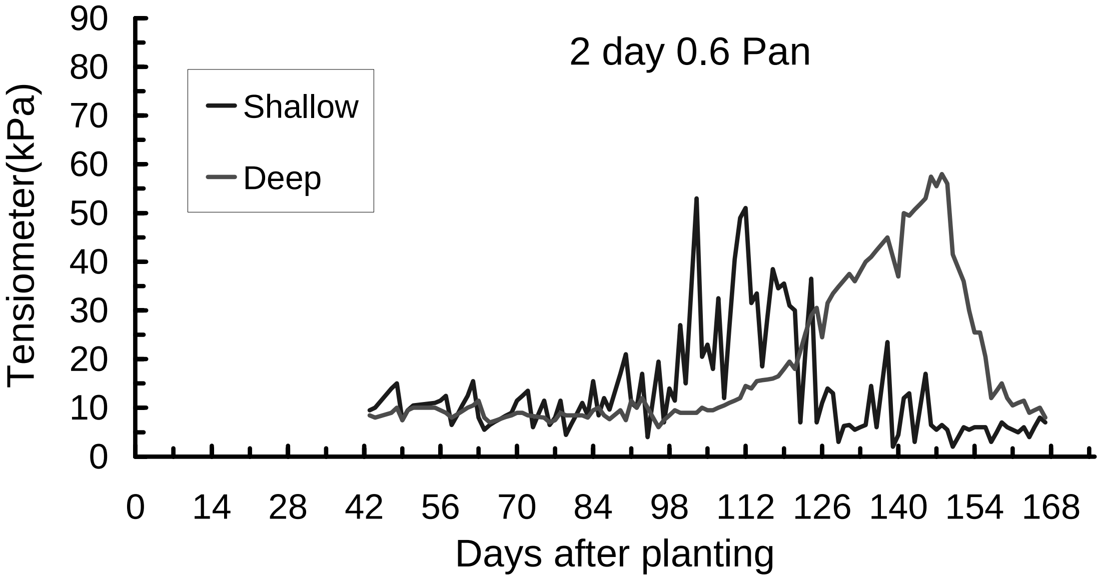


Figure 11. Changes in tensiometer values under an onion crop deficit irrigated with a drip system every 2 days.

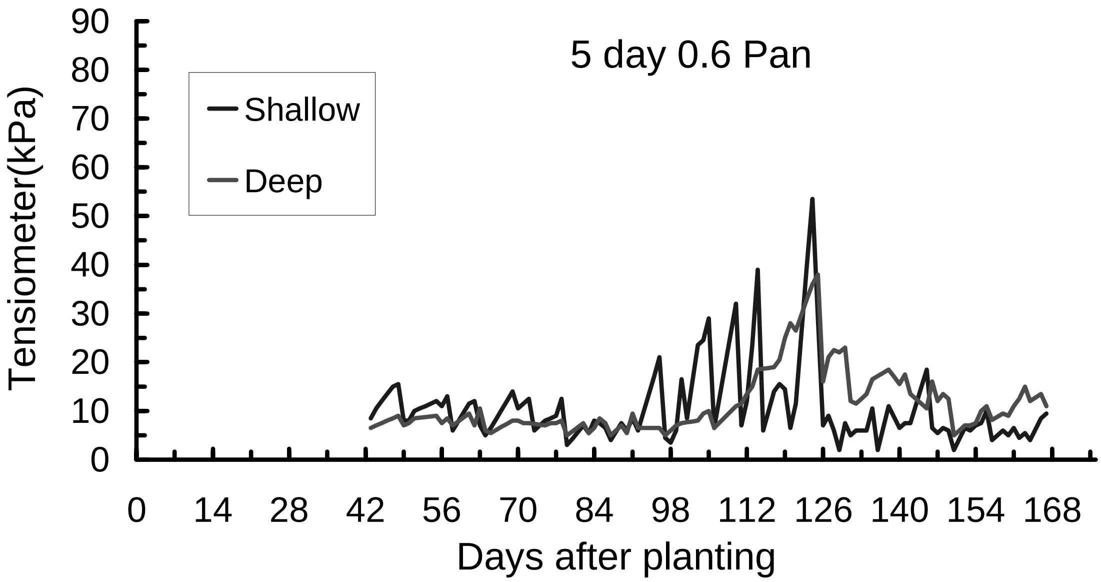


Figure 12. Changes in tensiometer values under an onion crop deficit irrigated with a drip system every 5 days.

Total irrigation on the moderate deficit irrigation treatment (60% Epan), was 5.3 ML/ha, less than the conventionally drip irrigated onions, which received 6.9 ML/ha. These relatively high irrigation values should be read in the context of a very hot, windy, dry growing period, where only 78 mm of rain fell during the 23 week period, and no event greater than 19 mm. Both the conventionally and deficit irrigated onions achieved similar marketable yields of 50 t/ha (Fig. 13), although as will be shown in another section, the deficit irrigated treatment had a greater proportion of No 1 grade and a lesser proportion of Large onions than the conventional drip treatment.

In conjunction with total onion yield (Fig. 14), it can be seen that more than 5.5 ML/ha irrigation increased total onion yield, whilst marketable yields remained static. Providing more than 550 mm of irrigation resulted in more split onions, and more double onions (bulbs with two internal growing points), both of which are unmarketable. These defects are more common in large onions. Less irrigation (moderate deficit) did reduce onion bulb expansion, resulting in a greater proportion of yield as medium onions, but also reducing the quantity of defective bulbs.

As detailed in a following section, there were major differences between responses of cultivars in this experiment. **Rio Zena** split very badly once irrigation exceeded 600 mm, whilst **K5156** was prone to excessive doubles with increased watering.

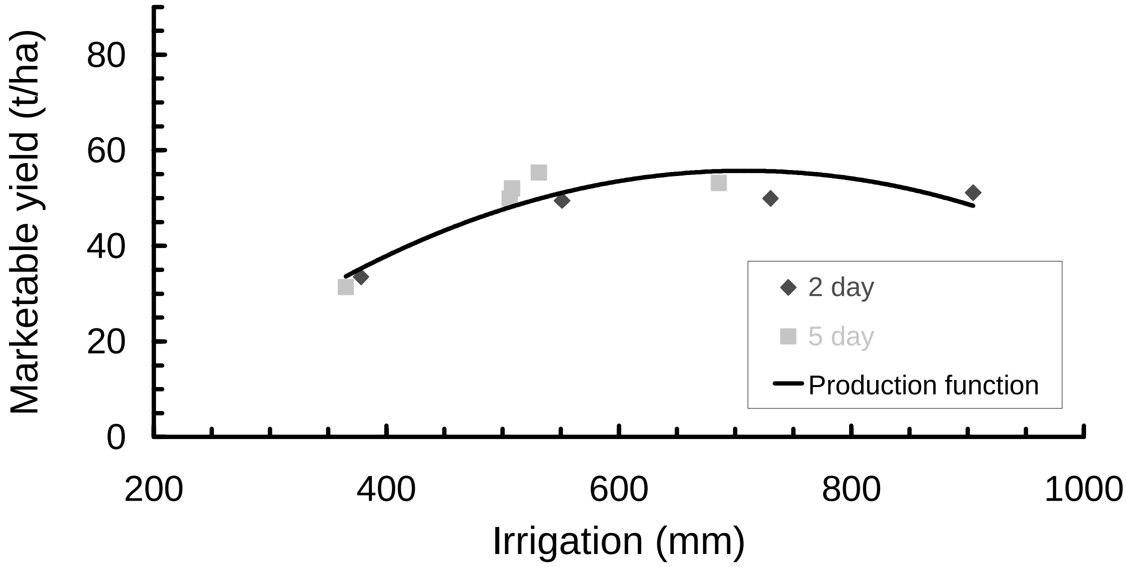


Figure 13. Impacts of irrigation deficit and irrigation frequency on marketable yields of onion.

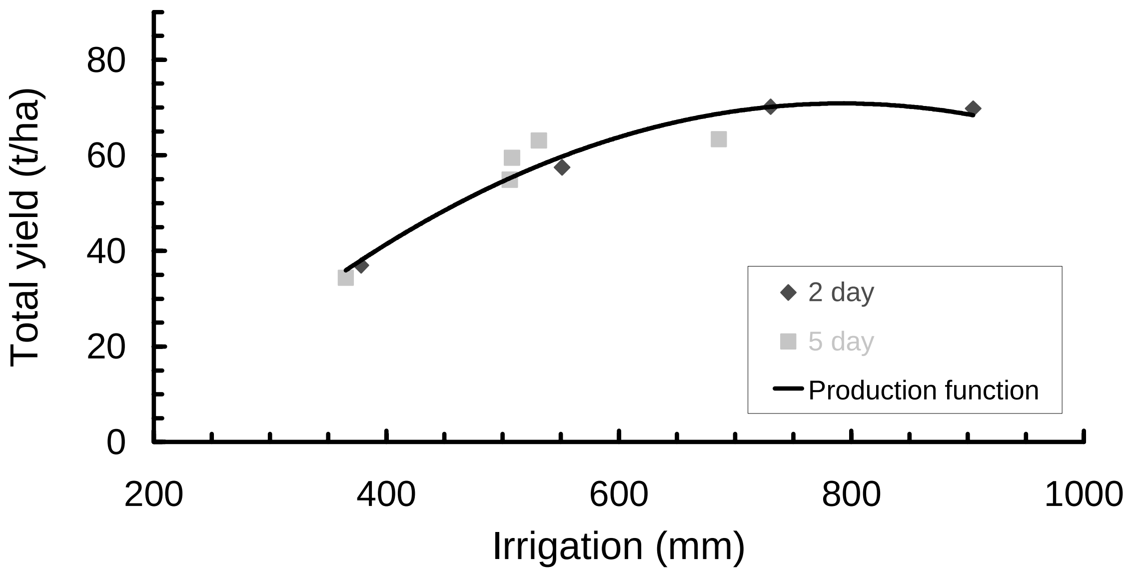


Figure 14. Impacts of irrigation deficit and irrigation frequency on total yields of onion.

These onion results confirm that there is scope to move back along the production function line, use less water, and maintain marketable yields. There may be an issue if the producer is specifically targeting Large grade onions, however it may simply require fine-tuning of the deficit, or a change in strategy toward the end of the growing period.

An important point to ponder. What would have been the effect of rain in the moderate deficit treatments? Would it simply have pushed those deficit treatments to a performance characteristic similar to the wetter treatments?

Potato

In contrast with the lettuce and onion experiments, yields of potatoes in our potato deficit irrigation experiment were maximised by completely filling the root zone at each irrigation, achieved by supplying 90%E_{pan} (3.1-3.4 ML/ha). All deficit irrigation treatments (60%E_{pan}, 2.5 ML/ha) or (30%E_{pan}, 1.8 ML/ha) reduced potato yields, (Fig. 15). Depending on how critical water saving is, and the price of potatoes at the time, there may be instances where a yield loss from deficit irrigation is acceptable. As yield for any given amount of irrigation was maximised by the most frequent irrigation, if a deficit irrigation strategy was to be implemented to save water, at this stage we would be recommending watering every few days if possible. A field evaluation of this strategy is described later in the report.

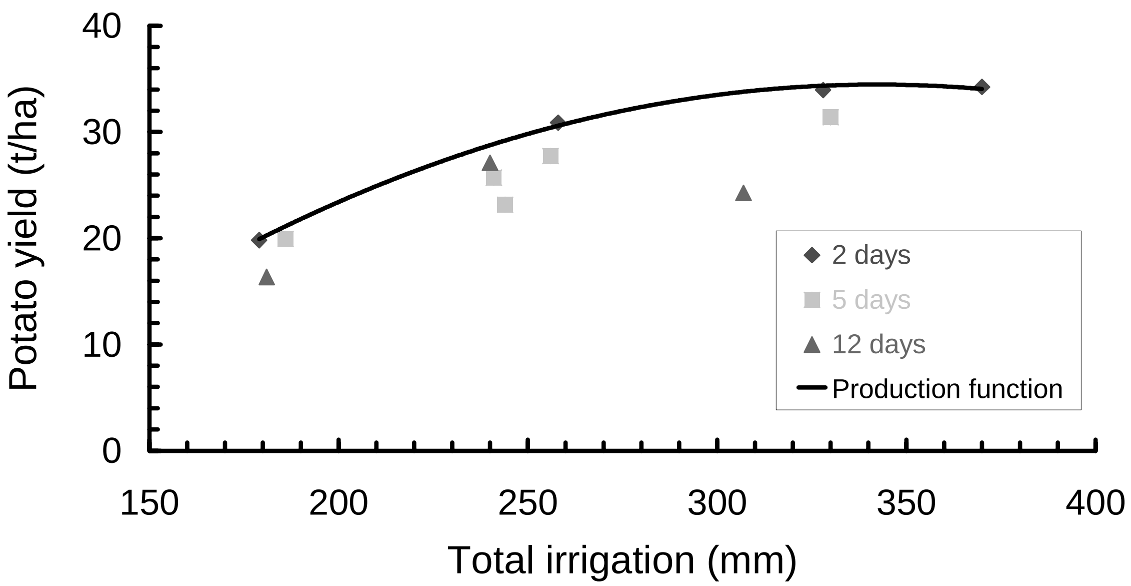


Figure 15. Impacts of irrigation deficit and irrigation frequency on marketable yields of potato.

Deficit irrigation can create a soil environment more capable of retaining rain, compared to a strategy of completely refilling the soil profile at each irrigation. There can be subsequent water use efficiency and environmental benefits from this rain capture. Deficit irrigation can also move the system toward the critical part of the water use/marketable yield production function, i.e. the point where any further reduction in irrigation involves a significant yield penalty. Previous irrigation strategies in vegetable production have generally operated in the wetter zones of such a production function. Interestingly, our research suggests that there may also be some product quality risks associated with irrigating for maximum total yields. We have found increased levels of split and double onions, incidence of brown fleck in potatoes, and discolouration of sweetpotato roots, in treatments that were irrigated luxuriously.

Conclusions

- In specific circumstances, deficit irrigation can capture more rain and reduce deep drainage, compared to conventional irrigation strategies that refill the root zone at each irrigation. During the drought of 2002 until the present, we have had limited opportunity to test this hypothesis more extensively.

- We found deficit drip irrigation could maintain marketable yields (lettuce, onion, sweetpotato, sweet corn), or only slightly reduce yields (potato) compared to conventional drip irrigation, but markedly increase water savings. It may be possible to minimise the risk of reducing marketable yields by fine-tuning the deficit irrigation strategy for specific crops.

- Our initial studies suggested that in a deficit irrigation strategy, frequent irrigation (every 2 days) minimised the risks of yield reduction.

- There are differences in the tolerance of crops, and cultivars within crops, to deficit irrigation strategies.

Improving agronomic water use efficiency by increasing vegetable yields and/or reducing crop water use.

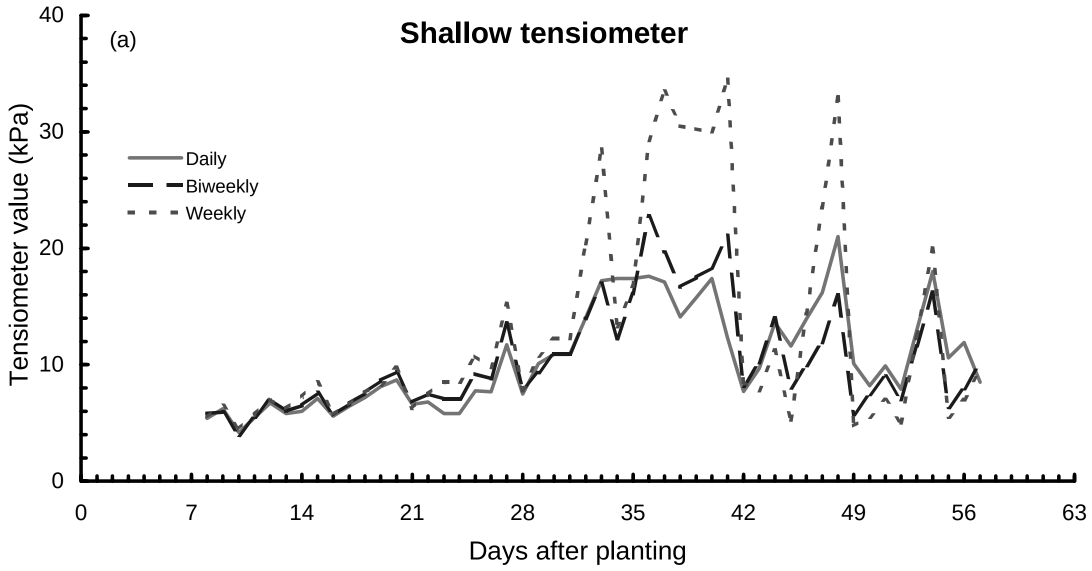
The results and discussions in this section will focus on irrigation strategies to optimise yields whilst minimising water use for range of vegetable we investigated. Impacts on specific quality issues will be detailed in following sections, even though in an enterprise sense, they will need to be considered as a whole.

Lettuce

Experiment details are outlined in the relevant individual experiment reports, and are only summarised here.

Our first experiments included irrigation treatments involving watering **Daily**, **Biweekly** or **Weekly**, in the morning or afternoon, and a range of calcium and nitrogen fertigation sub-treatments. In both experiments, the total amounts of irrigation supplied to all treatments were around 1.8 ML/ha; the differences being small amounts often, or larger amounts less often.

In these first experiments, the irrigation needed to grow high-yielding lettuce crops under drip irrigation (1.8 ML/ha) was much less than we had previously required under well managed sprinkler systems (2.3-2.5 ML/ha). The comparative benefits of the drip system appeared greater during conditions of high evaporative demand (warm, low humidity and windy), and during the early lettuce growth stages. Irrigating twice a week kept tensiometer values in the main crop root zone (≅15 cm) below 20-25 kPa, whilst watering once a week resulted in readings of 35-45 kPa just before irrigations (Fig. 16).



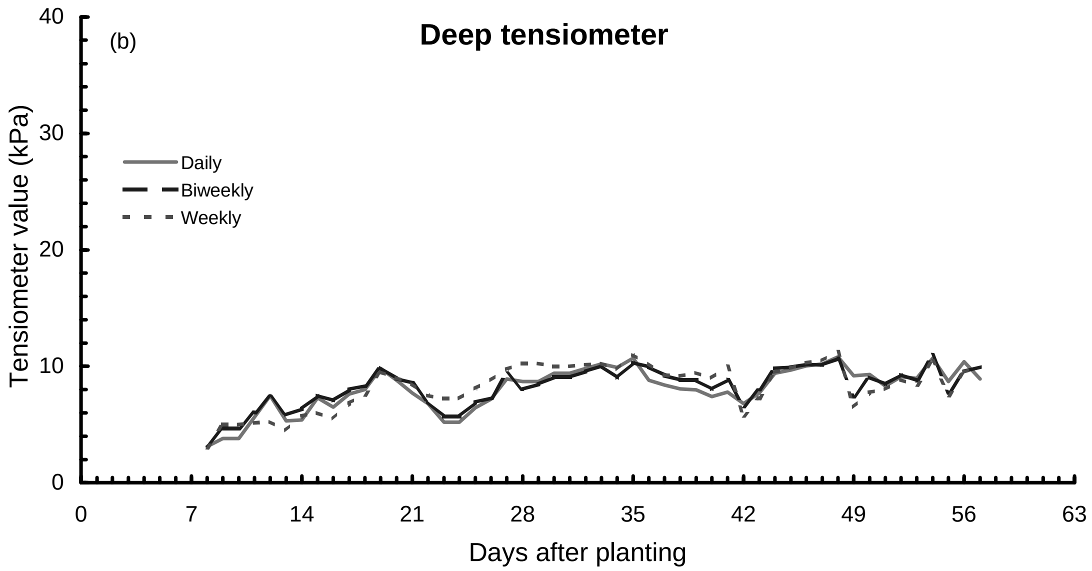


Figure 16. Fluctuations in tensiometer values at depths of (a) 15 cm and (b) 45 cm below the soil surface in treatment classes irrigated at different irrigation frequencies within lettuce experiment **Let1**.

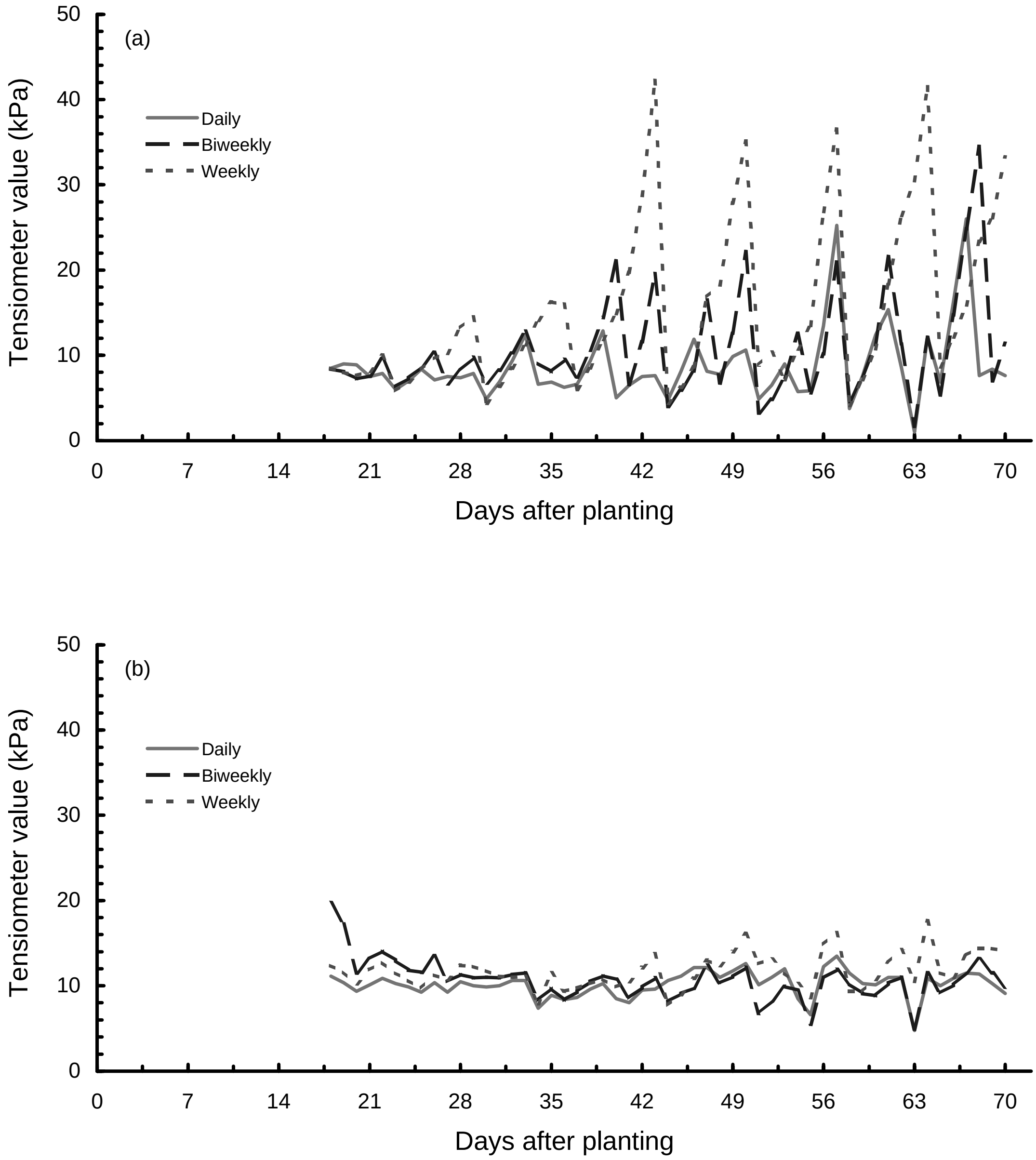


Figure 17. Fluctuations in tensiometer values at depths of (a) 15 cm and (b) 45 cm below the soil surface in treatments irrigated at different irrigation frequencies within lettuce experiment **Let2**.

In the deficit irrigation experiment, irrigating every 2-5 days at 60% of pan evaporation was sufficient to keep shallow tensiometers at less than 20-25 kPa for the growing period (for example Fig. 18). Irrigating every 10 days allowed the shallow tensiometer values to reach 60 kPa between irrigations, irrespective of how much water was applied.

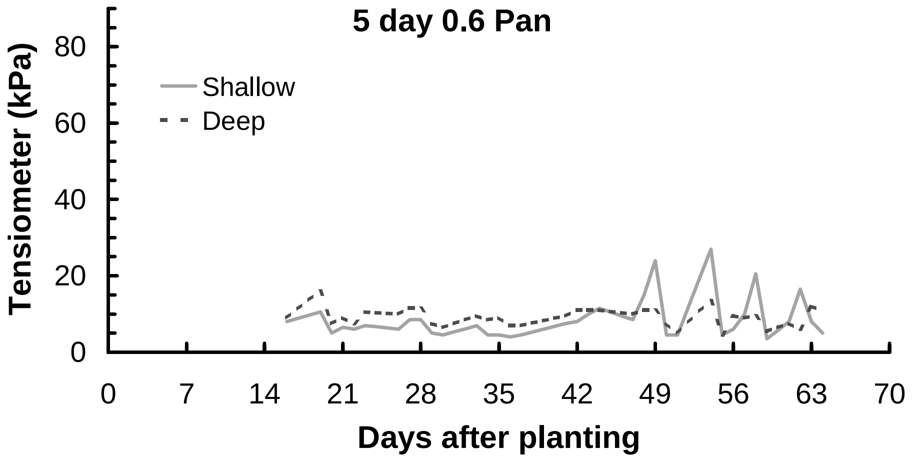


Figure 18. Fluctuations in tensiometer values at depths of (a) 15 cm and (b) 45 cm below the soil surface in a conventionally drip irrigated lettuce crop.

Although lettuce yield data generally showed no statistical differences due to irrigation frequency, grouping the experimental information suggests that for 3 of the 4 cultivars, irrigation intervals of more than 5 days always produced lower mean yields than more frequent irrigation. The warm season genotype **Raider** appeared to be more tolerant of 7-10 day irrigation intervals (Table 10).

Table 10 Impacts of irrigation frequency on yields (t/ha ± Standard Error of Mean) of lettuce cultivars.

	Experiment 1		**Experiment 2**		**Experiment 3**	
Irrigation interval	**Greenway**	**Titanic**	**Oxford**	**Raider**	**Oxford**	**Raider**
7-10 days	46.8±4.1	41.5±4.1	58.5±1.6	55.0±1.6	42.3±1.8	34.5±1.8
1-5 days	50.1±1.2	48.9±1.2	60.4±1.1	54.4±1.1	44.6±1.0	34.2±1.0

Yields in the first 2 experiments were exceptional, with 83-87% of transplanted seedlings producing marketable heads, and a total yield of 50-60 t/ha from the best treatments. In the third experiment we were forced to harvest 3-4 days too early, resulting in about 17% of immature heads not being harvested, hence the lower yields in that experiment.

There were no impacts on lettuce yields or quality from increasing irrigation frequency from **Biweekly** to **Daily**, watering in the morning or afternoon, adding supplementary nitrogen beyond 100 kgN/ha, or additional calcium fertigation to manage tipburn.

During the warm Spring harvest period, the date of harvesting is critical. In experiment 2, the percentage of marketable heads fell from 87% at 9 weeks after transplanting (possibly 1-2 days too early), to 64-68% one week later. Thus, even though the heads increased in weight by nearly 300 g/head over that week, the actual marketable yields remained the same, due to increased splitting and sunburn of heads. With that additional week, tipburn in **Oxford** also became much worse. It certainly appears to be a better option to err on the side of harvesting too early, rather than too late.

The best treatments in our experiments demonstrated irrigation requirements under drip irrigation (approximately 1.8-2.2 ML/ha) were substantially less than we would have anticipated under a well-managed sprinkler system. The commonly quoted industry irrigation budget for lettuce is 3-4 ML/ha (Heisswolf *et al.* 1997), although most producers would currently be budgeting for 2.5-3 ML/ha. Of course, the 17 mm, 48 mm and 50 mm of rain in the respective experiments assisted crop growth, but nevertheless the drip system certainly provided very efficient water use.

Our experiments confirm that lettuce irrigation systems need to be able to deliver water at an absolute maximum interval of seven days. Even that weekly interval will in all probability be too extensive in warm weather, particularly combined with a young crop and a poorly established root system, or alternatively a crop nearing harvest with a high transpiration demand.

Onion

Experiment details are outlined in the relevant individual experiment reports, and are only summarised here.

In our first experiment we sought to relate irrigation and nutrition decisions to onion product outcomes; specifically linking pungency, yield, size, and uniformity of harvested onions, to irrigation frequency and sulphur nutrition treatments. We examined the interactions between irrigation frequency (**Daily**, every **Five** days, and every **Ten** days via drip tape), cultivar choice, and sulphur supplementation via fertigation. We measured water balances, soil water status, onion establishment, yield, bulb marketability, size and grade, and pyruvic acid concentrations.

The impacts of sulphur nutrition on onion pungency are discussed in a later section. None of the nutrition treatments in our initial experiment impacted on onion yields.

At around 3 ML/ha, the water used across the experiment indicated very efficient irrigation, with minimal waste. The commonly quoted industry irrigation budget for onions is 4 ML/ha (Duff *et al.* 1999), although many producers currently budget for slightly more (4.5-6 ML/ha). The drip system and crop were very efficient at utilising the irrigation water, with a crop coefficient (water use divided by estimated potential evapotranspiration) of 0.75, compared to values from the literature of 0.85-1.1 (Doorenbos and Kassam, 1979). This efficiency was not at the cost of crop performance, as yields (around 60 t/ha) and onion quality were extremely good.

The different irrigation frequency treatments during the first ten weeks after planting had little impact on measured water uptake or apparent soil water status, with irrigation quantities matching crop water use, and low tensiometer values maintained in all treatments.

However, during bulb enlargement, we unintentionally deficit irrigated the W_1 (**Daily**) and W_5 (**Five** day) treatments. That is, we did not refill the root zone at each irrigation. Not only did the shallow tensiometers (15 cm below ground level) not return to 0-5 kPa after irrigation, values for deep tensiometers (at 45 cm) in these treatments also started to rise, indicating water extraction from relatively deep in the soil profile. Examples are shown in Figs. 19 and 20.

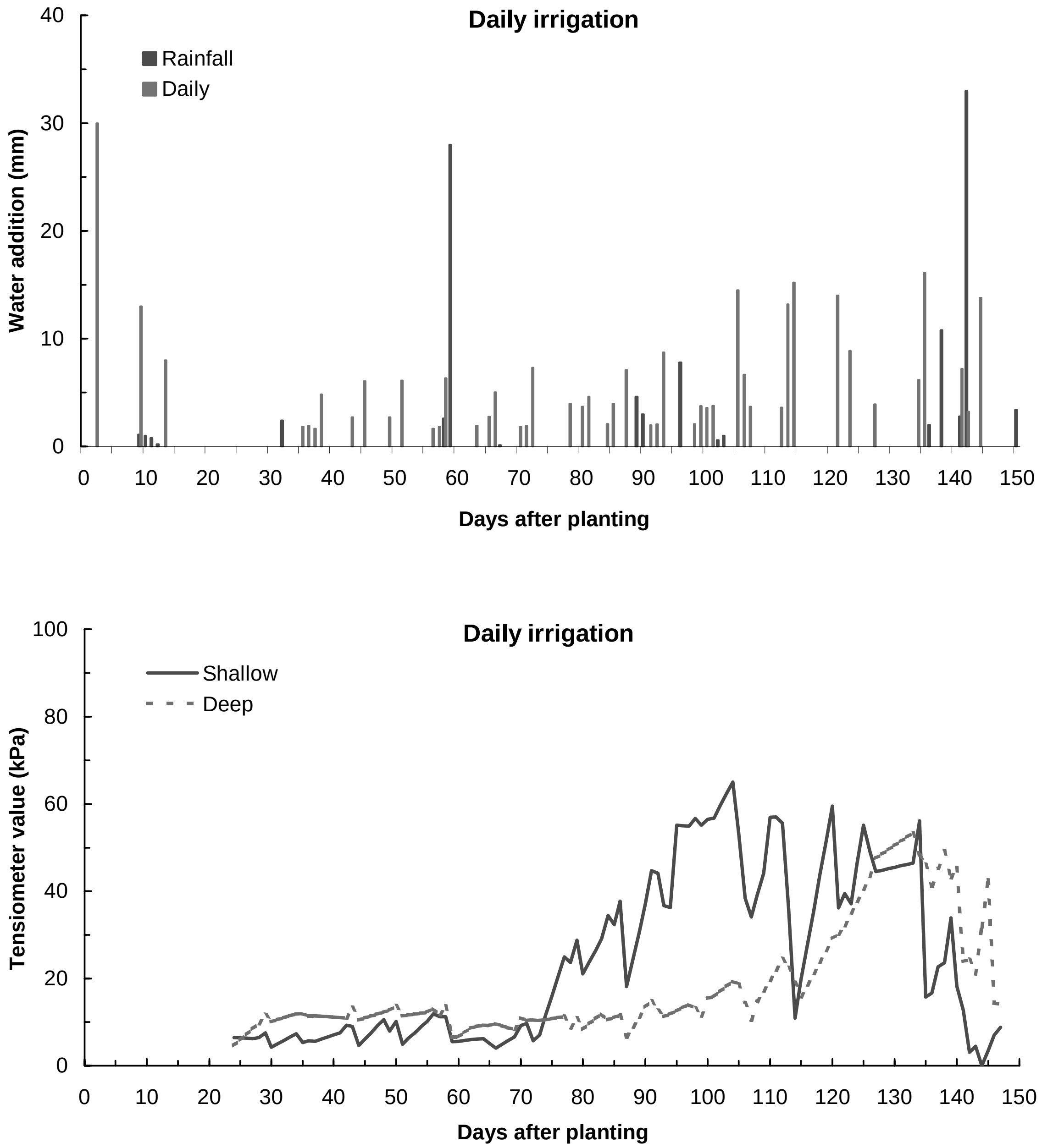
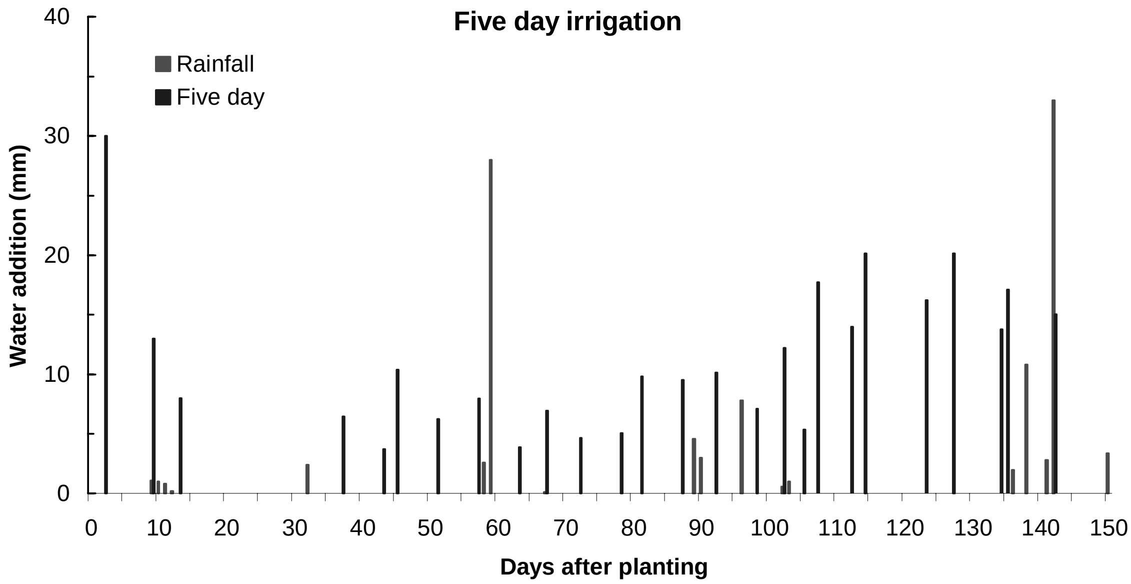


Figure 19. (a) Irrigation program and (b) fluctuations in tensiometer values at depths of 15 and 45 cm below the soil surface, for the **Daily** (W_1) treatment class.



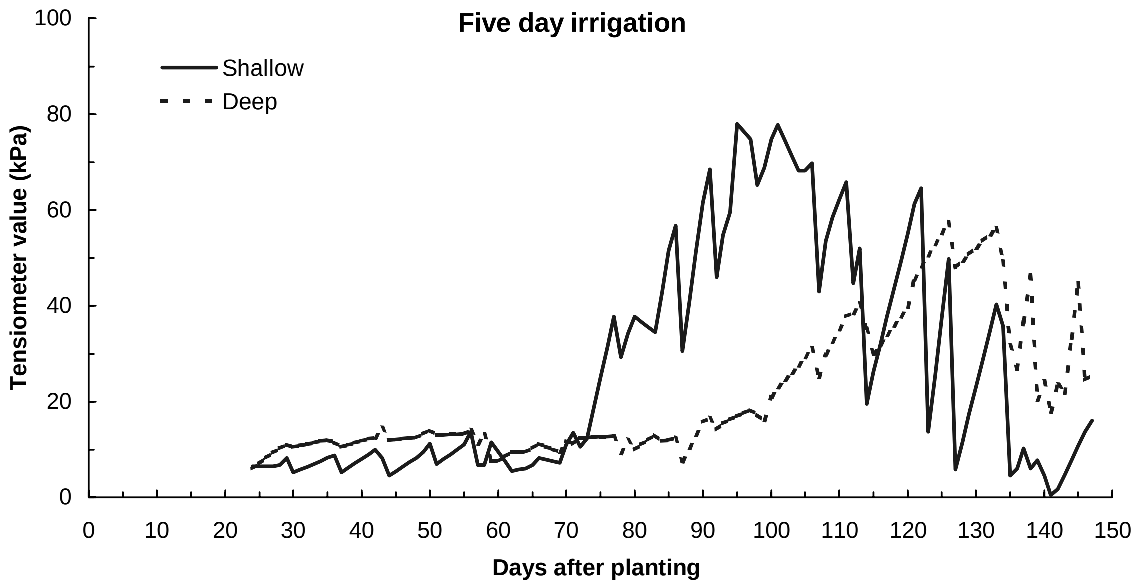


Figure 20. (a) Irrigation program and (b) fluctuations in tensiometer values at depths of 15 and 45 cm below the soil surface, for the **Five Day** (W_5) treatment class.

The cultivar **Predator** was very tolerant of different irrigation strategies, producing virtually no doubles, and marketable onions from every plant. About 80% of the onions were No 1 Large grade, giving a very consistent packout of uniform onions.

Although **Wallon Brown** gave very good yields, its performance was less uniform than **Predator**. Its size gradings were more affected by irrigation strategy, and in all conditions it had a greater spread of bulb sizes than **Predator**. As we extended the irrigation interval beyond 5 days to 10 days, we shifted a greater proportion of the bulbs from No. 1 Large, back to No 1. Grade. In the opposite direction, very frequent irrigation increased the proportion of double bulbs in the **Wallon Brown** cultivar.

The onion cultivar **Predator** produced a greater yield of marketable onions (Picklers, No. 1 Grade and No. 1 Large) than **Wallon Brown** (Fig. 21). **Predator** also had a higher proportion of large onions than **Wallon Brown**. Neither sulphur nutrition nor irrigation frequency influenced marketable yields.

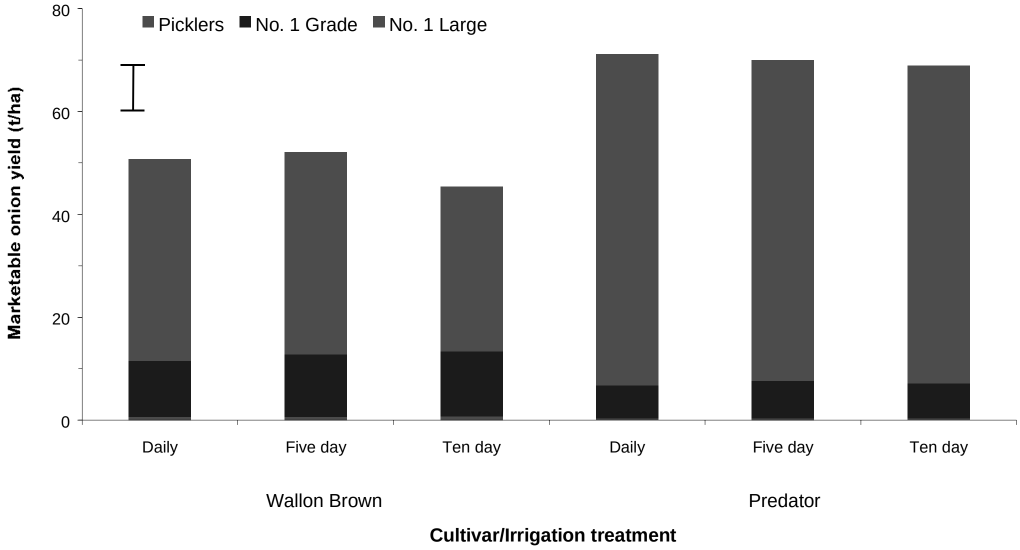


Figure 21. Cultivar selection affected yields of marketable onions, whilst irrigation frequency did not. Bars are protected LSD values ($P \leq 0.05$) for comparing yields between treatments.

There was only a trivial outturn of doubles from the **Predator** harvest, whilst **Wallon Brown** produced a much greater amount of this unmarketable bulb type (Fig. 22). The tonnages of **Wallon Brown** doubles produced declined as the time interval between irrigations increased.

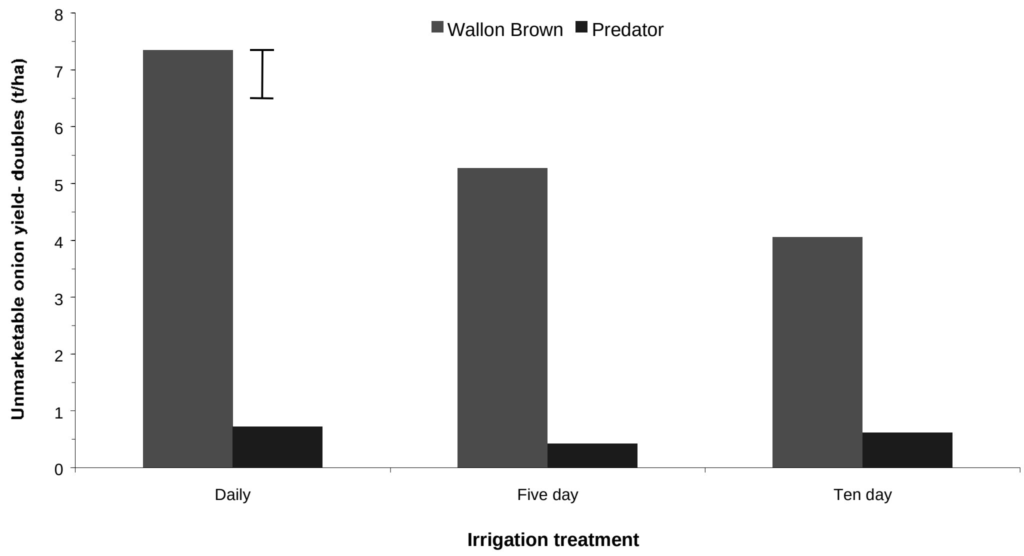


Figure 22. Yields of double onions were affected by cultivar selection and irrigation frequency. Bars are protected LSD values (P≤0.05) for comparing yields between treatments.

Almost all the **Predator** onions were marketable, with few doubles (Fig. 23 and 24). The greatest proportion of **Predator** bulbs was No. 1 Large, with no impacts of irrigation frequency on the proportions of different size grades. In contrast to **Predator, Wallon Brown** had fewer marketable onions overall. **Wallon Brown** produced many more doubles than **Predator** (Fig. 24). **Wallon Brown** had a greater proportion of No. 1 grade and Picklers than did **Predator** (Fig. 23). As the time interval between irrigations increased, the proportions of **Wallon Brown** in the smaller size grades also increased, whilst the proportions of No. 1 large and doubles decreased.

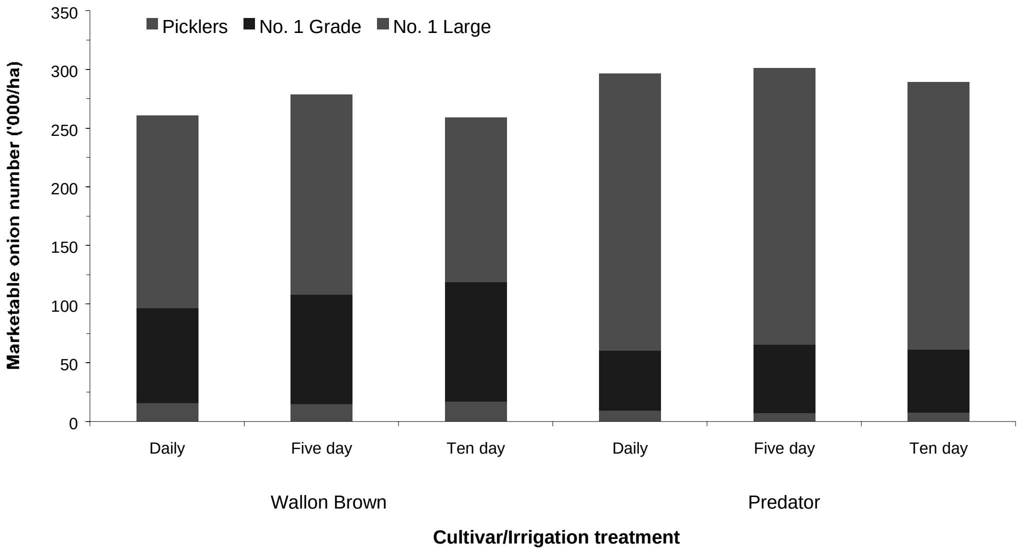


Figure 23. Marketable onion number and size grade proportions were impacted by cultivar selection and irrigation frequncy.

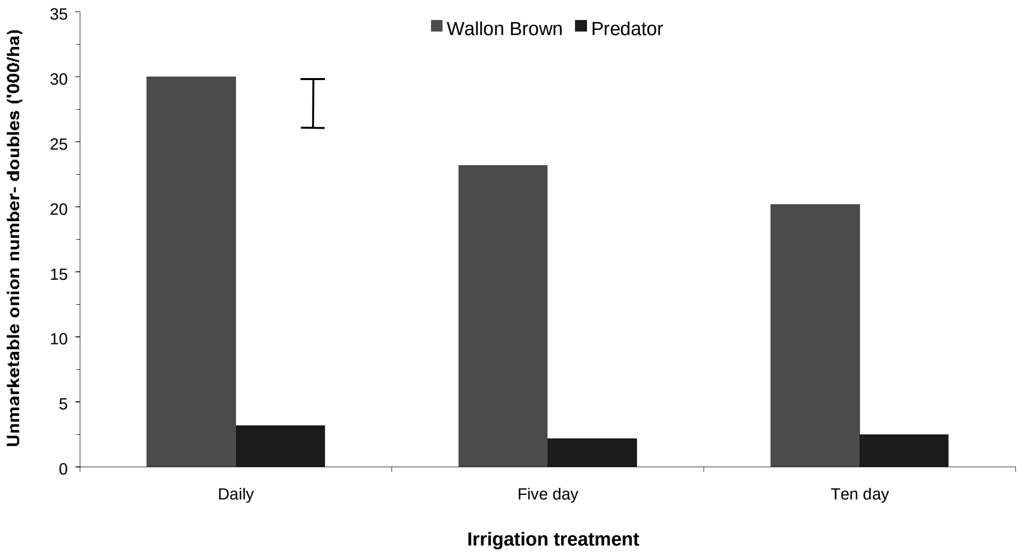


Figure 24. Numbers of double onions were affected by cultivar selection and irrigation frequency. Bars are protected LSD values (P≤0.05) for comparing densities between treatments.

Our experiments confirm that onion irrigation systems should be able to deliver water at least at weekly intervals. Some cultivars may be able to withstand longer intervals, however there is the risk of changing size gradings and affecting bulb uniformity. During the establishment phase, more frequent irrigation may be needed.

With our unintentional deficit irrigation of the **Daily** and **Five** day treatments, there were obviously significant areas within the rooting zone of soil that were never saturated. However it seems the wet zone at the immediate surface (from the deficit irrigation) was sufficient to avoid yield-limiting stress in these treatments.

In our deficit irrigated onion experiment, several clear points emerged. Firstly, irrigating every 12 days created yield-limiting stress, irrespective of the amounts of water applied (Fig. 25). Similarly, the amount of water stress associated with supplying only 0.3 pan evaporation during the growing period reduced marketable bulb yields, with much greater proportions of picklers (small onions) and No. 1 grade bulbs, and less yield of No. 1 Large onions. The 'Wet' treatment received 9.0 ML/ha of irrigation, compared to 6.9 ML/ha for the 0.9 pan evaporation treatments, and 5.3 ML/ha for the 0.6 pan evaporation treatment (moderate deficit). All of these treatments provided the same total marketable yields (apart from the 12 day intervals as previously mentioned).

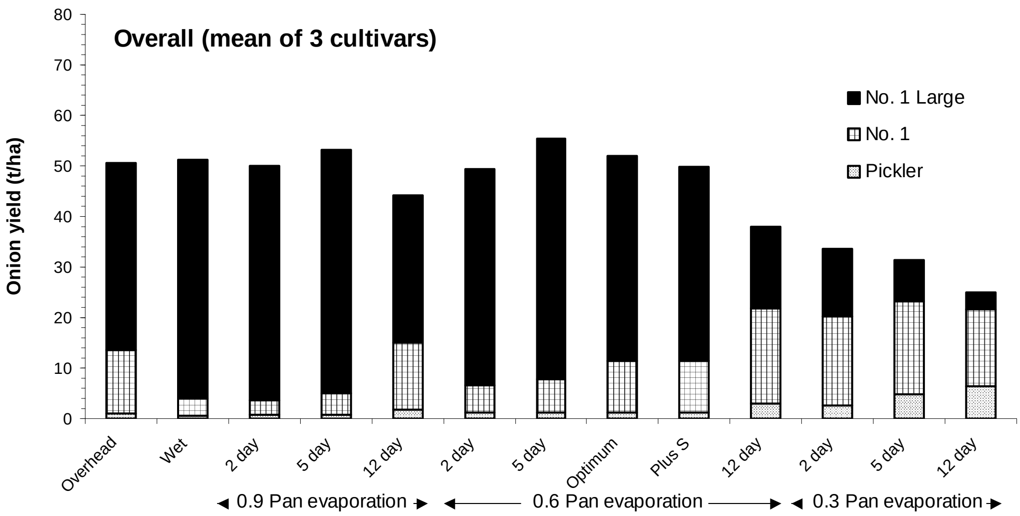


Figure 25. Impact of deficit irrigation and irrigation frequency on size grades of marketable onions.

There was a strong interaction between cultivar and the effects of irrigation management. In Table 11, we compare onion yield characteristics under the conventional (90% E_{pan}) and moderate deficit irrigation (60% E_{pan}) treatments described previously. In the **Colossus** cultivar, total marketable yields were unaffected by reduced irrigation, although it did reduce the proportion of Large grades onions. In **K5156**, conventional drip irrigation maximised marketable yields and the proportion of Large onions, but also significantly increased the amount of double onions. **Rio Zena** was the cultivar that benefited most from the reduced irrigation strategy, as it maximise marketable yield by significantly reducing the amount of splitting in the principally Large grade onions, as well as reducing doubles. Splitting was not an important issue with the other cultivars.

Table 11. Impacts of irrigation strategy on marketability and size grades of onion (all values in t/ha).

Cultivar	Drip irrigation strategy	Picklers	No 1	Large	Total marketable	Unmarketable doubles	Unmarketable splits
Colossus	Conventional	0.6	2.9	52.0	55.5	4.9	3.1
	Deficit	0.8	7.4	46.8	55.0	3.5	1.4
K5156	Conventional	1.1	4.5	51.4	57.0	7.4	1.9
	Deficit	1.2	9.7	42.7	53.5	3.9	0.5
Rio Zena	Conventional	0.8	2.8	38.5	42.1	6.3	21.9
	Deficit	1.6	7.3	37.5	46.5	2.8	9.1

Potato

As described in the deficit irrigation section, potato yields declined with reduced irrigation. A 12 day interval between irrigation resulted in sufficient stress to reduce yields compared to the more frequently irrigated treatments (Fig. 15). The yields in this experiment were potentially limited by a lack of irrigation between 6 and 8 weeks after planting, due to a problem with pumping equipment. Nevertheless, the relative performances of the treatments once they were implemented 8 weeks after planting are still relevant. Differences between treatments were due to differences in yields of medium size potatoes (Table 12).

Table 12. Impacts of irrigation strategy on size grades of potato

Irrigation interval	**Drip irrigation strategy**	**Irrigation (ML/ha)**	**Potatoes<80 g (t/ha)**	**Potatoes 80-200 g (t/ha)**	**Potatoes 200-350 g (t/ha)**	**Total marketable (t/ha)**
2 day	Conventional (90% E_{pan})	3.3	7.7	25.0	1.2	34.0
5 day	Conventional (90% E_{pan})	3.3	8.1	22.4	0.8	31.4
2 day	Deficit (60% E_{pan})	2.6	8.0	21.5	1.0	30.9
5 day	Deficit (60% E_{pan})	2.5	8.4	16.5	0.6	25.5

Sweet corn

A summer sweet corn experiment involved combinations of drip tape in rows 0.375 m, 0.75 m or 1.50 m apart, in a sweet corn crop with a row spacing of 0.75 m. The 1.50 m drip rows were in between every second sweet corn row; the 0.75 m treatment had drip tape immediately next to every sweet corn row, whilst the closest spacing had tapes 19 cm either side of each sweet corn row. For each of these row spacing treatments, we had irrigation frequencies of **Fortnightly**, **Weekly**, **Biweekly**, or **tensiometer based**. The **tensiometer-based** irrigation involved watering when tensiometers installed 20 cm below the ground level reached values of 40 kPa.

These irrigation treatments resulted in total irrigation applications varying from 1.7 ML/ha up to 2.9 ML/ha, and unhusked marketable yields varying from 17.8 t/ha to 22.6 t/ha. (Fig. 26). This experiment was conducted during summer 2002, with 50 mm of rain 3 weeks after sowing negating the need for early irrigation, and another 45 mm of rain 6 weeks after planting. These rain events were fully utilised by the sweet corn crop, with no deep drainage, and thus reduced the total amounts of irrigation required. In interpreting this figure, for each of the irrigation frequencies, increasing drip tape spacing reduced the total amount of irrigation received.

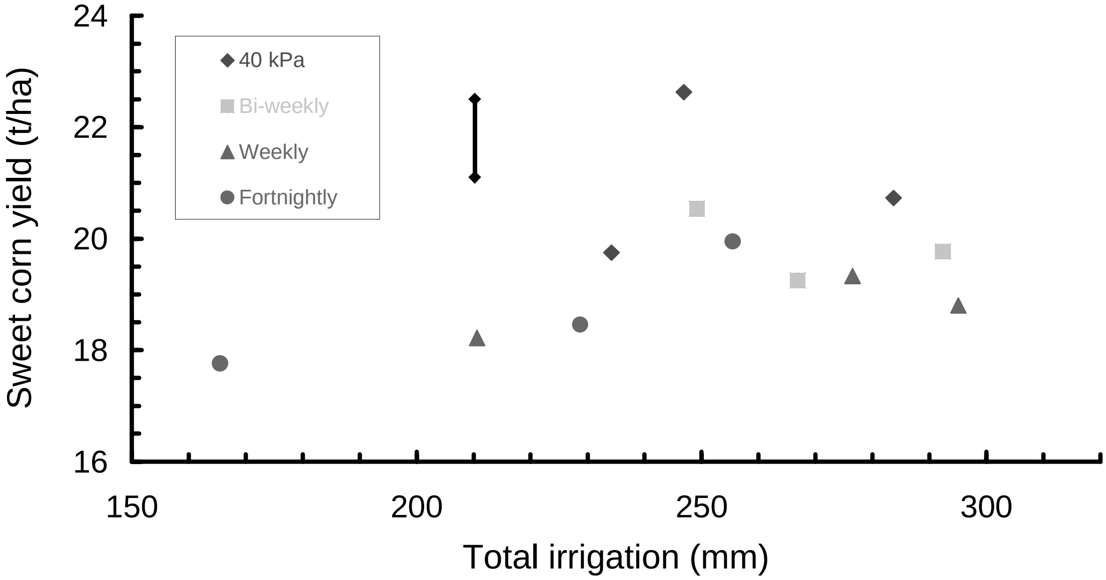


Figure 26. Impacts of drip tape spacing and total irrigation supplied on unhusked sweet corn cob yields. Bar is the protected LSD value ($P \leq 0.05$) for comparing yields.

The narrowest row spacing was used as an experimental construct, as is not further mentioned in this discussion of practical outcomes. For any given quantity of irrigation, scheduling using tensiometers increased yields compared to watering on a regular basis. The best yields were achieved at drip row spacings of 0.75 m for the **Weekly** and **tensiometer-scheduled** treatments, or by irrigating twice weekly if drip tapes were 1.5 m apart. Applying less total irrigation with wide tape spacing, or less frequent watering, reduced sweet corn yields, but much less than the proportional reduction in water use.

The sweet corn cobs from treatments irrigated on a **Fortnightly** or **Weekly** basis were significantly lighter (329 g) than the treatments watered **Biweekly** or **tensiometer scheduled** (341 g).

The field evaluation in a later section economically assesses these tradeoffs in irrigation costs and yields, in comparison with a sprinkler irrigated block of sweet corn.

Sweetpotato

This experiment is described in the accompanying experimental report, so only the summary findings are presented in this section.

Crop variability.

Our experiment was confounded by substantial variability between individual sweetpotato plants, in terms of storage root initiation, development, and yields. This was probably due to a combination of variable tip cuttings and planting techniques, the impacts of which were magnified by a heat wave at establishment. At an investigative harvest 12 weeks after planting for example, the number of marketable storage roots per plant varied from 2.4 in the worst plot to 9.4 in the best plot for **Beauregard**, and 0.7 roots/plant to 4.6 roots/plant respectively for **Northern Star**.

We hypothesise that to reduce this variability, and thus maximise crop potential, more uniform cuttings and planting protocols may be necessary. It is also vital that the tip cuttings are kept well watered at establishment. In many circumstances it may be necessary to irrigate the cuttings every 1-2 days if planting in hot weather, therefore the irrigation system during establishment should have that capacity.

Post-establishment irrigation management.

The scientific literature, and results from this experiment, suggests that once the sweetpotato crop is established, sweetpotato irrigation can be scheduled when tensiometers in the main root zone reach 60-70 kPa. There are probably minimal adverse effects from erring on the dry side of even that value. Lower soil moisture levels during bulking will probably improve storage root quality as well, in terms of flesh colour, taste and keeping quality.

Once established, both **Beauregard** and **Northern Star** developed effective root systems, capable of extracting water to at least 60 cm below the tops of the hills. With these root systems, they were able to maintain high evapotranspiration levels under a range of irrigation strategies. In our experiment, once the sweetpotato crop was well established, it made little difference whether we irrigated with small amounts (e.g. 10 mm) regularly, or larger amounts (e.g. 30 mm) less frequently. A reasonable rule of thumb is looking to provide around 75-80% of pan evaporation for the life of the crop, by a combination of effective rain and irrigation. This agrees with findings in a range of overseas studies. In our experiment, this equated to rain + irrigation of around 500 mm (5 ML/ha) for the life of the crop.

We conducted our experiment on an alluvial clay-loam to light clay soil in the Lockyer Valley, which is very different to the soils in the major sweetpotato producing regions. In the sandier soils of those latter areas, there is generally less available soil water, and so less capacity to provide crop water needs from stored soil water during extended dry periods. Sweetpotato crops will probably move into moisture stress more rapidly than in our experiment. Producers would have less tolerance for delays in irrigation, once critical soil moisture levels (e.g. as indicated by tensiometer values) were reached. Although we could probably budget to irrigate every 8-14 days on the alluvial clay loams, on the sandier soils the interval may be closer to every 6-12 days, depending on prevailing weather.

Using a drip system, in many of our treatments we successfully implemented a deficit irrigation strategy, i.e. relying on stored soil water to supply some of the crop water requirements between rain events.

Sweet potato performance.

Beauregard was a consistent, well-performed cultivar, capable of providing a good, marketable packout under a range of soil moisture conditions and irrigation strategies. **Beauregard** was not disadvantaged by a dry finish to the growing period, which may also have marginally improved flesh colour. There were no obvious impacts of irrigation treatments on the performance of **Beauregard** (Fig. 27). The average number of marketable **Beauregard** storage roots per plant was 3.9, of which 70% were 'Small', and 30% the premium 'Medium' grade (using the Woolworths® specification standard). Yields averaged 42.6 t/ha; 43% by weight were 'Medium' grade (equivalent to 1250 18 kg cartons/ha), with a further 1000 cartons/ha of 'Small' grade. There were virtually no unmarketable **Beauregard** storage roots, averaging 2.1 ± 0.4 t/ha.

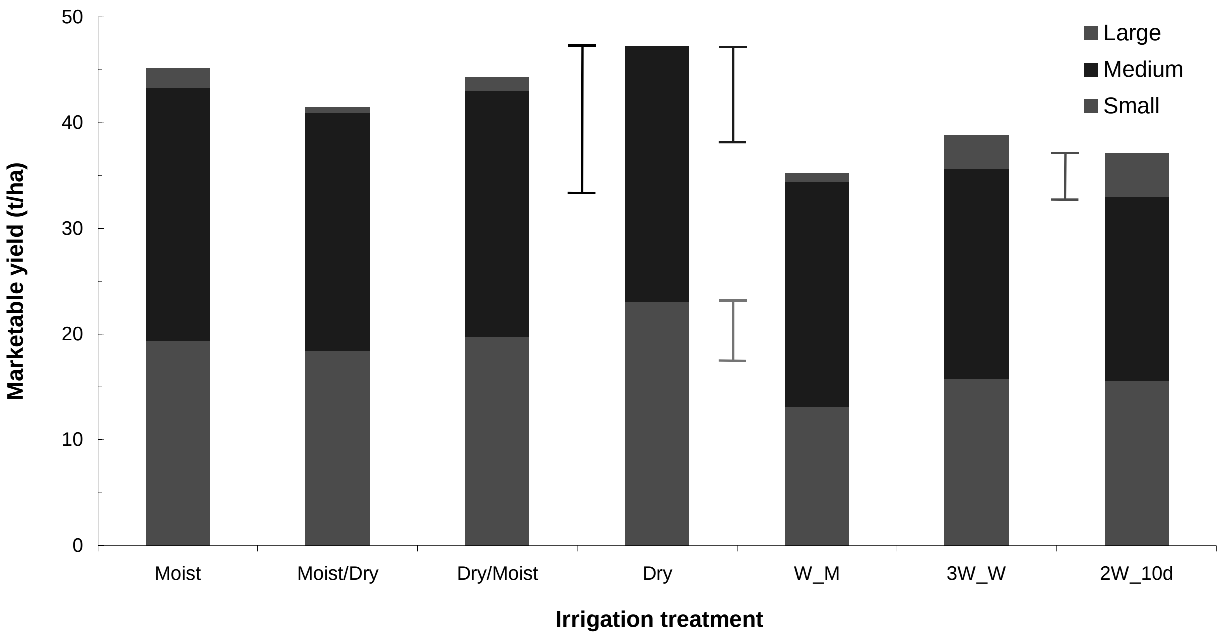


Figure 27. Irrigation management effects on the yields of marketable storage roots harvested from **Beauregard** sweetpotatoes. Coloured bars are the $LSD_{0.05}$ for the corresponding size grades. The black $LSD_{0.05}$ bar is for the total yield of marketable storage roots.

Marketable yields of **Northern Star** were less than half of **Beauregard**, with 30% of **Northern Star** roots being unmarketable, primarily due to severe cracking. There did not appear to be much scope for managing cracking in **Northern Star** by relatively intense irrigation. Even plants that were kept in reasonably moist soil for the whole of the growing period developed significant levels of severely cracked storage roots.

Irrigation treatments did not affect storage root numbers in **Northern Star**, which were disappointing at only 1.9 marketable storage roots per plant (80% 'Small' and 20% 'Medium'). Yields averaged 17.2 t/ha of marketable storage roots Fig. 28); 40% by weight were 'Medium' grade, and 9.9 t/ha were 'Small'. There was a slight but significant trend for irrigation treatments with a very dry finish to have marginally reduced yields and lower proportions of 'Medium' grade storage roots than the other treatments. There was an average of 10.5 t/ha of unmarketable **Northern Star** sweetpotatoes in the experiment.

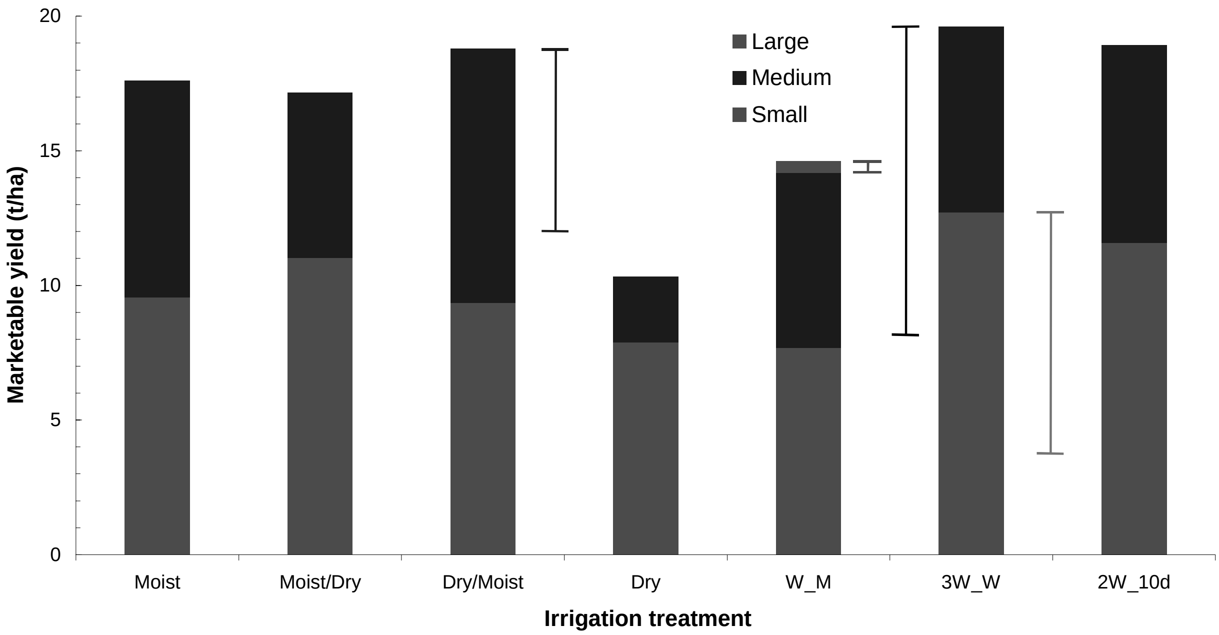


Figure 28. Irrigation management effects on the yields of marketable storage roots harvested from Northern Star sweetpotatoes. Coloured bars are the $LSD_{0.05}$ for the corresponding size grades. The black $LSD_{0.05}$ bar is for the yield number of marketable storage roots.

In both cultivars we recorded very few oversize storage roots, and a large number of 'Small' sweetpotatoes. **Beauregard** and **Northern Star** probably still had potential to keep filling the storage roots, and thus convert more 'Small' grade roots to 'Medium' grade roots. Because it was mid-winter, it is unlikely that if we had delayed harvest by 2-4 weeks, that there would have been any dramatic increases in total yields or marketable pack out. However, in assessing the performance of the treatments and crops, it is worthwhile considering the potential outcomes if we had planted in early January, rather than early February.

Implications for Rural Water Use Efficiency.

For many of the irrigation treatments in this experiment, water supplied to the crop was similar to amounts budgeted for in the Irrigation component of the Sweetpotato Agrilink kit (Loader *et al.* 2000), with evapotranspiration about 75% of pan evaporation, the level often suggested as optimal. Note that the actual irrigation provided in those treatments (around 3.2 ML/ha), was substantially less than the 4.5 ML/ha budgeted for in the Economic component of the Sweetpotato Agrilink kit (Loader *et al.* 2000). Also note that pan evaporation during the cropping period was around 60 mm (8%) higher than average for Gatton Research Station at that time of year. Thus the water supplied to the moderately irrigated treatments in our experiment was certainly at the relatively efficient end of the optimal supply range.

There may even be an opportunity to use less water, given the relatively good yields (particularly with **Beauregard**), of the treatments that used 0.5 ML/ha less irrigation than the other well-performed treatments described above,

Conclusions

- Lettuce yields and quality were maximised by watering at least every 5 days, although warm season cultivars such as **Raider** may tolerate greater levels of water stress between irrigations.

- We found substantial differences in yield and general quality responses between onion cultivars to reducing irrigation frequencies and quantities. Most cultivars require watering at weekly intervals, although some may cope with slightly longer intervals without significant yield/quality impacts.

- Luxurious levels of irrigation increased doubles and splitting in some onion cultivars.

- Potatoes suffered reduced yields when irrigated at 12 day intervals during tuber bulking, compared to more frequently irrigated crops.

- Scheduling using tensiometers increased sweet corn yields for any given total quantity of irrigation, compared to crops irrigated on a regular time basis.

- At a standard crop row spacing of 75 cm, yields of sweet corn could be maintained with drip tape between every second row of sweet corn, compared to sweet corn with drip tape next to every crop row.

- 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.

- Vigorous establishment of uniform planting material may be the key to consistent, high yields of quality sweetpotato.

Impacts of irrigation frequency and fungicides on severity and incidence of onion white-rot, crop water use and onion yield

Detail on this experiment is located in attached documentation.

Despite previous research suggesting a link between high soil moisture levels and increased incidence of onion white-rot, neither our experimental results, not those of a major white-rot project being conducted at the same time, showed any evidence of such linkages.

In our experiment, we received a total of 126 mm of rain, whilst total Class A pan evaporation during the growing period was only 577 mm. The most frequently watered treatment was moist the whole growing period, with tensiometers 15 cm below the ground surface peaking at <20 kPa between irrigations (Table 13). Whilst the treatment irrigated twice a week dried out the soil slightly more between irrigations, it had the same levels of white-rot infection and marketable onion yields as the wetter treatment. The onions irrigated only once per week on average had the most white-rot and lowest marketable yields in the experiment, although these differences were only significant at the p=0.1 level. Our fungicide treatment did not reduce white-rot under any irrigation regime.

Table 13. Impacts of irrigation interval on white-rot incidence and onion yields.

	2 day interval	**4 day interval**	**7 day interval**
Total irrigation (ML/ha)	4.0	3.5	3.4
Peak shallow tensiometer value (kPa)	18	33	51
Incidence of white-rot infection (% bulbs affected)	35	33	48
Marketable yield (t/ha)	20.6	21.6	15.1

For the first 19 weeks after sowing, all irrigation treatments refilled the crop root zone after each irrigation, as deep tensiometers (45 cm below ground level) remained at <10 kPa. There were a number of irrigations in all treatments that resulted in drainage below the root zone. From 19 weeks after sowing until the onions were harvested 4 weeks later, values for the deep tensiometers steadily rose to 25-30 kPa.

Although using 3.5 ML/ha of irrigation is less than the commonly quoted industry irrigation budget for onions of 4 ML/ha (Duff *et al.* 1999), there was certainly scope for improved efficiency via less deep drainage, particularly during the early growing period. The performance of this crop can be contrasted with our other onion experiment grown during nearly the same period. Best treatment in that experiment yielded 60 t/ha, used only 3 ML/ha of irrigation, with the same amount of rain and nearly 150 mm more pan evaporation. The result for our white-rot experiment suggested there was little scope for managing onion white-rot by manipulating irrigation (within the irrigation ranges needed to optimise crop performance), so we did not continue with this line of investigation.

Irrigation and seed priming affect the establishment of four beetroot cultivars

The full report for this experiment is available in the individual experiment report. The principal outcomes as described in that experiment report are given below, with reference to some key results.

Planting irrigation.

Beetroot that received 21 mm of water in the first 4 days after planting (DAP) emerged rapidly, achieving their relatively uniform, dense stands by 10 DAP. Beetroot that received 13 mm of irrigation in the first 4 DAP achieved 70-85% of their final plant densities by 10 DAP. In contrast, plantings irrigated with only 6 mm of water in the first 4 DAP, established only 45% of their eventual plant density by 10 DAP (Fig. 29). Beetroot plants that emerged most rapidly produced the largest seedlings (Fig. 30) and the healthiest root systems by 36 DAP (Fig. 31).

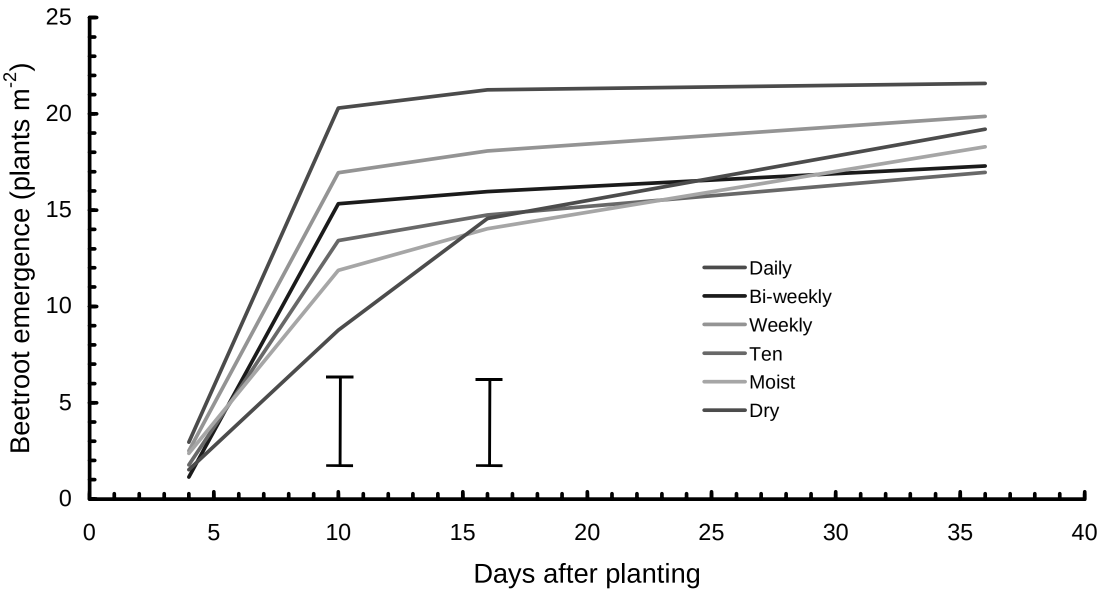


Figure 29. Wetter irrigation regimes increase the rate and final stand establishment of beetroot seedlings in a low-disease environment. Bars are protected LSD values ($P \leq 0.05$) for each date that there were significant treatment effects.

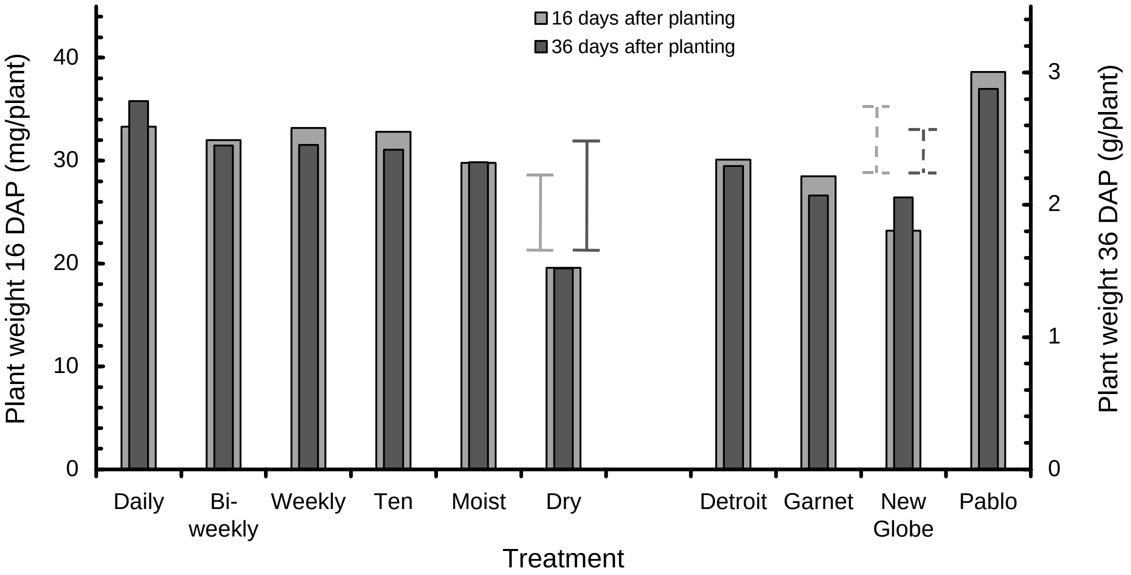


Figure 30. Irrigation and cultivar choice affect dry weights of beetroot seedlings16 and 36 days after planting in a low-disease environment. Bars are protected LSD values (P≤0.05) for comparing irrigation treatments (solid bars) or cultivars (dashed bars).

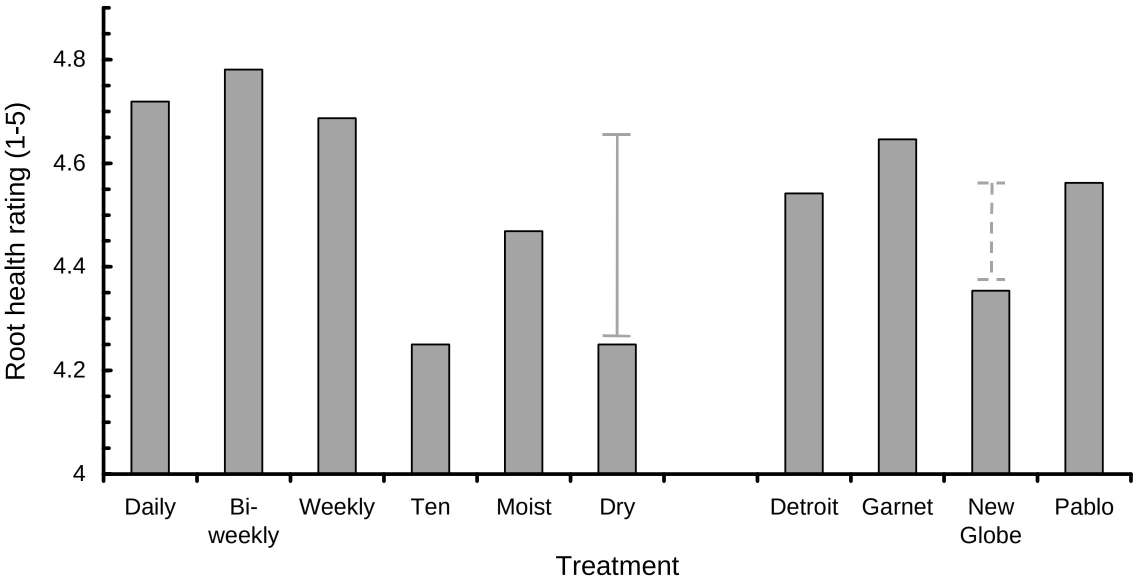


Figure 31. Irrigation and cultivar choice affect dry weights of beetroot seedlings16 and 36 days after planting in a low-disease environment. Bars are protected LSD values (P≤0.05) for comparing irrigation treatments (solid bar) or cultivars (dashed bar).

Irrigation at planting is a compromise between managing the risks that under-watering will reduce seed germination and seedling emergence, compared to providing a soil moisture environment that enhances disease infection. In making the irrigation/planting decision, producers should account for; estimates of soil disease loads, current soil profile moisture, and likely weather during the ensuing week.

Seed priming.

Our system of priming the beetroot seed before sowing may have marginally improved initial emergence of beetroot that received sub-optimal planting irrigation. However, beyond 4 DAP, our priming treatment did not benefit any of the four cultivars we evaluated, and reduced final densities of **Pablo** and **Detroit Dark Red**. Seed priming protocols need to be specifically determined for each beetroot cultivar. Seed priming will probably only be beneficial when combined with specific systems of irrigation and planting management.

Cultivar performance.

In a low disease environment, **Pablo** and **Detroit Dark Red** established more rapidly, and in greater densities, than **Garnet** and **New Globe**. Individual **Pablo** seedlings were largest, whilst **New Globe** seedlings had slightly less well-developed root systems, compared to the other cultivars. Initial observations by others suggest different relative cultivar performance in circumstances with higher disease loads.

Implications for Rural Water Use Efficiency.

Soil water management at planting is important for rapid, uniform beetroot stand establishment. A system for monitoring soil water status at planting would help optimise initial irrigations, and would likely continue to be used to maximise irrigation efficiency through the growing season. Whilst there may be less deep drainage with better irrigation practices, the main economic benefits would accrue from increased production per unit inputs (including land, seed, chemicals and water). The benefits would result from reduced instances of re-planting, and higher yields (via less disease and more uniform plant stands).

During their R&D prioritisation process, our beetroot industry consultative group (producers, Golden Circle P/L and DPI scientists) decided that further research on beetroot irrigation was not a priority, particularly with respect to a system for managing their soil-borne diseases. At that point we made the decision not to pursue any more work in beetroot in this project.

Conclusion

- We did not find scope to manage onion white-rot or soil borne diseases in beetroot through manipulating irrigation.

Managing produce disorders and general quality in vegetables through improved irrigation management

This section deals with specific quality issues in the target vegetable crops, and not general quality attributes such as size grade distributions, which have been dealt with in a previous section.

Tipburn in lettuce

A full discussion on lettuce tipburn is included in the detailed experiment reports, and is not repeated here.

Cultivar tolerance is the best management tool lettuce producers can use to manage tipburn risk. However, there are severe performance penalties associated with growing tipburn-tolerant cultivars in cool conditions. The art/science is managing the transitional changeover from cool season, tipburn susceptible cultivars (e.g. **Oxford**) to warm-season, tipburn tolerant cultivars (e.g. **Raider**), whilst maintaining crop performance and marketable product volumes. In both lettuce experiments where tipburn occurred, **Raider** was not affected.

Additional calcium (Ca) supplementation via fertigation, may need to be at least weekly to be effective, with any benefits easily swamped by practices such as additional N supplementation and/or delaying harvest, which although they may increase yields, also exacerbate tipburn. In this context, it probably makes more sense to try and manage tipburn by ensuring that N fertilisation is on the borderline of being under-supplied, and that harvesting is definitely not delayed, rather than the difficult exercise of weekly, high-volume Ca applications to the soil (Fig 32).

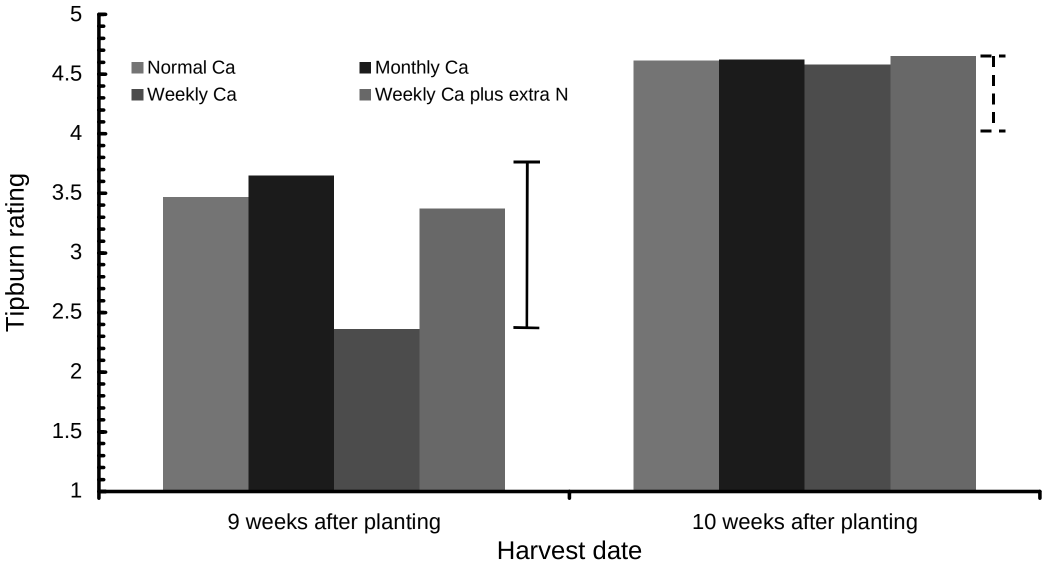


Figure 32. Nutritional impacts on tipburn ratings in **Oxford** lettuce were not statistically detectable, but were more variable at 9 weeks after planting, compared to greater and more consistent tipburn incidence one week later. Bars are protected LSD values ($P \leq 0.05$) for comparing nutrition treatments 9 weeks after transplanting (solid bars) or one week later (dashed bars).

Provided irrigation management is sufficient to prevent water stress, it appears unlikely there is much scope to manage tipburn by fine-tuning irrigation strategies, e.g. by watering more regularly than twice a week, or irrigating at certain times of the day. In our deficit irrigation experiment with lettuce, where we irrigated every 2, 5 or ten days, replacing 30%, 60%, 90% or 120% of pan evaporation, we recorded a consistent tipburn rating of 4.0 for the **Oxford** cultivar across the whole experiment. This was despite the fact that some treatments received only 1.7 ML/ha of irrigation, and other received 3.3 ML/ha. There was also no reduction in tipburn from applying additional calcium in the form of micro-fine gypsum at 50 kg/ha through the drip system every 10 days.

Tipburn management is about minimising risk events. This means not pushing the growing window of susceptible cultivars, and planting tolerant cultivars as early as possible, maintaining adequate soil moisture, and harvesting early rather than delaying harvest to bulk up the head. It appears that any calcium supplementation needs to be at least weekly, and married with a strategy to use the minimum amount of nitrogen that doesn't compromise plant and head development. It is probable that if calcium supplementation were desired, a well-operated drip system with which to fertigate would be the best option.

Our experiments suggest that applying calcium through the drip system is not a panacea for tipburn. As such, it probably cannot be promoted as a key reason for lettuce producers to adopt the water use efficient drip systems. This is not to discount that there may be other water use related factors that can influence tipburn (for example the advantage of drip systems ability to effectively irrigate in windy conditions).

Brown fleck in potato

Potato brown fleck is a physiological disorder, resulting in the breakdown in phloem cells and surrounding tissues within the potato tuber. It causes a brown discolouration in the tubers and can result in serious price penalties or total rejection of produce. At certain times of the year (particularly harvests in Spring and early summer), in certain cultivars, and on certain soil types, it can be a very significant issue.

The literature indicates that the incidence of brown fleck is most pronounced under conditions favouring rapid growth, during the late bulking stage and in large tubers. Specifically, with regards to irrigation management, a high incidence of brown fleck is associated with excessive irrigation, while, for nutrition management, such incidence is associated with poor calcium and excessive nitrogen nutrition.

In our first experiment, we received a total of 110 mm of rain, with a major event of about 30 mm around 9 days after planting and again 92 days after planting, and several minor falls during the rest of the 16 week growing period. It was a relatively warm, windy Spring, with total Class A pan evaporation during the growing period of 570 mm. Although it was our intention not to differentiate our irrigation treatments until late in the tuber bulking period (when brown fleck problems develop), we probably left it a little too late, not differentiating until just 3 weeks before harvesting. Due to miscommunication with operational staff, between 6-13 weeks after planting, the potatoes were under watered, receiving only 30% of pan evaporation. During this stress period, tensiometers 20 cm below the top of the hill peaked at 70 kPa between irrigations, whilst tensiometers at 60 cm steadily rose to 80 kPa during the same time. Once we commenced differentiating our irrigation treatments, water applied was 100% of pan evaporation, and values for the deep tensiometers slowly declined until harvest.

During the treatment period, (91-113 days after planting), our treatments were irrigated every 2, every 4 and every 8 days respectively. There was virtually no difference between the total amounts of irrigation applied to each treatment (Table 14). During the final 3 weeks before harvesting, differences in irrigation interval had no effect on water status in the potato hill, incidence of brown fleck or marketable potato yields. The yields themselves were only moderate, reflecting the excessive moisture stress experienced during period between 6-13 weeks after planting.

Table 14. Irrigation interval late in tuber bulking did not influence soil water status, brown fleck incidence, or marketable tuber yields.

	2 day interval	**4 day interval**	**7 day interval**
Total irrigation (ML/ha)	2.8	2.6	2.7
Peak shallow tensiometer value 13-16 weeks after planting (kPa)	15	14	19
Incidence of brown fleck (mm^2 per tuber)	26	24	26
Marketable yield (t/ha)	26.6	25.6	27.1

The plots that received an additional 100 kg/ha of Ca (as calcium nitrate) through the drip system, between 11 and 12 weeks after planting, produced potatoes with 19 mm^2 brown fleck per tuber. Plots that received the equivalent amount of nitrogen (as ammonium nitrate), to the above treatments, but no additional Ca, produced 31 mm^2 brown fleck per tuber. Due to large variability in brown fleck incidence, this difference was significant at the P=0.1 level. Different nitrogen rates did not affect brown fleck incidence, and none of the nutrition treatments affected marketable potato yields.

In our second experiment investigating deficit irrigation in potato, we measured brown fleck incidence in potatoes from each of our irrigation and nutrition treatments described earlier. Note that plots receiving 180 mm total irrigation were the 30% pan evaporation treatments, 240-260 mm were 60% pan evaporation treatments, 300-340 mm were 90% pan evaporation treatments, and 370 mm was the 120% pan evaporation treatment. Although there was a significant decline in the incidence of brown fleck with reduced irrigation (Fig. 33), the reduction in the disorder was also clearly associated with reduced yields (Fig. 34). This fits in with the latest hypothesis on the causes of brown fleck being investigated by Steve Harper (pers. comm.). His recent research results suggest brown fleck is due to high respiration rates in plant tops and tubers associated with warm night temperatures during the last 4 weeks before harvest. The risk of the disorder is greatest in crops with vigorous top growth, high potential yields and large tubers, parameters that are all enhanced in well-irrigated crops.

This work suggests there is limited scope to reduce brown fleck by manipulating irrigation, without reducing potential yield. It may be that there is scope for trading off yields and brown fleck incidence by managing irrigation in conjunction with other agronomic practices, such as mechanical removal of tops in the weeks leading up to harvest.

There was no benefit from providing 55 kg/ha of Ca (as calcium nitrate) 4 weeks before harvesting. Interestingly, the infrequently irrigated treatments (every 12 days) had much lower incidences of brown fleck in proportion to their total amounts of irrigation, or total yields, than all other treatments. At this stage we cannot speculate what the special attributes of those treatments that led to lower brown fleck levels might be, however they may give a clue to future management options.

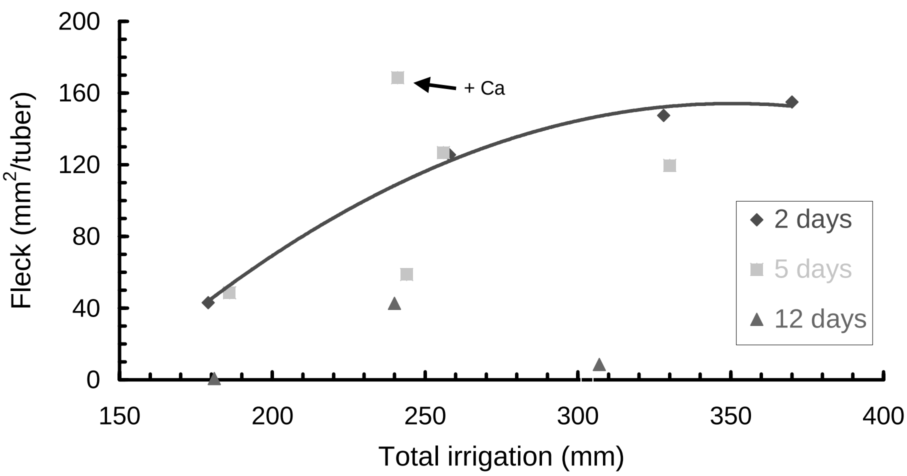


Figure 33. Impact of irrigation interval and quantity on brown fleck incidence in potatoes

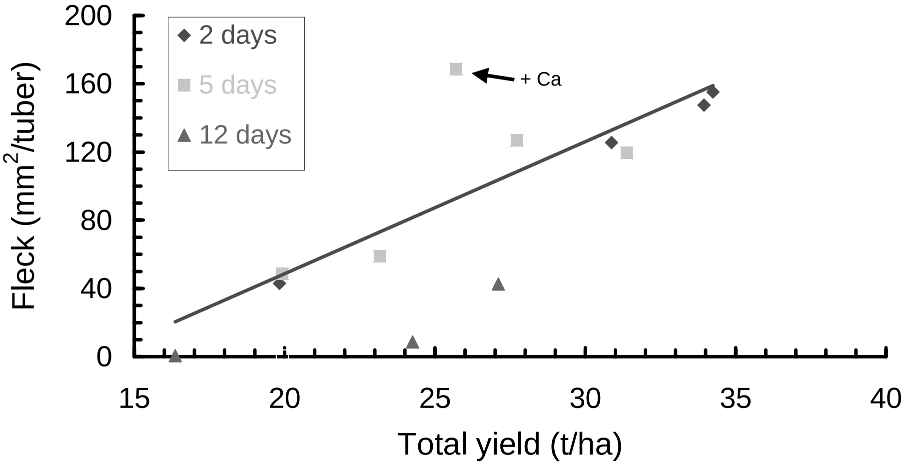


Figure 34. Relationship between total tuber yield and potato brown fleck incidence.

Pungency in sweet onions

A full discussion on pungency in onions is included in the detailed experiment reports, and is not repeated here.

In our initial experiment, pungency level (as indexed by pyruvic acid concentration) of the onions was unaffected by both irrigation frequency and sulphur nutrition. Cultivar selection, however, did impact on pungency, with **Wallon Brown** (7.8 µmol/g) less pungent (milder) than **Predator** (8.7 µmol/g). In our experiment evaluating deficit irrigation however, we found that very frequent irrigation at 90-120% of pan evaporation, increased pyruvic acid levels by 0.7 units compared to the less irrigated treatments (Fig. 35). Addition of 200 kg/ha of sulphur (in the form of ammonium sulphate) 11 weeks after sowing also increased pyruvic acid levels by the same amount. As in the previous experiment, there were differences between cultivars, i.e. **Colossus** (6.1 µmol/g) and **Rio Zena** (5.9 µmol/g) had significantly greater pyruvic acid concentrations than **K5156** (5.4 µmol/g).

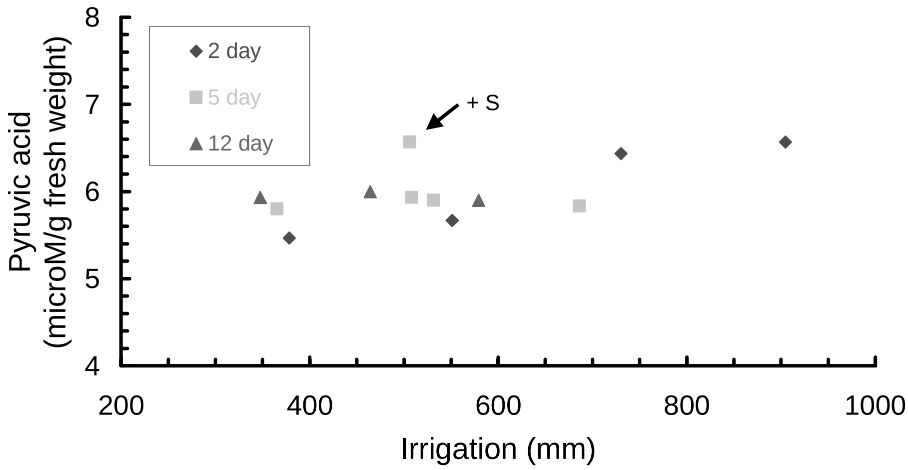


Figure 35. Impact of irrigation interval and total quantity on pyruvic acid concentration in onion bulbs.

Sweet corn cob quality

Within the range of drip tape row spacings (37.5-150 cm), irrigation frequencies (**Biweekly** to **Fortnightly**), and total irrigation quantities (1.65-3.0 ML/ha) investigated in our sweet corn experiment, there were no significant effects on cob quality ratings. All treatments averaged a rating of 7.4±0.1 (scale of 0-10). On our scale, 5 is barely acceptable to the market, and 10 is a perfect quality cob.

Sweetpotato storage root quality

There were virtually no unmarketable storage roots for the sweetpotato cultivar **Beauregard** in our experiment, averaging 4.7 ± 0.9% by weight, with no impact of irrigation treatments.

However, the **Northern Star** cultivar had a large proportion of storage roots classed as unmarketable (27% by number, 38% by weight). Generally it was the larger roots that were classed as unmarketable, primarily due to severe cracking. Of the unmarketable storage roots only 10% were deformed, the rest were cracked. The total numbers and yields of unmarketable **Northern Star** storage roots are shown in Fig. 36, averaging 10.5 t/ha across the experiment, with no consistent effects of irrigation strategy on cracking levels.

There did not appear to be much scope for managing cracking in **Northern Star** by relatively intense irrigation. Even plants that were kept in reasonably moist soil for the whole of the growing period developed significant levels of severely cracked storage roots.

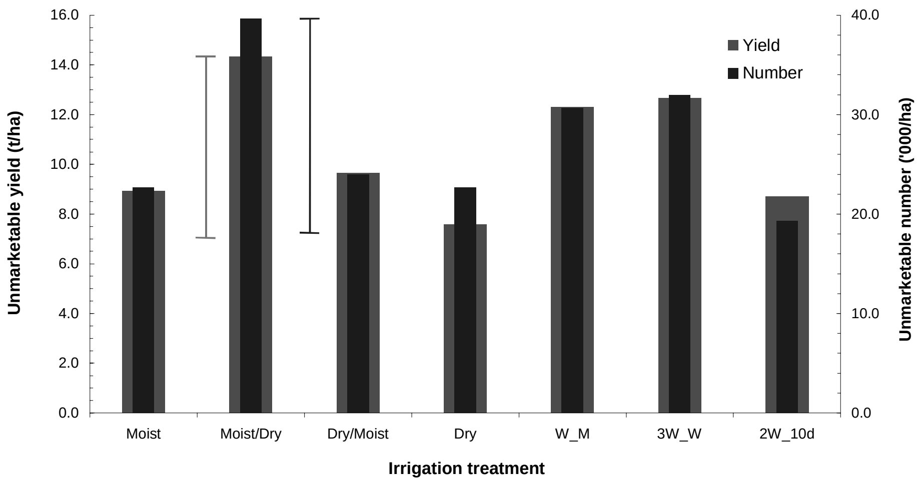


Figure 36. Irrigation management effects on the numbers and yields of unmarketable storage roots harvested from **Northern Star** sweetpotatoes. Coloured bars are the $LSD_{0.05}$ for the corresponding harvest analysis parameter.

For the cultivar **Beauregard**, we rated flesh colour on a scale from 1-5. Ten 'Medium' storage roots from each plot were sampled, and each root was sliced 3 cm from either end and through the middle. We rated the slice on consistency and hue of the orange flesh colour, and the degree of green or white mottling.

Our rating scale gave a value of 5 for very good flesh colour, reducing to 1 for very poor flesh colour. Examples of various ratings are shown in Plate 3.

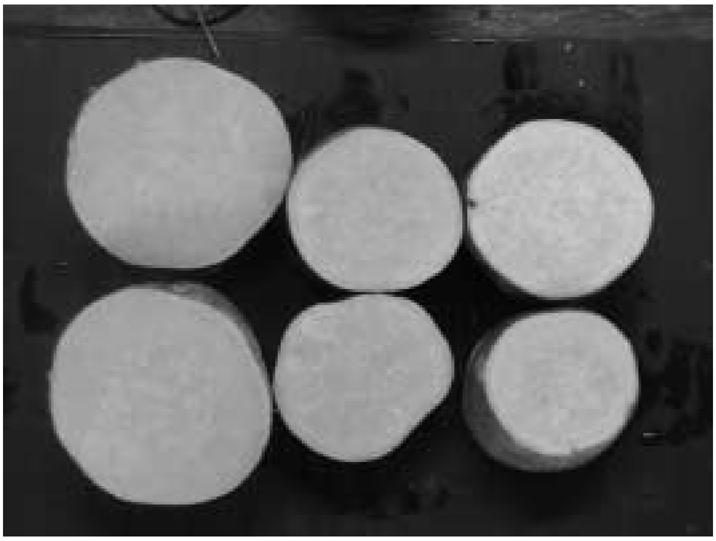


Plate 3. From left to right, Good (rating 4), Moderate (3) and Poor (2) sweet potato flesh colour in **Beauregard**.

In analysing the flesh colour of the harvested **Beauregard** sweetpotatoes, we found no significant differences in the mean flesh colour rating of samples from the irrigation treatments, which averaged 3.4 ± 0.1. However, there was a slight trend for the least irrigated treatments to have more roots rated 'Good' or better, than the treatments that received more irrigation (Fig. 37).

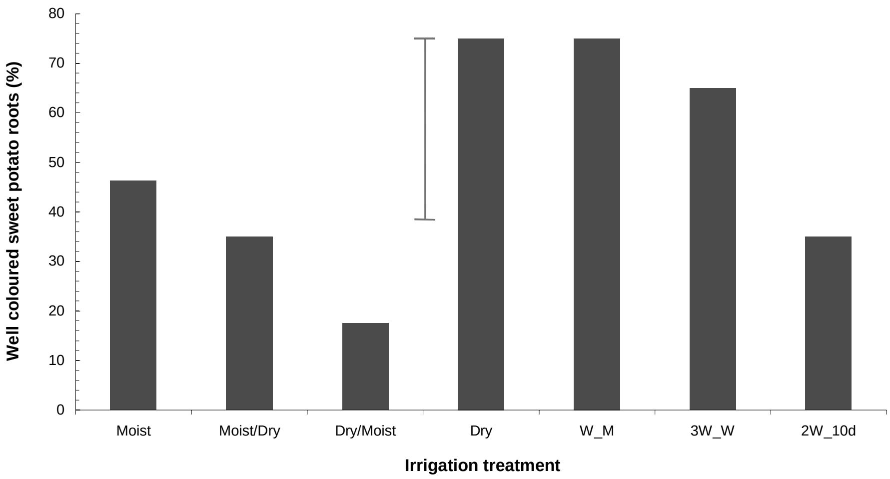


Figure 37. Irrigation management effects on the proportion of **Beauregard** storage roots with flesh colour rated 'Good' or better. The coloured bar is the $LSD_{0.05}$ value for comparing treatments.

Sweetpotato dry matter

Irrigation regimes had no effect on the dry matter contents of the harvested sweetpotatoes, although the **Beauregard** cultivar ($21.2\% \pm 0.4\%$) had lower dry matter content than **Northern Star** ($25.8\% \pm 0.4\%$).

Conclusions

- We did not find any impact of irrigation management or supplementary calcium fertigation on tipburn in lettuce. This disorder was best managed by appropriate cultivar selection in relation to expected seasonal conditions, early harvesting, and minimising nitrogen applications.

- There appears to be minimal scope to manage brown fleck in potato by irrigation management, as yields also decline if irrigation is withheld to reduce brown fleck. We did not find any consistent reduction in brown fleck from supplementing calcium nutrition via fertigation.

- Onion pungency is primarily determined by cultivar selection. Consistently moist soils increase pungency levels compared to less frequent irrigation, or deficit irrigation strategies.

- High levels of sulphur fertiliser increase onion pungency.

- Within the range of irrigation strategies we evaluated, there were no differences in sweet corn cobfill, kernel blanking or straightness of kernel rows.

- Frequent irrigation had a minor deleterious effect on flesh colour in **Beauregard** sweetpotato.

- We could not reduce cracking in **Northern Star** sweetpotato by keeping soils consistently moist, or any other irrigation strategy.

- Sweetpotato dry matter was influenced by cultivar, but not by irrigation strategy.