VG407

Improved irrigation management in potatoes and onions

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QLD Department of Primary Industries

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Craig Henderson

Industry and technical summary

In detailed experiments at Gatton Research Station, we investigated irrigation requirements for optimum production of both potatoes and onions. We obtained best yields when crops were irrigated once shallow tensiometers (installed 20 cm below the tops of potato hills, or 15 cm below the ground surface in onions) gave readings of about 40 kPa. In early growth stages, this generally meant applying 20-25 mm every 5-7 days. During peak growth, these requirements increased to 30-35 mm per irrigation. These are only guides; producers would need to adjust these values for their different soils, climates, and water qualities.

In conjunction with the detailed experimental research, we used commercial-scale demonstrations and producer collaboration to maximise interaction and the chance of technology adoption. Eight potato producers (23 sites) and 3 onion producers (8 sites) were involved in completed Demonstrations. Collaborating producers were provided with information on irrigating potatoes and onions, and using tensiometers.

At each Demonstration, at least 2 monitoring sites were installed in a representative paddock, with tensiometer values, irrigation, rainfall, and crop performance recorded. QDPI staff maintained and serviced the tensiometers as required in most instances. At the end of each Demonstration, producers were sent a report detailing findings for their individual situation.

Potato crops were generally watered when values for shallow tensiometers reached an average 60 kPa. This is at the top end of the acceptable range for optimum potato production. Several Demonstrations suggested significant periods of water stress in the monitored crops, which probably suffered reduced yields as a result. In the onion crops we monitored, tensiometer values often reached 70 kPa between irrigations, well above the value we would normally recommend. Again yields and onion bulb sizes may have declined slightly because of these stresses. In almost all instances, the water-stressed conditions did not persist for more than a few days. Using tensiometers enabled many producers to judge the value of intermittent rainfall, and extend irrigation intervals without stressing their crops.

Surprisingly, of the producers we monitored, those with solid-set sprinklers did not appear to be taking advantage of their systems' flexibility to water when crops were first encountering stress. Watering was often delayed, so that intervals between irrigationswatering were similar to those producers who used hand-shift systems. In most situations, 25-35 mm of irrigation was sufficient to fill the root zone of well-grown potato or onion crops that were not under stress. If irrigation was delayed, then slightly more could be applied without getting excessive through-drainage. However, delaying irrigation increases the risk of water stress levels high enough to affect produce yields or quality. As these Demonstrations took place toward the end of the worst drought in the irrigated history of southern Queensland, the delays in irrigation were not entirely unexpected. There were also several examples where excessive irrigation led to significant deep drainage of water.

Future studies into the relationships between irrigation management and the occurrence of internal brown fleck in potatoes, and onion bulb quality (presence of 'doubles', storage life, and pungency of sweet onions) may be useful.

Producers who regularly monitored the tensiometers every 1-2 days, and kept reliable irrigation and rainfall records, obtained more meaningful results. They also became more familiar with the tensiometers, and were able to overcome simple problems. Those producers unable to regularly monitor their crops may need to employ a consultant, or alternatively invest in electronic monitoring systems (with the much greater associated technology requirements, expense, and probable need for outside assistance). Whilst it is very time and resource consuming, we have found that collaborative work, on-farm with producers, is the most effective way of extending moderately complicated, new technology. In that way, the little hurdles that individual producers may encounter can be addressed, without them losing faith in the system, because of simple problems that can be readily fixed.

Introduction

Irrigation management in potatoes and onions in southern Queensland has generally relied on a combination of tradition, calender scheduling (eg. water every 8-9 days) and gut feeling, occasionally accompanied by a kick at the ground. Our prior experience monitoring producers' crops, and experimental results, meant we were very confident that irrigation scheduling would be of major benefit to both potato and onion producers. QDPI recommendations indicate about 4 ML/ha of irrigation are required for potatoes and onions.

Water stress affects yields and quality

Many studies have shown that potatoes produce highest yields and best quality tubers when the soil is kept relatively moist during the growing period (Jackson *etal* 1993, Wright and Stark 1990, Doorenbos and Kassam 1979, Taylor 1972). Water stress is particularly to be avoided at, and just prior to, tuber initiation (when stress will reduce tuber numbers), and during the bulking up phase, when stress will reduce tuber size, and may also cause tuber deformities and lower dry matter contents (Howell 1990, Wright and Stark 1990, Doorenbos and Kassam 1979, Taylor 1972).

Onions are similarly sensitive to moisture stress, requiring frequent light irrigations for maximum yield. Production is particularly inhibited by water deficits during the bulb development and enlargement period, although skin quality can be improved by withholding water during the maturation phase (Allwright and Chapman 1993, Stanley and Maynard 1990, Doorenbos and Kassam 1979).

Monitoring water status

Because both potatoes and onions have the bulk of their roots in the upper 30 cm of the soil (Wright and Stark 1990, Doorenbos and Kassam 1979), any soil water monitoring device used for irrigation scheduling needs to concentrate on this part of the soil profile. Without intensive calibration, neutron probes are not very sensitive to moisture contents in the upper 20 cm of the soil profile, although they are very good at showing drainage beyond the root zone. More recent technologies such as Time Domain Reflectometry (TDR) and Capacitance Probes (eg. the ENVIROSCAN® system from SENTEK P/L) can function more precisely at shallow soil depths, however their use in vegetables was still very much in its infancy (Henderson 1993b). Over the past 18 months, the capacitance probe systems have been strongly promoted by consultants, with significant adoption by some vegetable industry sectors. Infrared thermometry is probably not appropriate for potatoes or onions, because of restrictive use conditions and lack of sensitivity (Jolly 1991).

Using tensiometers in potatoes and onions

Tensiometers can be used successfully to monitor soil water status in shallow root zones, particularly in horticultural crops that are frequently irrigated (Campbell and Mulla 1990, Taylor 1972). They have not been widely adopted in many areas because of a perception that they are difficult and time-consuming to operate. Whilst this may have been true of earlier models, the latest tensiometers are user-friendly and effective. We decided to base our irrigation scheduling strategies on tensiometers because they are easy to use, relatively cheap to install and maintain, and can be operated by individual producers with a minimum of training and experience. An irrigation scheduling project in WA established the use of tensiometers in potatoes for areas of that state (HRDC 1992).

Overseas research suggests that potatoes should be watered at tensiometer values between 30 and 50 kPa in the main root zone (Taylor 1972). Western Australian data suggests values of 20-25 kPa may be most appropriate for sandy soils and 45 kPa for loamy soils. They also found some differences between cultivars (HRDC 1992). Our preliminary work on potatoes suggested a value of around 45 kPa was suitable for southern QLD situations (Jackson *etal* 1993, Henderson unpublished data).

Taylor (1972) suggested critical tensiometer values for onions of 45-55 kPa during early growth, increasing to 55-65 kPa during bulb formation and filling. Irrigation frequencies also have to take into account the impacts on diseases such as downy mildew (Tesoriero etal 1993) and onion quality (Allwright and Chapman 1993).

Matching irrigation to crop requirements maximises production by minimising plant water stress, nutrient deficiencies and some diseases, as well as preventing build-up of salinity problems. By preventing over-watering, problems with leaching of nutrients and pesticides into groundwater (and beyond the zone of usefulness to the crop) are reduced, as well as a decrease in disease levels. There is increasing financial pressure on producers to use inputs such as water, fertilisers and pesticides more efficiently. There is also substantial community pressure mounting for efficient use and conservation of these inputs and natural resources.

Field observations

During an on-farm investigation in 1992, a fresh-market potato producer who applied 3.8 ML/ha produced 40 t/ha of potatoes. Another, who more closely followed district practice, applied 1.9 ML/ha and produced 23 t/ha (about the district average). In irrigation experiments, potatoes watered: every 4-5 days during the tuber initiation and yield formation stages (total 3.7 ML) yielded 41 t/ha; every 7-8 days (3.3 ML) 20 t/ha; every 10-12 days (2.4 ML) only 14 t/ha. These observations indicate correct irrigation timing and quantities are critical to successful potato production. Irrigation scheduling is particularly important at both tuber initiation and during the bulking-up periods. The results also show that irrigation scheduling can substantially improve water use efficiency in the potato crop, i.e. the tonnes of tubers produced per ML of irrigation.

Project objectives

This project sought to improve irrigation management in potatoes and onions, augmenting results from previous projects in other vegetables. The project had 2 components. Firstly, to conduct detailed experiments at Gatton Research Station, confirming best practices for irrigating potatoes and onions. A concurrent strategy focused on monitoring irrigation practices with collaborating producers, demonstrating irrigation management techniques in commercial circumstances. These on-farm sites involved installation of tensiometers in crops, with monitoring several times per week, to record changes in soil water status. With the cooperation of the producers, irrigation regimes, crop growth, and any other events, such as disease or pest incidence, were also recorded. We sought to run demonstrations with as many potato and onion growers in southern QLD as wished to participate.

Materials and methods

Gatton Research Station irrigation experiments

Three experiments investigating irrigation management in potatoes and onions were conducted at Gatton Research Station during this project. Only a single experiment was carried out with potatoes, as this crop had been the subject of several experiments in a previous project. Two specific experiments researched irrigation responses of onions, whilst another monitored irrigation management as part of study into weed control in onions. In each experiment, the use of tensiometers to schedule irrigation, the performance of different application systems, and the water requirements of both potatoes and onions were evaluated. Full methodologies, data, results and conclusions for each of these experiments conducted within the project are included as Appendices 1-3. Crops, cultivars, planting and harvest dates are shown in Table 1.

Table 1. Agronomic details for 3 experiments investigating irrigation management.

Code	Crop	Cultivar	Planting date	Harvest date
ONI94	Onions	*Gladalan Brown*	06-06-94	15-11-94
POT94	Potatoes	*Wilwash*	30-06-94	09-11-94
ONI95	Onions	*Golden Brown*	23-3-95	03-10-95

The experiments were conducted on a black earth soil (*Ug5.15*) at Gatton Research Station (lat. 27°33'S, long. 152°20'E). The experimental designs were randomised complete blocks. The 1994 studies comprised 5 irrigation treatments replicated 3 times, whilst in the second onion experiment, there were 2 sowing dates, each with 4 irrigation treatments replicated twice. Treatment plots in each experiment were 1.5 m wide and 10 m long. This involved 2 rows per plot for the potatoes and 4 rows per plot for onions. In the 1994 studies there were 2 buffer plots between each treatment plot, whilst in the second onion experiment, there was only 1 buffer plot in between the treatment plots. We initially irrigated with hand-shift or solid-set systems to establish the crops. Once irrigation treatments started, we used systems of mini-sprinklers or drip tape to individually water each plot. Schematics of individual plot layouts are shown in Figure 1.

In the plots watered with overhead irrigation, lines of mini sprinklers were installed down the 2 outer edges of the treatment beds, with 2 m between each sprinkler within the a line. The sprinklers in the 2 lines were offset by 1 m, to give a staggered pattern down the bed (Fig. 1a). Each sprinkler was mounted on a 1 m high stake, with an output radius of about 2 m and volume of 70 L/hr at 130 kPa operating pressure. Using this system, irrigation was relatively uniform across the treatment bed, with no drift into neighbouring treatment beds. The application rate was around 20 mm/hr over the treatment beds. An electronic timing system was used to commence irrigation at 2 am on the appropriate days, to avoid windy conditions often prevalent during daylight hours.

Plots watered with drip-tape had tapes positioned on the top of the 'treated' potato rows as well as the 2 adjacent buffer rows (Fig 1b). Where onions were watered with drip systems, there were still 2 tapes per plot, positioned between the 4 rows such that each row was within 17 cm of a tape. We used "T-Tape Row Crop" with emitters every 0.2 m and an output of about 7.3 L/m/hr at an operating pressure of 70 kPa. This corresponds to an overall application rate of ≅ 9 mm/hr on a total area basis.

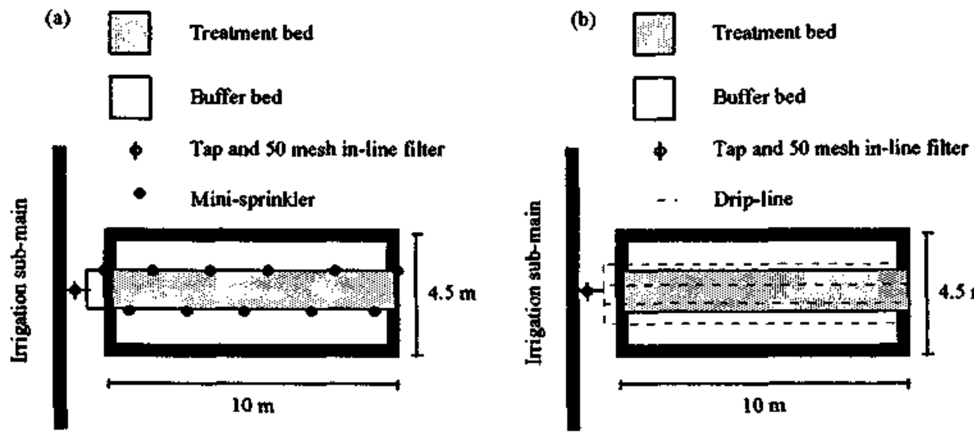


Figure 1. Individual plot irrigation system layouts for treatments watered by (a) mini-sprinklers and (b) drip-lines.

Tensiometers were installed 20 cm and 60 cm below the tops of the hills in a treatment row in each plot of potatoes, and 15 cm and 60 cm below the ground surface in each onion plot. LOCTRONIC® tensiometers were used, which consist of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum at the top of the tensiometer, while an electronic vacuum gauge attached to the syringe records the vacuum in the small air gap below the septum. Tensiometer readings were recorded around 8-9 am daily.

Critical Tensiometer Values (T) were used to trigger irrigations in these experiments. Irrigation was applied when readings for the shallow tensiometers were greater than the **T** individually set for each treatment. The irrigation treatments for each experiment are detailed in Table 2.

Table 2. Treatment details for 3 experiments investigating irrigation management.

Code	Crop	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5
ONI94	Onions	DRP30	SPR30	SPR45	SPR60	SPR80
POT94	Potatoes	DRP30	SPR30	SPR45	SPR60	SPR80
ONI95	Onions	DRP20	DRP35	DRP60	DRP75	-

The letter codes in Table 2 refer to: DRP - irrigated with surface drip tape; SPR - irrigated with overhead sprinklers; numbers indicate the shallow tensiometer values (x kPa) at which plots were irrigated

Weather data, including rainfall, Class A Pan evaporation, maximum and minimum temperatures were recorded daily. The amounts of irrigation applied were calculated from data collected with a water meter at the irrigation pump, calibrated with actual measurements of sprinkler and dripper outputs.

In the potato experiment, tubers were hand harvested, graded into 5 weight classes; <80 g, 80-200 g, 200-350 g, 350-450 g, >450 g; counted and weighed. Dry matter contents were determined on 2 samples of 80-350 g potatoes for each plot. In both onion experiments, heights of plants were measured on several occasions during the growing period. When the bulbs matured and were harvested, they were graded into 3 size grades; picklers (<40 mm diameter), No. 1 (40-75 mm), No. 1 large (>75 mm); counted and weighed. Dry matter contents were determined on a processed sample of 6 No. 1 grade onions for each plot. Double onions, seed heads and other off-types from each plot were also counted and weighed.

All growth, yield and quality parameters were analysed using standard analyses of variance.

On-farm irrigation monitoring

During this project we collaborated with 8 potato producers and 3 onion producers, monitoring irrigation management in several crops on their farms. Some producers were involved on more than one occasion (Table 3).

Table 3. Irrigation management demonstrations in potato and onion producers' crops between 1994 and 1996.

Producers	Location	Sites	Period	Crop
Barry Stephan	Mt Sylvia	2	May - Sep. 1994	Potatoes
Craig Wilson	Redlands	8	May - Oct. 1994	Potatoes
Dudley Peck	Charlwood	4	Jul. - Oct. 1994	Potatoes
Murray Hughes	Mulgowie	2	Mar. - Jul. 1995	Potatoes
Paul Wruck	Cleveland	2	May - Oct. 1995	Potatoes
John Foley	Allora	1	Sep. - Dec. 1995	Potatoes
Robert Haines	Lowood	2	Feb. - May. 1996	Potatoes
John Keller	Lowood	2	Apr. - Jun. 1996	Potatoes
Bevan Schiewe	Thornton	2	Mar. - Jul. 1995	Onions
Merv Hodges	Thornton	2	Mar. - Aug. 1995	Onions
Greg Banff	Coominya	2	May. - Oct. 1995	Onions
Bevan Schiewe	Thornton	2	Aug. - Oct. 1995	Onions

A typical demonstration involved the following sequence of operations. In collaboration with the producer, a representative crop on the property was selected for monitoring. Two sites were chosen in the selected crop. In potatoes, the tensiometers were installed as soon as possible after final hilling or cultivation (to avoid damage to the equipment). With onion crops, the tensiometers were put in place once the onions had 3-4 true leaves. At each site, a shallow tensiometer was placed 20 cm below the top of the potato hill, or alternately 15 cm below ground level in onions. In both crops, deep tensiometers were installed to depths of 60 cm. The collaborating producer would monitor the tensiometers on a regular basis, recording readings in a notebook. Amounts of rainfall and irrigation were also noted. In most instances, the tensiometer sites were regularly inspected and serviced by Craig Henderson or Mick Webber. The tensiometers were removed before crops were harvested.

At the start of each demonstration, producers were provided with the QDPI booklet 'Water It Right - Irrigation Using Tensiometers' (Daniels *etal*, 1994), and an article reprint 'Tensiometers in vegetables made easy' (Henderson 1993a). These provided information on installing, using, and trouble-shooting tensiometers, as well as interpreting tensiometer data. This material also outlined the factors to be taken into account before making irrigation decisions. During the crop growing period, we discussed irrigation options with the collaborating producers, and what their individual tensiometer values were indicating with regard their irrigation management. Each producer was still responsible for their decisions on when and how much to irrigate their crops.

The tensiometer, rainfall and irrigation data were entered into an EXCEL® Worksheet. In instances where tensiometer data were not available for certain days, we estimated values, based on previous experience, irrigation/rainfall timing, crop growth stage, etc. Final data were plotted on EXCEL® Charts, transferred to POWERPOINT® Presentations, and included in a written report. Each producer received an individual report about their specific demonstration, outlining key irrigation and crop management issues and suggesting areas for possible improvement. Examples of these written reports, with personal references deleted, are given in Appendices 4 and 5.

Results and discussion

Irrigation scheduling methods

In previous projects we confirmed that most water uptake by well-grown vegetable crops is in the top 20-30 cm of the soil profile, although some roots will obviously penetrate substantially deeper (Henderson 1994). The key issue when scheduling vegetable irrigation on the basis of soil water status is the need to intensively monitor this section of the soil profile. In experiments with potatoes we found they had very shallow root systems in the clay-loam soils of the Lockyer Valley. When irrigated for maximum production of high quality tubers, 85% of water uptake was from the upper 25 cm of the soil profile, with 70% from the upper 20%. Even in virtually non-irrigated potato crops, there was little uptake of soil water from more than 50 cm below the top of the potato hill (Henderson 1994). Literature suggests that onions are similarly shallow rooted.

Although relatively old technology, in our research we have found tensiometers to be the most cost-effective method for monitoring soil moisture status under shallow-rooted, quick maturing vegetables. They are easy to install and use, give accurate, reliable readings, require little maintenance, and are relatively cheap. One problem with the tensiometer system was determining the correct quantities (as opposed to frequencies) of irrigation to apply to avoid excess losses of water through drainage beyond the root zone. The amount of irrigation applied at a given tensiometer reading relies to some extent on experience with the particular soil type/crop combination. We aim to lose less than 10% of the applied irrigation as drainage.

In our project work we generally used LOCTRONIC® tensiometers, consisting of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum, while an electronic vacuum gauge attached to the syringe records the vacuum in the tensiometer air gap. These tensiometers cost approximately $ 30 each, with the electronic pressure sensor around $ 800.

Standard tensiometers, as used in our Demonstrations, consist of a ceramic tip, plastic housing, vacuum gauge and water reservoir. In modern designs, each component is individually replaceable, minimising repair costs. In addition, the best of these models have a water reservoir with a rubber membrane and valve design capable of removing air bubbles from the tensiometer without the need for a vacuum pump. This enhancement improves field operations and reliability of tensiometers in the field. A standard tensiometer with the above features costs about $ 110. In situations where more than 10 tensiometers are required by a single operator, it becomes more economic to use the LOCTRONIC® tensiometer system.

Interpretation of results

In both the detailed experiments at Gatton Research Station, and the on-farm Demonstrations, tensiometer, rainfall and irrigation values were plotted in a series of stacked graphs as shown in Fig. 2. They show the changes in readings for the shallow and deep tensiometers in response to crop water use, rainfall and irrigation as the season progressed. The top graph shows readings for the shallow tensiometer (scale on left side); the middle graph for the deep tensiometer (scale on right). Underneath are the corresponding irrigation and rainfall values. With the on-farm Demonstrations, where the 2 sites within the monitored paddock behaved similarly, mean values for the sites were plotted (as in Fig. 2). Occasionally the 2 sites had different responses, in which case values for the individual tensiometers were shown.

The example in Fig. 2 comes from a late Spring potato crop on a loam soil, watered with a hand-shift irrigation system. In the warm weather that occurred during this period, there were rapid increases in shallow tensiometer values between irrigations, to peaks of 60-70 kPa. After each irrigation or substantial rainfall, the shallow tensiometer values fell to 5-10 kPa, indicating moist soil in the potato hill. In an ideal situation, we recommend that the potatoes are irrigated when these shallow tensiometers reach 40-50 kPa. In most instances, optimum irrigation occurs when the deep tensiometer values are relatively stable at about 20-30 kPa. In this example, deep tensiometer values consistently rose, particularly in the period between 8 and 12 weeks after planting. When deep tensiometer values rise to levels above 40 kPa, it indicates the potatoes are extracting moisture from deep in the soil profile, which is generally a sign of water stress in the main crop root zone. A period of significant water stress around 10-12 weeks after planting is confirmed by extended high readings for both the shallow and deep tensiometers. Note that the 25 mm irrigation at 78 days after planting did not even fully wet the potato hill (the shallow tensiometer value only dropped to 40 kPa), while the deep tensiometer value continued to rise. Although the 45 mm of rain 82 days after planting wet the potato hill, it did not fully wet the soil profile to 60 cm (the deep tensiometer value fell to 40 kPa via capillary water movement). It was only when more than 100 mm of rain fell around 14 weeks after planting that the soil profile was again fully wet.

Situations where significant amounts of irrigation or rainfall are draining beyond the crop root zone are indicated by dips in the deep tensiometer values to less than 10 kPa. For example, there was probably some deep drainage (maybe 5 mm) when 12 mm of rain followed 27 mm of irrigation around 6 weeks after planting (Fig. 2).

By looking at the tensiometer values in conjunction with irrigation and rainfall, we can also calculate how much water is needed to refill the crop root zone at various tensiometer values. For example, at 55 days after planting, both shallow and deep tensiometers were averaging about 40 kPa. The 30 mm of rain on that day nearly filled the profile (indicated by the deep tensiometer falling to about 20 kPa). In an ideal situation, where the producer could irrigate on demand, we would therefore be suggesting that 30 mm of irrigation would be the best guess as to the amount of water to apply, if watering when shallow tensiometer values reached 40-50 kPa. Note that if irrigation is delayed, then the amount of water needed to fill the root zone increases. For example, when shallow tensiometer values were allowed to reach 70 kPa between 9 and 12 weeks after planting, 30 mm irrigations were not sufficient to refill the profile and cause the deep tensiometer values to drop.

By assuming the water holding capacities of the root zone at various tensiometer values, we can then estimate the amount of irrigation or rain that will have drained (or run-off) if that amount is exceeded. By knowing the amounts of water applied, and the quantities lost through drainage or run-off, we can then calculate water used by the crop (evapotranspiration) using a simple water budget approach. In the example shown in Fig. 2, during the stress period between 55 and 81 days after planting, the crop received 60 mm of irrigation and 27 mm of rain, with no evidence of drainage or run off. There was little difference in soil water storage at the beginning and end of this period, therefore we can calculate that the average evapotranspiration was 3.3 mm/day. This is probably 15-25% less than expected at that time of year.

These patterns of analysis were used in all the experiments and on-farm demonstrations where information was available. With the Demonstrations, it was substantially easier where tensiometers were read every 1-2 days, compared to where we had to estimate many of the tensiometer values. Examples of complete interpretations are given in Appendices 1-5.

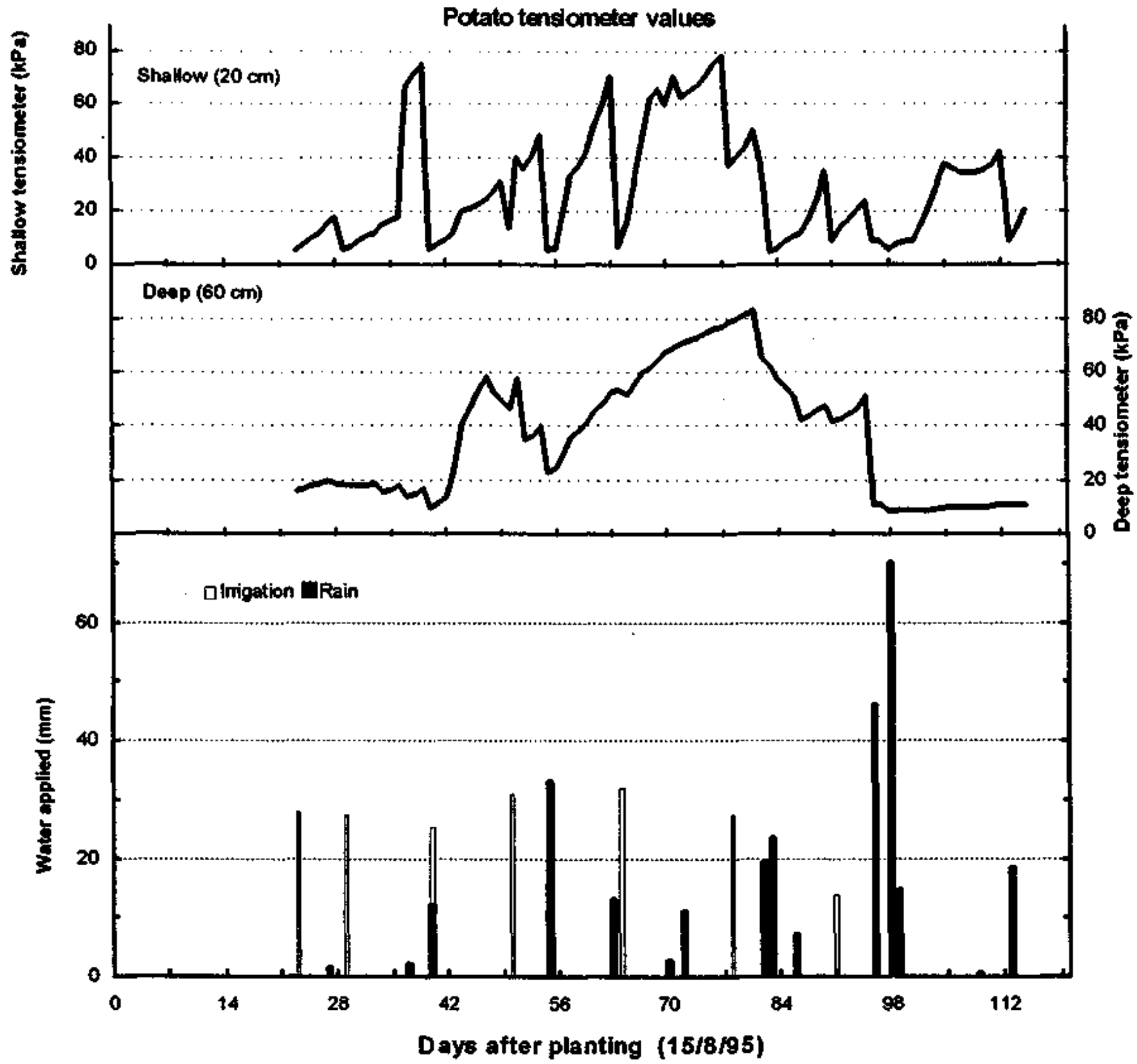


Figure 2. Example of tensiometer changes and irrigation regime in a potato crop.

This example shows how we can use a tensiometer monitoring system to precisely apply water in relation to actual crop needs; optimising the efficiency of water use while maximising crop yields and quality. Further examples can be found in each of the individual experiment reports. It is very important to note that there is no substitute for experience and persistence in developing a tensiometer-based irrigation scheduling system. It does take time to become confident with handling, installing and operating the equipment. It also takes time to determine the optimum irrigation response to a given set of tensiometer values in a particular crop/environment combination. The results from this project provide guidelines for irrigation management, however each vegetable producer would have to adapt the techniques and critical irrigation values for their individual crops, soils, weather and irrigation systems.

Detailed experimental work

Potatoes

An outline of our research and conclusions into irrigation management in potatoes is described in Appendix 6 'Irrigating potatoes for optimum performance'. It discusses the responses of the different potato plant growth stages to water stress and irrigation; the benefits of irrigation scheduling, and outlines a system for irrigation scheduling in potatoes. It gives an example irrigation program for potatoes grown on black earth soils in southern Queensland, which producers can adapt for their particular environment and equipment.

Experiment summary

A detailed description of the single detailed experiment conducted on potatoes during this project is given in Appendix 1. Due to a labour shortage, separation of irrigation treatments did not start until 76 days after planting (DAP), well into the yield formation growth stage. The treatment period involved the last 8 weeks prior to harvesting the potatoes, with no irrigation during the maturation period 2 weeks before harvest.

The drip irrigation treatment was watered every 3 days, whilst the wetter of the sprinkler-irrigated treatments received 5-6 irrigations during the same period (Table 4). The drip irrigation treatment was watered at lower shallow tensiometer values, with both the SPR30 and SPR45 treatments irrigated at values of 45 kPa. The drier sprinkler treatments were irrigated less frequently, and consequently reached higher peak tensiometer values between irrigations. There was minor deep drainage associated with excess irrigation in some treatments.

Table 4. Peak values of shallow and deep tensiometers installed in a potato crop increased as irrigation frequency declined.

Treatment	Peak shallow tensiometer values (kPa)	Peak deep tensiometer values (kPa)	Number of irrigations during treatment period	Total water applied during treatment period (mm)	Deep drainage
DRP30	30	50	14	178	no
SPR30	45	40	6	189	yes
SPR45	45	40	5	158	no
SPR60	55	40	3	107	no
SPR80	60	50	2	114	yes

Total potato yield was greatest for drip-irrigated plots (28.4 t/ha). The best performed sprinkler-irrigated treatment, watered when shallow tensiometers reached 30 kPa, yielded 25.6 t/ha (Fig. 3). As critical tensiometer values and intervals between irrigations increased, yields declined. The 80 kPa treatment yielded 21.6 t/ha. Yields from both 60 kPa and 80 kPa treatments were significantly less than that from drip-irrigated potatoes.

Higher yields in better performing plots were due to increased production in heavier weight grades (Fig. 3), particularly in the 3 grades >200 g. Shorter intervals between irrigations, and thus greater total irrigation, increased the proportions of initiated tubers that made larger size grades. The total number of tubers initiated and harvested were relatively similar across all 5 treatments. There were no important effects of irrigation treatment on average sizes of potatoes within each size grade.

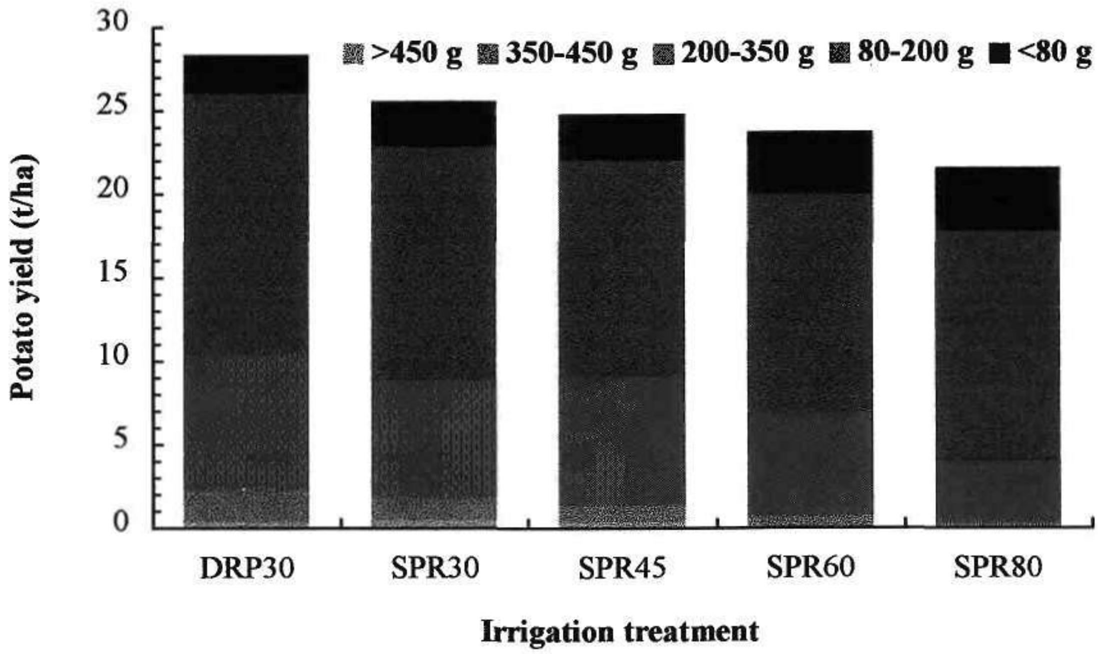


Figure 3. Increasing the critical tensiometer value for initiating irrigation reduced the total weight of tubers in grades greater than 200 g in weight.

Best yields in this experiment (≅28 t/ha) were substantially less than normally achieved in experiments at Gatton Research Station. We suspect this was due to poor quality water we were forced to use because of the prolonged drought. This may have particularly affected tuber initiation, as the total number of tubers harvested was around 25% less than recorded in previous experiments. Higher yields from drip-irrigated potatoes may also have reflected inherent advantages of this system when using poor quality water. Leaching of salts away from drip lines is readily achieved, while leaves are not damaged by continual evaporation of high salinity water on their surfaces.

In this experiment, tuber yields declined as the critical value increased above 30 kPa. In previous experiments, a value of 40-45 kPa for triggering irrigation has been optimal. It may be that where poorer quality water is used, this critical tensiometer value needs to be reduced. Note that yield differences between 30 kPa and 45 kPa treatments (<1 t/ha) were minor.

Due to the late imposition of irrigation treatments, yield differences reflected tuber sizes rather than tuber numbers. No doubt, if irrigation stresses had occurred earlier, yield variation between treatments could have been more substantial.

Irrigation program for potatoes

Following a water budget approach, a potato crop should only use 30-40% of the available soil water in its root zone before irrigating. On the alluvial soils of the Lockyer Valley, research has shown potatoes should be irrigated according to the following schedule:

(i) For the first month after planting (minimise irrigations between planting and emergence), irrigate after the crop has used ≅15 mm.

(ii) For the following month allow 20-25 mm water use between irrigations.

(iii) From then until the maturation stage, irrigate when the potatoes have used 30-35 mm.

For potato producers wishing to use tensiometers to schedule irrigation, a tensiometer site should include the following. One tensiometer is installed 20 cm below the surface of the hill, and another tensiometer 60 cm below the top of the hill. Both tensiometers are placed midway between plants within the row, with at least 2 tensiometer sites per 5 ha of potato planting. Tensiometers should be read daily, or at least every 2 days, preferable at the same time each morning (best between 7 and 9 am).

Overseas data suggests that for maximum production, potatoes should be irrigated when tensiometer values in the root zone reach 30-50 kPa. Our investigations in southern Queensland confirm that optimum production occurs if potatoes are irrigated when values for shallow tensiometers reach ≅40 kPa. Lower critical tensiometer values should be used in warmer conditions with high evaporative demand, or on sandier textured soils such as sandy loams. These critical levels are only guides; potato producers can develop different criteria for commencing irrigation as they become familiar with their irrigation and crop water use patterns. An average value for the total amount of irrigation required to produce an optimum potato crop in southern Queensland is ≅350 mm (ie. 3.5 ML/ha) on the ground. Producers may have to pump a greater water volume, to take into account evaporative losses and other inefficiencies in their irrigation systems. Obviously any rainfall would reduce requirements, although there may still be a need to irrigate for other purposes, such as frost control, fertiliser or pesticide incorporation. Irrigation regimes will also be affected by cultivar selection and agronomic practices.

In Queensland, frequent irrigation for maximum yield results in large bushes with substantial leaf canopies. This may create a micro-climate more favourable for diseases such as *Sclerotinia, Alternaria*, etc. Potato producers need to take this into account in their pest management programs.

Too much available nitrogen at planting can delay tuber set and increase the number of small tubers. It is advantageous to have multiple N applications during the growing period, particularly on sandier soils with lower nutrient retention capacities. A nutrient monitoring program, involving pre-plant soil testing and in-crop tissue or sap testing is recommended to be used in conjunction with irrigation scheduling, in order to optimise crop performance and minimise leaching losses.

Potatoes are classified as moderately sensitive to soil salinity; overseas research suggests a 25% yield reduction where irrigation water has an electrical conductivity of 2.5 mS/cm. In practice, some producers have successfully grown potatoes with water of this quality, provided adequate leaching occurs.

Where irrigation water is limited, the potato growing enterprise should maximise yields over a reduced area, rather than spread the limited water supply over larger areas. In humid regions with more frequent rainfall, producers may be more willing to risk the chance of timely rainfall. If irrigation per unit area is restricted, irrigation should cover the most critical periods (tuber initiation and bulking), with selection of cultivars more tolerant of water stress. Potatoes are more tolerant of stress during the early vegetative growth stage and late tuber bulking. Water deficits can be allowed immediately prior to and during maturation. This makes harvesting easier, improves the dry matter content of tubers, and makes full use of stored soil water. Soils should not be allowed to dry excessively during this period, otherwise harvesting becomes difficult, with bruising and tuber damage more likely.

Because of high fertiliser requirements, there are significant risks of groundwater contamination where excessive irrigation occurs in potatoes. In sub-humid and humid production areas, it may be important to leave a reserve of unfilled soil water storage, to act as a buffer against leaching rains. This can be achieved by growing potatoes after a deep-rooted crop (such as forage sorghum) used to dry out the soil profile, and/or deficit irrigation (not completely refilling the root zone at each irrigation).

As producers are aware, timing and amounts of irrigation are influenced by factors other than soil moisture and plant water requirements. Irrigation must be incorporated in the whole crop management program, taking into account; application of herbicides, fungicides, insecticides and fertilisers; cultivation; field access, harvesting, etc. The decision to irrigate is affected by the type of irrigation system used, the availability of labour, and the availability of water. The presence of foliar diseases such as *Alternaria* or *Sclerotinia*, may influence the irrigation pattern. Potato producers may wish to apply sufficient water to get a small amount of drainage at each irrigation. This is essential when using poor quality water; the saltier the water the more leaching is required at each irrigation. By irrigating to achieve a small amount of drainage beyond the root-zone, the interval between irrigations can be slightly extended. This is because (a) such a policy ensures the root-zone is completely filled and (b) some water will move back up into the root-zone from the subsoil via capillary action. In many situations this can be a viable irrigation strategy, provided the drainage is not excessive.

Onions

Experiment summaries

Detailed descriptions of experiments conducted on onions during this project are given in Appendices 2 and 3. In the first study, the irrigation treatment period extended from 5 weeks after sowing until the bulbs were harvested 23 weeks after sowing. In the second experiment, the period until onions were harvested was extended by an additional 2 weeks.

In the first experiment, the drip irrigation treatment was watered every 3-4 days, however the shallow tensiometer values still rose to 60 kPa on occasions (Table 5). At about 12 weeks after sowing, the deep tensiometer readings started to rise, and eventually reached values of 70 kPa. In contrast, shallow tensiometer values in the most frequently irrigated sprinkler treatment reached a maximum of 40 kPa between irrigations, and the deep tensiometer readings stayed around 30-40 kPa for most of the growing period. The 3 other sprinkler irrigated treatments had peak readings for their shallow tensiometers closely related to their target values, whilst the deep tensiometer readings rose steadily during the growing period. In no treatment was there excessive irrigation leading to deep drainage.

Table 5. Peak values of shallow and deep tensiometers installed in an onion crop increased as irrigation frequency declined.

Treatment	Peak shallow tensiometer values (kPa)	Peak deep tensiometer values (kPa)	Number of irrigations during treatment period	Total water applied during treatment period (mm)	Deep drainage
DRP30	60	70	32	340	no
SPR30	40	30-40	20	452	no
SPR45	50	40-50	19	418	no
SPR60	60	40-50	14	367	no
SPR80	70-80	40	9	322	no

Onion yields were greatest for the SPR30 (76.9 t/ha) and SPR45 (79.0 t/ha) treatments (Fig. 4). The drip and SPR60 treatment yields were similar at ≅68 t/ha. At 55 t/ha, yield of the SPR80 treatment was significantly less than maximum. There were no significant differences in the total number of onion bulbs harvested from each treatment. However, the higher yielding treatments had more onions in the larger grades and fewer picklers. As a consequence, the SPR30 and SPR45 plots had the greatest yields of #1 grade and #1 large onions, and the lowest yield of picklers (Fig. 4).

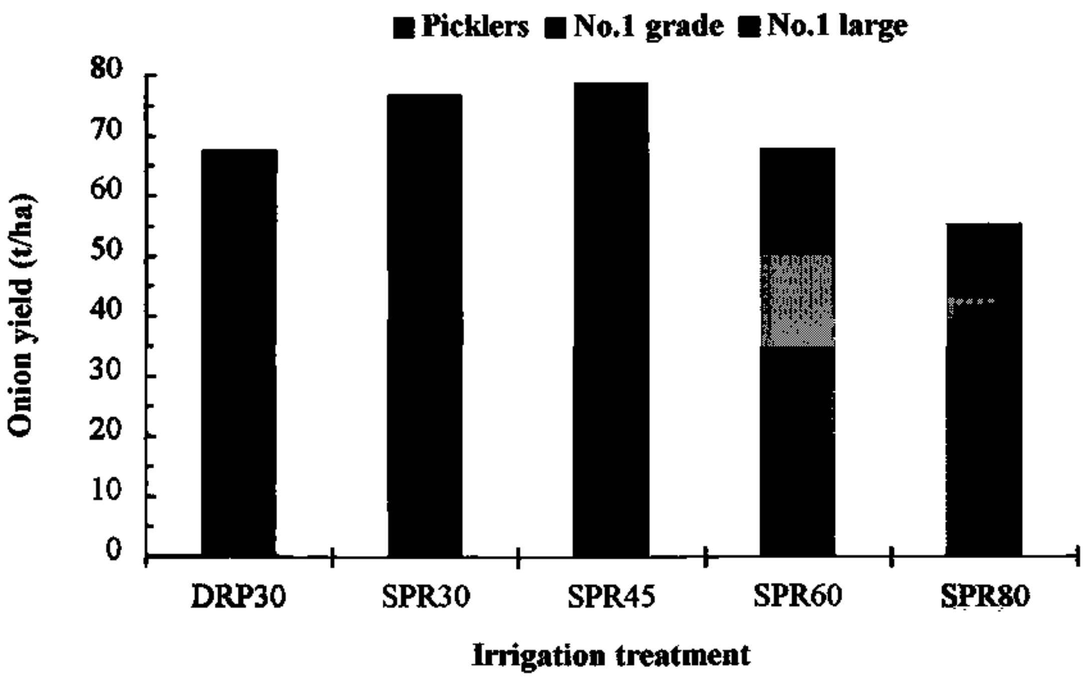


Figure 4. Increasing the critical tensiometer value for initiating irrigation reduced yields of large onion bulbs.

Maximum yields in this experiment (≅80 t/ha) were good considering the poor quality of irrigation water. In this experiment, onion yields and mean size declined as the critical value increased above 45 kPa. The sub-optimal performance of the drip-irrigation system may have been due to clogging of emitters with calcium deposits. This resulted in uneven distribution across the bed, with subsequent poor performing sections of crop. This problem can be overcome by regularly flushing a weak acid solution through the system.

In the second experiment, we were forced to rely completely on drip irrigation, because of the severe water shortage.

Tensiometer peaks for both shallow and deep instruments increased as irrigation frequency declined (Table 6). The second planting required more irrigations than the first planting to maintain similar tensiometer values, reflecting warmer conditions during the latter part of the growing period. In no treatment was there excessive irrigation leading to deep drainage.

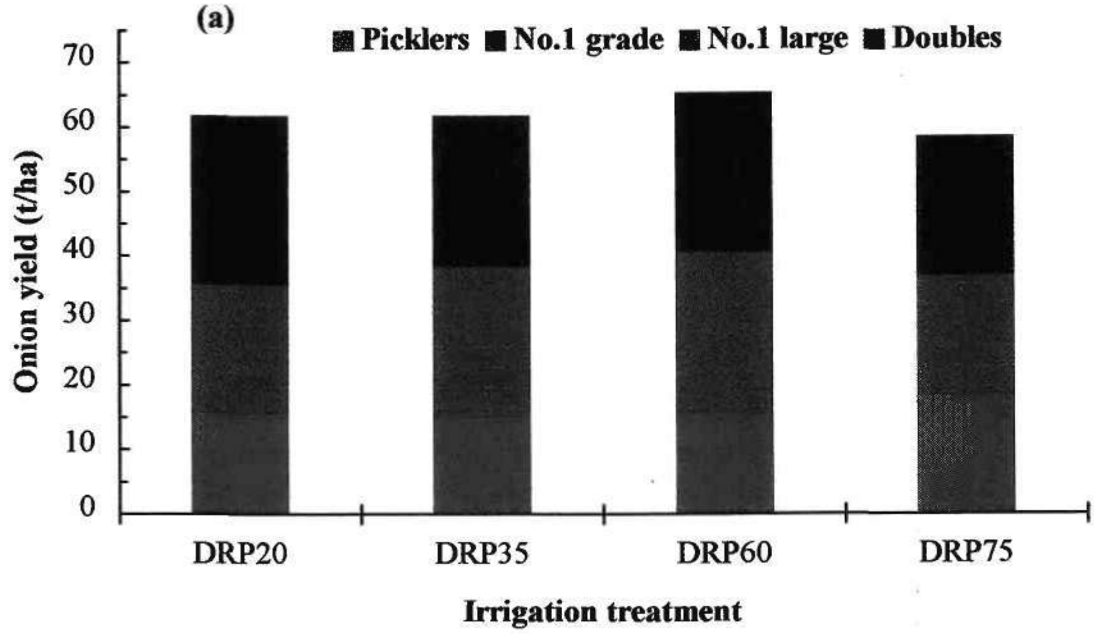
Table 6. Peak values of shallow and deep tensiometers installed in an onion crop increased as irrigation frequency declined.

Treatment		Peak shallow tensiometer values (kPa)	Peak deep tensiometer values (kPa)	Number of irrigations during treatment period	Total water applied during treatment period (mm)
DRP20	Planting 1	20	40	32	368
	Planting 2	20-30	50	35	452
DRP35	Planting 1	40	40	25	311
	Planting 2	60	50	31	407
DRP60	Planting 1	60	40	14	199
	Planting 2	60	40	21	276
DRP75	Planting 1	70	50	13	158
	Planting 2	75	75	19	270

In Planting 1, yields were maximised in the 35-60 kPa treatments, although the yield decline in the least irrigated plots was not significant (Fig. 5a). There were significantly greater yields of No. 1 and No. 1 large onions in the 35-60 kPa treatments, compared to onions irrigated at 75 kPa. This was because there were significantly more of those larger onions in the wetter treatments, while the 75 kPa treatment had more pickling grade onions

In Planting 2 the 20 kPa treatment gave the highest yields, with no significant differences between the other 3 treatments (Fig. 5b). Analyses of the data show consistent trends for a greater proportion of small onions in the drier treatments, ie. 20% picklers/No. 1 grade in 20-35 kPa plots, 25% in 60-75 kPa plots.

In both plantings there was an extraordinarily high proportion of 'double' onions (35-40%), mainly in the larger size bulbs. In both plantings there were trends for a greater proportion of 'double' onions in the more frequently irrigated treatments. According to literature, some cultivars are more prone to doubling than others. It also seems to be exacerbated by high temperatures around sowing time, and high nitrogen and irrigation inputs. Dry matter levels were 10-11% in Planting 1 and 9-10% in Planting 2, and were unaffected by irrigation management.



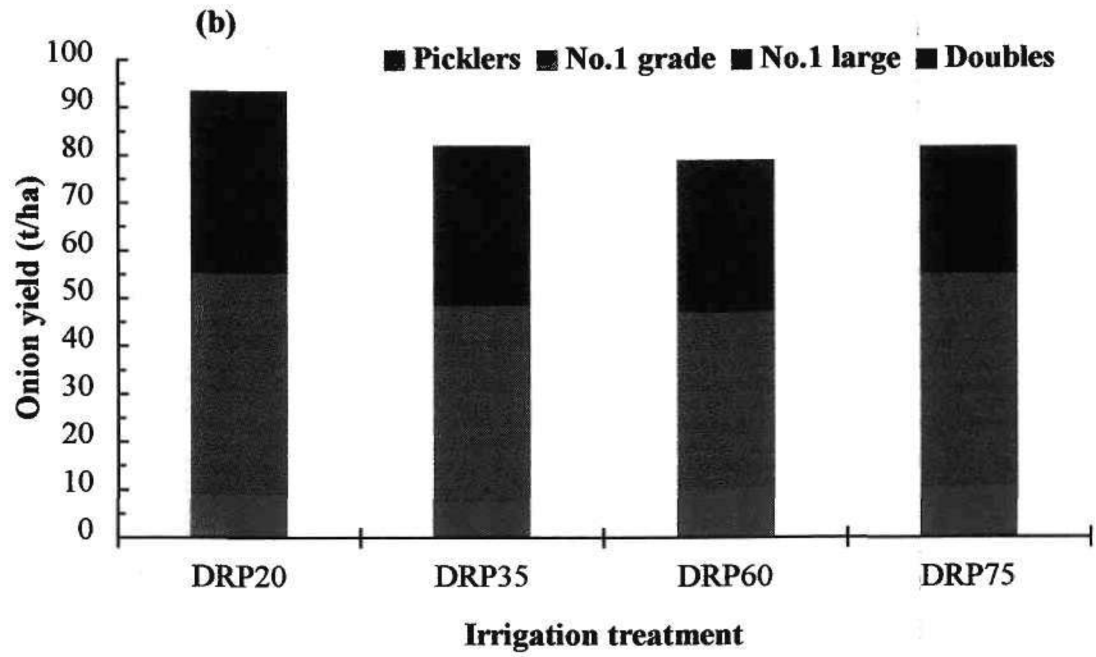


Figure 5. Increasing the critical tensiometer value for initiating irrigation slightly affected yields of onions in a range of size grades, in experiments sown on (a) 23 March 1996 and (b) 4 April 1996.

The higher yields in Planting 2 reflected slightly more onions, and marginally higher individual average weights in each size grade. From cultivar performance studies conducted at Gatton Research Station, yields of *Golden Brown* are known to decline as sowing dates are pushed earlier into mid-March.

In previous experiments it has been shown that maximum onion yields are obtainable using a critical figure of ≅40 kPa for tensiometers installed 15 cm below the soil. The results from both experiments tend to bear out this strategy, although with an extremely high proportion of 'double' onions in the latter experiments, conclusions are difficult. By using tensiometers, we were able to eliminate drainage due to excessive irrigation.

In most instances, 20-25 mm of irrigation on any one occasion is sufficient to maximise yields in a sprinkler irrigated crop, with a return interval of 5-7 days. In situations where poor quality water is used, the critical tensiometer value may need to be reduced and the irrigation quantities increased. Using drip irrigation, irrigating with 12-14 mm every 4-5 days gave optimum yields.

On-farm irrigation monitoring

The methods used to interpret data from the Demonstrations are detailed earlier in this report. Examples of the complete interpretations for individual sites, as provided in written reports to collaborating producers, are given in Appendix 4 (potato) and Appendix 5 (onion). The following discussions summarise the findings from the full complement of completed Demonstrations. Note that the full suite of data were not available from all Demonstrations.

Irrigation regimes and crop responses

In this study, potatoes and onions were grown on soil types ranging from loamy sands to heavy clay loams (Table 7). Climatic conditions also varied, from cold periods in the Lockyer Valley in mid-winter, to warm spring weather at Redland Bay. Irrigation systems used to water the crops were either hand-shift or solid-set overhead sprinklers. Rainfall during the Demonstration periods ranged from nil, to amounts such that very little irrigation was required.

Table 7. Summary of environmental, management, irrigation, water balance and crop performance parameters for the 16 completed Demonstrations of irrigation management in fresh-market potatoes and onions in southern Queensland. ***Note that to preserve anonymity of collaborating producers, the sequence of presentation is unrelated to the order shown in Table 3.***

Demo.	Soil type	Growing season	Irrigation system	Demonstration period rainfall (mm)	Peak tensiometer value before irrigation (kPa)	Average irrigation interval (days)	Average irrigation (mm)	Average root-zone water capacity (mm)	Average daily crop water use (mm)	Time between tensiometer readings (days)
Potato										
A	Loam	Autumn	Solid-set	42	70	6	25	30	4.6	1-2
B	Clay-loam	Winter	Hand-shift	-	80	13	30	30	2.3	3
C	Loam	Spring	Solid-set	-	50-60	9	30	30	3.3	4
D	Loam	Spring	Solid-set	-	40	9	30	25	3.3	4
E	Clay-loam	Autumn	Hand-shift	-	40-80	8	35	30	3.8	2
F	Clay-loam	Winter	Solid-set	72	60-80	8	30	25	3.5	1-2
G	Clay-loam	Winter	Solid-set	72	50-60	7	25	25	3.5	1-2
H	Loam	Winter	Solid-set	-	50	10	30	30	3.0	2-3
I	Loam	Winter	Solid-set	-	60-70	11	30	30	2.7	3-4
J	Clay-loam	Spring	Solid-set	-	60	11	30	30	2.7	3
K	Loamy sand	Winter	Solid-set	-	50-60	12	25	20	1.7	3
Onions										
L	Clay-loam	Autumn	Hand-shift	70	60-70	10	25	25	2.5	2-3
M	Sandy-loam	Winter	Solid-set	108	50	4-5	15	20	3.0	1-2
N	Clay-loam	Winter	Solid-set	57	70-80	10	30	20	2.5	2
O	Clay-loam	Winter	Solid-set	57	70-80	9	20	20	2.1	2
P	Clay-loam	Spring	Hand-shift	66	80	8	30	25	3.0	3-4

In this study with fresh-market producers of potatoes and onions, there was a broad range of shallow tensiometer values at which irrigation was started, and a wide range of intervals between irrigations. Some producers started irrigating once shallow tensiometer readings reached 40 kPa, whilst values in other producers' crops consistently reached 80 kPa. Average peak values for shallow tensiometers were 60 kPa in potatoes and 70 kPa in onions. These values contrast with a similar study conducted with crisping potato producers, where most were watering once shallow tensiometers were reading 50-60 kPa. In crops on sandier soils, or those grown in warmer weather, the tensiometer values tended to rise rapidly between irrigations. This meant the values could increase from 40 kPa to 70 kPa over an interval of 1-2 days. Provided shallow tensiometer values were not above 60-70 kPa for extended periods of time, these levels of water stress were unlikely to have adversely affected crop yields or quality. In well-grown potato or onion crops, because shallow tensiometer values increase so rapidly between 40 and 60 kPa, it does not particularly matter what value in this range is used to trigger irrigation. The decision to irrigate will only vary by 1-2 days, irrespective of whether low or high values are chosen. However, extended periods over 50-60 kPa, particularly accompanied by steadily rising deep tensiometer values, should be avoided.

Of the monitored crops, Demonstrations B and K had periods where potatoes may have been under significant water stress during sensitive growth stages. In Demonstration B, the producer made a deliberate decision to delay irrigations in the final stages of the growing period, as he was extremely short of water to finish off his planted area. Demonstration K was on a loamy sand soil, which was difficult to manage. It tended to crust readily, with low infiltration capacity, and the potato crop was growing relatively poorly. Many of the onion crops were not irrigated at the ideal time, with irrigation delayed until shallow tensiometer values reached 60-80 kPa. It is unlikely that any of these 1-3 day delays in irrigation substantially affected bulb yields or quality. In Demonstrations N and O, insufficient irrigation during the latter 4-6 weeks of the growing period may have slightly reduced yields.

There were no clear correlations between growing season, and the tensiometer values at which the decision was made to irrigate. In the loams and coarser textured soils, irrigation was initiated when shallow tensiometer values reached 55 kPa on average, whereas for the clay-loam soils, the average value was closer to 70 kPa (Table 7). There were slight trends for higher tensiometer values where hand-shift irrigation systems were used, due to slightly longer intervals between irrigations. Because of the greater effort involved in irrigating with these systems compared to solid-set sprinklers, this was not an unexpected result.

One of the major benefits of using an objective soil water monitoring system is that it enables sensible accounting of the value of intermittent rainfall. A good example is in Demonstration O, where the irrigations could be omitted with confidence that the soil profile had been fully wetted by 15 mm of rain.

Irrigation patterns

In contrast to our findings in the crisping potato producer study, in this project we did not find any major differences in irrigation intervals nor average irrigation quantities between solid-set and hand-shift systems. Both systems were averaging 26 mm of irrigation every 9 days in potatoes and onions (compared with 25 mm every 7 days for crisping potatoes). Solid-set systems have the most flexibility in terms of frequency and amounts of irrigation applied. A number of the fresh-market potato and onion producers who had solid-set systems did not appear to be taking full advantage of their equipment. Irrigation was delayed several days past optimum, with consequent risk of crop stress. Because of the higher labour and operational requirements, it is reasonable that irrigation intervals where hand-shift systems are used would be longer.

Crop water use

Using the process described earlier, we calculated the average daily crop water use during the monitoring period for each of the Demonstrations. The expectation would be for values around 3 mm/day for good crops grown during cooler periods, increasing to 4-5 mm/day for crops grown in warmer weather. Most of the potato crops fitted this scenario, although Demonstrations B and K were below the expected values (Table 7). Values below 3.5 mm/day for potatoes are probably marginal, and would indicate a risk of sub-optimal crop performance, except in conditions of low evaporative demand. Of the onion crops, the low water use values of 2.1-2.5 mm/day for several Demonstrations also indicate some problems with crop growth. In conjunction with extended periods of high tensiometer readings, low water use values indicated problems with irrigation management. In situations where there are low water use values, but not high tensiometer values, it suggests some other factors (eg. nutrition, pests/diseases, poor plant stands or planting arrangements) are affecting crop performance. These other factors may have impacted in Demonstrations E, K and M, and have certainly been evident in other studies we have conducted with fresh market potato producers' situations (Jackson *etal* 1993).

Irrigation efficiency

Matching the amount of irrigation to what the root zone can hold is another important component of irrigation management. As noted in the section on interpreting the results, we can calculate the average root zone water capacity for each of the Demonstrations, based on the change in deep tensiometer values following irrigation or rain. In almost all instances, these values ranged from 20-35 mm of water storage available in the root zone of a well-grown potato crop, and 20-25 mm for a well-grown onion crop due for irrigation. If irrigation is delayed, and hence more water is extracted from the soil, then this water storage capacity will obviously rise, however there is also increased risk of crop stress.

We had observed in previous studies that fresh market producers of potatoes and onions often waited too long between irrigations, but then over-irrigated when water was applied. In this project, there were several instances of irrigation in excess of soil storage capacity (Demonstrations E, F, K, L, N and P). On most occasions this deep drainage was not substantial. However, deep drainage was around 0.3 ML/ha during the monitoring period in Demonstration E, and 0.75 ML/ha in Demonstration N. In situations where hand-shift systems are used, it may be a valid strategy to slightly over-irrigate. By irrigating sufficiently to get drainage below the root-zone, the interval between irrigations can be slightly increased, with reductions in labour and management requirements. This is because such a policy ensures the root-zone is filled, and a proportion of the excess water can move from the sub-soil, back up into the root-zone under capillary rise. At Demonstrations A, B and M, a little more water could have been applied, to fully wet the root zone and thus increase the time between irrigations. Given the drought situation present at the time, leaving a drier subsoil can be a valid strategy to try and make most efficient use of any rainfall that does occur.

In our studies with fresh market producers, in very few circumstances (even warm weather and clay soils) could single irrigations of more than 40 mm be justified, unless the crop had been under severe water stress for an extended period, and forced to extract most of the water from its root zone. In some instances, we found fresh market producers were applying 50-60 mm of irrigation in a single application, of which 15-25 mm was being wasted.

Irrigation effects on produce yields and quality

Average fresh market potato yields in southern Queensland are currently around 23-25 t/ha. In general, tuber yields of crisping potato producers are substantially higher; mean yields from the crops monitored in a separate project were around 34 t/ha of marketable product. Although Atlantic (the predominant crisping cultivar) is high yielding, most of the production increases can probably be attributed to more careful management of the potato crop. The relatively efficient and effective irrigation practices of the crisping potato producers tends to bear this out.

Tuber quality is becoming more important in the marketing of fresh-market potatoes. Sectors in the marketing chain are becoming more exacting in their requirements with regard tuber size and shape, and the presence of internal and external defects. By optimising plant stands and as far as possible maintaining even growing conditions, without major fluctuations in soil water levels, most potato producers should now be able to dig tubers with good shape and size. The most significant quality problem of recent times has been the appearance of internal brown fleck, with no defined cause or explanation for its occurrence.

The occurrence of internal brown fleck can be very serious, as it can mean total rejection of the tubers. Although it is often associated with moist warm soil conditions at maturity, this is not always the case. There also appears to be a tie-up with nutrition, particularly calcium and possibly boron (Harper, pers. comm.). This should be a priority area for study for the fresh market industry, and probably for crisping producers as well.

Although average onion yields in southern Queensland (about 40 t/ha) are well below those achieved in experimental plots, probably only a small proportion of this can be attributed to irrigation management. Provided plant spacing and density are appropriate, most plants should produce a marketable onion bulb. Irrigation management generally affects the size of the bulb; we commonly find that more effective irrigation increases the proportions of #1 and #1 large onions, with a consequent yield improvement.

The most important impacts of irrigation management on onion production (apart from concerns about maximising water use efficiency and minimising deleterious environmental effects), are interactions with plant diseases, crop nutrition, and onion bulb quality. In our experiments we did not find any evidence of increased incidence of diseases such as downy mildew with more frequent irrigation. There were some minor trends for a slightly greater proportion of 'double' onions in plots that were watered more frequently, however this was neither consistent nor statistically significant. Generally 'doubles' are more evident in larger onions, and increased irrigation promotes larger bulbs. One of the marketing points of onions from southern Queensland is low pungency. I am not aware of any relationship between irrigation management and pungency; this may be a topic worthy of further investigation.

Producer collaboration

As with any group of people, the producers associated with this project varied in their level of interest, and the perceived importance of irrigation management in their situation. There was generally a high degree of initial enthusiasm from most producers. Once the tensiometers were installed in the selected crops, there was a variable level of commitment to reading them and recording the values, as well as measuring and noting irrigation and rainfall. Several producers and/or their staff took tensiometer and other readings every day, whilst most checked them at least every 2-4 days. The producers who took readings very regularly were usually those who already used tensiometers, or who very concerned about some aspect of their irrigation management, believing it was having a significant impact on their production. The overall levels of commitment were probably less than with the crisping potato producers. This may reflect less emphasis on the importance of irrigation management, or less perceived peer group pressure and interaction. Levels of cooperation with producers who did participate were very good, with positive and enthusiastic attitudes on all sides. This is important if such collaborative work is to succeed.

In early 1996, we described the project and findings to date in press releases via local newspapers and radio. As part of the process, we invited any potato or onion producers who were interested in the project to contact me to arrange a Demonstration on their property. We did not have a single response to those general releases. This was not an effective way of gaining collaboration. Much more effective was personally addressing group meetings, mentioning the project at field walks, or relying on informal producer networks to 'spread the word'. It was also very evident that it was only worthwhile working with those producers who showed real enthusiasm for the concept. Half-hearted collaborators tended to let the programs slip if they were not being constantly followed up. Working in such situations was frustrating, inefficient, and unlikely to achieve any long-term, worthwhile outcomes in terms of technology adoption, or improvements in productivity.

Although available for more than 60 years, tensiometers have not been commonly used, because of perceived problems with installation maintenance, use and interpretation. Many of these issues have been overcome with new tensiometer designs and simpler ways of using them. Detailed descriptions of tensiometers and procedures are included in the references mentioned previously; ie. the QDPI booklet 'Water It Right - Irrigation Using Tensiometers' (Daniels *etal*, 1994), an article reprint 'Tensiometers in vegetables made easy' (Henderson 1993a), and a potato irrigation booklet 'Irrigating potatoes for optimum performance' (Henderson 1995).

Apart from the need to monitor the tensiometers regularly, and to realise when they are not working properly, the Demonstrations in this project confirmed the importance of monitoring more than one site per crop. When readings from the 2 sites behave similarly, then the producer can have confidence in the values, even when they indicate soil water conditions are different from those intuitively expected. If, as in some of our Demonstrations, the 2 sites within the crop behave somewhat differently, this can be due to a number of reasons. It may indicate that one of the sets of tensiometers is malfunctioning, in which case the troubleshooting procedures outlined in Appendix 7 should be followed. More often, it indicates that either soil type, crop growth, or irrigation, varies between the 2 locations. In this project we most frequently found differences were caused by variation in irrigation, either intentional (one part of the paddock was watered at a different time to the other, and/or with different amounts), or unintentional (poor irrigation uniformity, blocked sprinklers, etc.) Because of these paddock variability factors, it is very important that more than 1 site is monitored per crop, whatever system of evaluating crop water needs is used.

Monitoring equipment comparisons

In comparing 2 models of tensiometers, the JETFILL® and IRROMETER®, we found no significant differences in their accuracy, robustness or reliability. For users unfamiliar with tensiometers, or those without a vacuum pump, the JETFILL® model, with an active refill and bubble removal mechanism seemed easier to use. It is more expensive to purchase, and less commonly available than the IRROMETER® brand.

On a few occasions, the tensiometer Demonstrations were in relatively close proximity to an ENVIROSCAN® system, operated by local consultants. On most occasions there was very good agreement between the interpretations from analysing the tensiometer or ENVIROSCAN® data. The advantage of the ENVIROSCAN® system was that it contiguously monitored soil water at a range of depths. This meant that wetting fronts and water drainage during and after irrigations could be observed, to see to what depths irrigation was penetrating, and from how deep crops were extracting water. This sort of information is very useful in problem solving and intensive research.

Another advantage of the ENVIROSCAN® system was that it did not rely on the producer or his staff visiting the site every day to take readings; they could be down-loaded by computer on a less regular basis. The disadvantage of this is that the producer is no longer regularly visiting the paddock, and thus may miss some other agronomic issue such as pest or disease incidences. Users also need to realise that such equipment is not infallible, and the crop should still be regularly physically checked. If the ENVIROSCAN® is used to help make irrigation decisions, rather than analyse after the event, then the producer needs to have rapid access to the information. Thus they either need a direct computer line to the equipment, or have the consultant visit on a very regular basis. This was one of the perceived advantages of the tensiometer system commented on by several producers; they could look at the tensiometers themselves and immediately determine whether to irrigate.

Extension/adoption by industry

One objective of the project was to confirm the irrigation requirements of both potatoes and onions, and systems of scheduling irrigation by using tensiometers. This was achieved by conducting the detailed experiments at Gatton Research Station, which built on earlier work in a range of other vegetable crops (including preliminary work on potatoes). Results from these investigations were incorporated in the various extension activities related below.

Another primary focus of this project, with a strong emphasis on technology extension and adoption, was the on-farm Demonstrations of irrigation scheduling techniques to potato and onion producers. At the very least, we were hoping to evaluate their current irrigation management, checking that they met the water requirements for optimum crop growth, without wasting water through inefficient application. If producers recognised that irrigation management was important in their enterprise, then we were also demonstrating a relatively cheap, simple and effective method of irrigation scheduling using tensiometers. Even if producers or their staff did not feel they had the time nor expertise to run such a program themselves, they may have been sufficiently interested to engage a consultant. Currently there are consultants in the region using either tensiometers or the ENVIROSCAN® electronic system in irrigation scheduling.

Potato and onion producers were made aware of the project via talks at field days, group meetings, and press releases to local newspapers and radio stations. Any producer who wished to participate in the project was included. Written reports (eg. Appendices 4, 5) were sent to the collaborating producers after successful completion of individual Demonstrations. As already indicated, each collaborating producer received information on irrigation management in potatoes, as well as using tensiometers for irrigation scheduling. Findings from our Demonstrations were included in extension activities detailed below.

Although many of the collaborating producers were relatively efficient irrigators, they still realise that there is room for adjustment and improvement. One of the key areas is the interaction between irrigation management and the occurrence of brown fleck in potatoes, particularly with regard nutrition (eg. calcium, boron). Another is effects of irrigation management on onion plant health and bulb quality. If producers need to fine-tune their irrigation strategies to overcome some of these problems, then they recognise that an objective method of measuring water status in the plant or soil is required. Some producers will decide to use tensiometers themselves, others will probably opt to use the services of consultants using ENVIROSCAN® or similar technology. Whatever the methods used, the outcome of this whole process has underlined the benefits of more precise irrigation monitoring and management.

Project extension activities

Field walks/days

Note: most field walks are advertised by announcement on local radio, articles in local papers, flyers in local businesses, and in 1996 by issuing individual invitations.

- *Vegetable irrigation* (producers, agribusiness), Cambooya (+handout) 29/5/96
- *Irrigation management in vegetables (broccoli & onions)*, EXPO 14 (+posters) 22-23/5/96
- *Irrigation management : vegetable case studies*, Pomona (+handout) 14/11/95
- *Onion irrigation management*, GRS (+handout) 13/10/95
- *Irrigation management in cabbages and onions*, Thornton (+handout) 1/9/95
- *Onion irrigation management*, GRS (+handout) 11/8/95
- *Drip irrigation in onions*, GRS 17/7/95
- *Onion irrigation management*, GRS (+handout) 19/10/94

General seminars to producers, agribusiness and producer groups

Note: most seminars are advertised by announcement on local radio, articles in local papers, flyers in local businesses, and frequently by issuing individual invitations.

- *Potato irrigation management*, Atherton producers 25/5/95
- *Irrigation scheduling in vegetables*, Mulgowie 7/3/95
- *Potato irrigation management*, GRS 20/5/94
- *Potato irrigation management*, Redlands 4/5/94

Tours, seminars and briefings for select groups (not including overseas visitors)

- Tour of GRS weed/irrigation experiments (Horticulture Conference delegates) 21/8/96
- Briefing on research to Heavy Vegetable QFVG meeting 11/10/95
- Briefing on research to Heavy Vegetable committee meeting 5/12/94
- Tour of GRS weed/irrigation experiments for Horticulture Consultative group 5/5/94

Conferences

- *Irrigation management in potatoes and onions*, paper and poster presented at 3rd Australian Horticulture Technical Conference, Gold Coast 19-22/8/96

Other non-publishing extension activities relevant to producers and agribusiness

- Discussions and explanations of research activities with:
  Local consultants (David Carey, Graeme Thomas, John Hall, Peter Broomhall, Julian Winch, Brendan Nolan)
- Other Australian consultants (Sandra Lanz, NSW; Ian Macleod, Tas; Neil Delroy, WA)
- Other Australian scientists and extension officers
- Rural radio (eg. Judy Kennedy 18/4/96, 29/2/96)

Significant activities with individual growers

- Tensiometer monitoring through a cropping cycle with 12 crisping potato producers (at least two sequential crops for 7 producers), including written reports to producers on findings, conducted 1995-96
- Tensiometer monitoring through a cropping cycle with fresh-market potato producers, and broccoli, cabbage, onion, and lettuce producers, including written reports to producers on findings, conducted 1994-96.
- Answering individual irrigation enquiries from producers and agribusiness, both local and throughout Australia. These may include on-farm visits.

Significant extension publications

- *Written irrigation sections for Agrilink packages* (new cornerstone of written QDPI vegetable extension information) on:
- *Potatoes* (to be released in mid 1997)
- *Onions* (to be released in mid 1997)
- *Tensiometers in vegetables made easy* (QDPI article), updated September 1996
- *Irrigation management in potatoes and onions*, Proceedings of the 3rd Australian Horticulture Technical Conference August 1996
- *Irrigation management in potatoes and onions* poster August 1996
- *Irrigating horticultural crops - be waterwise and be money sensible* (DPINote) August 1996
- *Root-zone tensiometer values for commencing vegetable irrigation in southern QLD* (article for agribusiness) August 1996
- *Irrigating potatoes* (Horticulture Highlights newsletter) May 1996
- *Drip irrigation* (National Marketplace News) March 1996

- *Improving irrigation efficiency in onions* (Onions Australia magazine) November 1995
- *Irrigating onions for optimum yield and quality* (Onions Australia magazine) November 1995
- *Irrigating potatoes for optimum performance* (QDPI booklet) September 1995
- *Irrigation scheduling in vegetables* (video) July 1995
- *Irrigation scheduling* (Chronicle Country) February 1995

Articles contained in HRDC Research Reports (circulated to all Good Fruit and Vegetable magazine subscribers)

- 1995/96 - *Irrigation of potatoes and onions*
- 1994/95 - *Irrigation of potatoes and onions*

Field walk notes

- *Irrigating horticultural crops - be waterwise not money stupid* 29/5/96
- *Improving the irrigation efficiency with tensiometers: vegetable case studies* 14/11/95
- *Onion irrigation management* 9/9/95
- *Onion irrigation management* 11/8/95
- *Efficient irrigation management in cabbages and onions* 1/9/95
- *Onion irrigation management* 19/10/94

General comment

At all field walks, and on almost all extension material, addresses and phone numbers for contacting me to get further information are detailed.

Directions for future research

The detailed experiments at Gatton Research Station confirmed that watering when values for shallow tensiometers reached around 40 kPa was appropriate for obtaining optimum yields of both potatoes and onions. These experiments also enabled approximate schedules for frequencies and amounts of irrigation to be outlined for the 2 crops. Apart from confirming these requirements for other regions and soil types, further research into these broader issues is probably not required.

The influence of irrigation and water availability on produce quality is not so clear cut. Particular examples are internal fleck in potato tubers, a very important issue for both fresh-market and processing potatoes. It can happen without the producer being aware of the problem until the crop is harvested, and can lead to total rejection of the potatoes for sale or processing. In the past 18 months, serious incidences of brown fleck have occurred on several occasions in both fresh and processing crops in southern Queensland. The causes cannot be definitively described, nor can we currently offer a strategy that will guarantee the problem will not eventuate. There may be links with nutrition, particularly calcium and/or boron, however these have not been confirmed. In any case, there may be an interaction with irrigation management as well. A study to identify the main factors causing this internal brown fleck, and then developing ways of minimising its impact, would be very useful for all potato producers.

With regard onions, the interactions between irrigation management and plant diseases, crop nutrition, and onion bulb quality may be worthy of further investigation. For example, the effects of water status on the formation of 'doubles', or on the pungency of onions to be marketed for salads, could be beneficial avenues of research.

From our studies, although many producers were relatively efficient irrigators, they could still benefit from some objective method of irrigation scheduling. Yields of the fresh-market producers were often less than the crisping potato growers, whilst onion yields were also well below experimental potentials. In a few instances there was also evidence of excessive irrigation. It should be noted that rather than just use the tensiometer monitoring to check their current practices, many collaborators actually adjusted their irrigation management almost immediately on the basis of the tensiometer readings. This was generally the case with the more enthusiastic producers. This showed that projects of this type are most effective where they are basically driven by the producers, rather than 'forced' upon them. If HRDC is to fund such projects, their likelihood of success will be very dependent on the level of enthusiasm and commitment by the cooperating producers, both as a group and as individuals.

The transfer of even moderately complex technology to producers can be very difficult. This appears to mainly be because they cannot devote sufficient time to sit and read/digest written information, computer programs, etc. In the context of the fluctuating marketing pressures, inevitable cost/price squeezes, adverse climatic conditions and constantly changing regulatory environments, this is not surprising. Whilst it is very time and resource consuming, we have found that collaborative work, on-farm with producers is the most effective way of extending moderately complicated new technology. In that way, the little hurdles that each producer may encounter can be addressed, without them losing faith in the system because of simple problems that can be readily fixed.

This does not mean that each producer needs individual service from the primary researcher. What it does mean\is that some network, either through consultants, field officers, industry development officers, agribusiness representatives, or even cooperative producer groups, would be of great benefit in transfer and adoption of new technology.

Financial/commercial benefits

The experimental components of the project showed how yields and quality of both potatoes and onions were very dependent on effectively matching water supply with crop demand. Where irrigation is sub-optimal, ie. too infrequent, or of insufficient quantity, quality, then marketable yields suffer. Excessive irrigation is a waste of resources, can affect produce quality, and may also have deleterious environmental impacts.

This project demonstrated to potato and onion producers systems for scheduling irrigation using tensiometers, that are effective and relatively inexpensive. Compared to an electronic monitoring system, the capital costs of tensiometers (around $100 each) is a substantial saving. There is also the advantage that they are simple to use, therefore the producer need not necessarily employ a consultant. Some producers, particularly those commencing new or extensive, high value operations, or with specific irrigation management problems, may benefit from more intensive, expensive, irrigation management systems, in conjunction with expert counsel from an irrigation adviser (public or private). However, for producers irrigation scheduling for the first time, tensiometers are a cost-effective way of developing skills and understanding in the management of water resources in relation to crop requirements.

Adoption of irrigation scheduling technology should result in (a) increased yields and produce quality; (b) lower relative irrigation costs; (c) more efficient use of water resources; (d) conservation of water and land quality through less leaching of fertilisers and pesticides; (e) potential for less pesticide use; (f) potential for higher profits or expanded markets with improved and consistent product quality. Producers have recognised that they need to meet these objectives, not just for their own economic survival, but also because of broader community expectations.

I conducted a simple analysis on the benefits of an irrigation scheduling strategy to potato and onion growers in Queensland, based on gross margins for Lockyer Valley crops. These gross margins are most sensitive to prices and yields, so can only be used as comparative guides. I costed irrigation scheduling at $ 40/ha (eg. 4 tensiometers per 5 ha paddock, monitoring 3 times per week), based on standard depreciation schedules, and labour for maintaining and reading tensiometers. The analysis assumes that no other agronomic changes are necessary as a result of changing irrigation regimes. Increased harvesting and post-harvesting costs associated with yield increases are taken into account. I used a standard cost/benefit computer package for analysing both on-farm and across-industry situations.

For potatoes, other assumptions included; current on-farm price of $250/t; yields 27 t/ha; yield increase from scheduling of 10%, price increase (due to reduced wastage) of 5%, and 30-50% adoption by producers after 5 years. The assumptions for onions included; current on-farm price of $250/t; yields 32 t/ha; yield increase from scheduling of 5%, price increase (due to larger sizes) of 5%, and 30-50% adoption by producers after 5 years. These yield and price increases, rates and time-frames of adoption are all conservative.

Using these values, the net benefit to irrigation scheduling in potatoes is then $802/ha to producers, and to society as a whole (taking into account increased price to the consumer) $462/ha. The benefit of irrigation scheduling to onion producers is $602, and to society $208/ha.

The net present value of adoption of the research is around $2,700,000, and the return on research funds about 130:1. This analysis ignores the marketing, resource use and environmental benefits referred to earlier.

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Appendix 1. Report on 1994 potato experiment

Experiment Report No. P1452.02 30/6/94-9/11/94

Irrigation Scheduling in Potatoes

by Mick Webber and Craig Henderson
QDPI Gatton Research Station

Summary

An experiment investigating relationships between potato yields and irrigation regimes was conducted at Gatton Research Station during June-November 1994. Potatoes (cv Wilwash) were grown using standard agronomy, with 5 irrigation treatments replicated 3 times in a RCB design. Plots were 4.5 m wide and 10 m long, with a total experimental area of 0.075 ha. One treatment was irrigated by drip tape; the other four used overhead mini-sprinklers, in which irrigation was commenced at different Critical Tensiometer Values (T kPa). This value was obtained from tensiometers installed 20 cm below hilltop level in each plot. The T values were; 30 kPa; 45 kPa; 60 kPa and 80 kPa. Irrigation differences were applied only during the yield formation period of the potato crop.

Yields for this experiment were substantially less than usually achieved at Gatton Research Station. This may have been due to poor quality water caused by the prolonged drought. Due to the late application of the various treatments for this experiment, yield differences reflected tuber sizes rather than tuber numbers. Total potato yield was greatest for the drip irrigated treatment (28.4 t/ha). Yields declined as critical tensiometer values, and thus the intervals between irrigations, increased. The best performed sprinkler-irrigation treatment was with T at 30 kPa (yield 25.6 t/ha), with 80 kPa yielding least (21.6 t/ha). Total numbers of tubers initiated and harvested were relatively similar across all treatments. Increased proportions of tubers in heavier weight grades produced higher yields in the better performing plots. Shorter irrigation intervals and thus greater total irrigation increased the number of initiated tubers that made larger size grades.

Higher yields of drip irrigated potatoes may have reflected inherent advantages of this system when using poor quality water. Leaching salts away from drip lines was readily achieved, while leaves were not damaged by continual evaporation of high salinity water on their surfaces. In this experiment, tuber quality declined as the critical value increased above 30 kPa. In previous experiments, a value of 40-45 kPa for triggering irrigation has been optimal. It may be that where poorer quality water is used, this critical tensiometer value needs to be reduced. Yield differences between 30 kPa and 45 kPa treatments (<1 t/ha) were minor.

This experiment confirmed the value of using tensiometers to schedule irrigation in potatoes. Using a critical figure of ≅ 40 kPa for tensiometers installed 20 cm below the top of the hill will maximise yields in a sprinkler irrigated crop. In most instances 25-35 mm of irrigation on any one occasion is sufficient, with a return interval of 5-7 days. In situations where poor quality water is used, the critical tensiometer value may need to be reduced and the irrigation quantities increased.

Relevance to industry

In many regions, including the Lockyer Valley, irrigation demands regularly exceed the reliable capacity of the water supply, resulting in scarcity or reliance on poorer quality water. In many vegetable enterprises irrigation is a significant proportion of overall production costs. Potatoes are a major water user, requiring 4-6 ML per hectare per crop. Until recently, frequency and amounts of irrigation were relatively ad-hoc, based on tradition and producer experience, combined with superficial observations of plant or soil conditions.

Some vegetable producers use tensiometers or neutron probes to monitor soil water status and schedule irrigations. More recently, an electronic logging system based on capacitance probes, is being employed by larger scale enterprises. These methods have advantages and disadvantages, however tensiometers appear to have the best immediate potential for use in potatoes in southern Queensland. Most water uptake in potatoes occurs in the upper 0.4-0.5 m of the soil profile.

Matching irrigation to crop requirements maximises production by minimising plant water stress, nutrient deficiencies and some diseases, as well as preventing build-up of salinity problems. By preventing over-watering, problems with leaching of nutrients and pesticides into groundwater (and beyond the zone of usefulness) are reduced, as well as a decrease in disease levels. Monitoring of growers' crops in the Lockyer Valley suggests there are substantial productivity and irrigation efficiency gains possible from improving irrigation.

Objectives

This experiment investigated and demonstrated the relationship between potato yields and tensiometer values under various irrigation regimes. It also attempted to determine the efficiency of scheduling systems, by quantifying the amounts of applied water draining beyond the root zone during the potato growing period.

Materials and methods

The experiment was conducted on a black earth soil (*Ug5.15*) at Gatton Research Station (lat. 27°33'S, long. 152°20'E). The experimental design was a randomised complete block, with 5 irrigation treatments replicated 3 times. Each plot was 6 potato rows (4.5 m) wide and 10 m long.

The soil was prepared as per standard practice for potatoes. Cv. *Wilwash* were planted on 30 June 1994, with 0.75 m between the rows and 0.25 m intra-row spacing. A total of 400 kg/ha of compound fertiliser (52 kg N, 9 kg P, 53 kg K, 75 kg S) was broadcast immediately before planting. A side dressing of 100 kg N/ha as urea was applied on 19 August 1994, 49 days after planting (DAP). This was incorporated with a hilling operation and 27 mm of irrigation the same day. Weeds were managed by spraying 0.6 L/ha of metribuzin immediately prior to irrigation. Occasional hand-hoeing also took place as other weeds emerged. Leaf diseases were managed by an application of 2.2 kg/ha of DITHANE® (mancozeb). The fungicide ROVRAL® (iprodine) was applied as a drench at 1 L/ha 77 DAP, in an attempt to control soil borne diseases. The miticide ROGOR® (pirimicarb) was periodically sprayed to control aphids.

Hand shift and solid set pipes with overhead sprinklers irrigated the whole experimental area, for the first 9 weeks after planting. For irrigations during the latter part of the season, systems of mini-sprinklers or drip tape were used to individually water each plot. A schematic of plot layouts is shown in Fig. 1a,b with 2 rows of potatoes per 'bed'. Each plot consisted of 6 rows of potatoes side by side; the central 2 rows were the treatment area, with the 4 remaining rows as buffer zones.

In the plots watered with overhead irrigation, lines of mini sprinklers were installed down the 2 outer edges of the treatment beds, with 2 m between each sprinkler within the a line. The sprinklers in the 2 lines were offset by 1 m, to give a staggered pattern down the bed (Fig. 1a). Each sprinkler was mounted on a 1 m high stake, with an output radius of about 2 m and volume of 70 L/hr at 130 kPa operating pressure. Using this system, irrigation was relatively uniform across the treatment bed, with no drift into neighbouring treatment beds. The application rate was around 20 mm/hr over the treatment beds. An electronic timing system was used to commence irrigation at 2 am on the appropriate days, to avoid windy conditions often prevalent during daylight hours.

Plots watered with drip-tape had tapes positioned on the top of the 'treated' potato rows as well as the 2 adjacent buffer rows (Fig 1b). We used "T-Tape Row Crop" with emitters every 0.2 m and an output of about 7.3 L/m/hr at an operating pressure of 70 kPa. This corresponds to an overall application rate of ≅ 9 mm/hr on a total area basis.

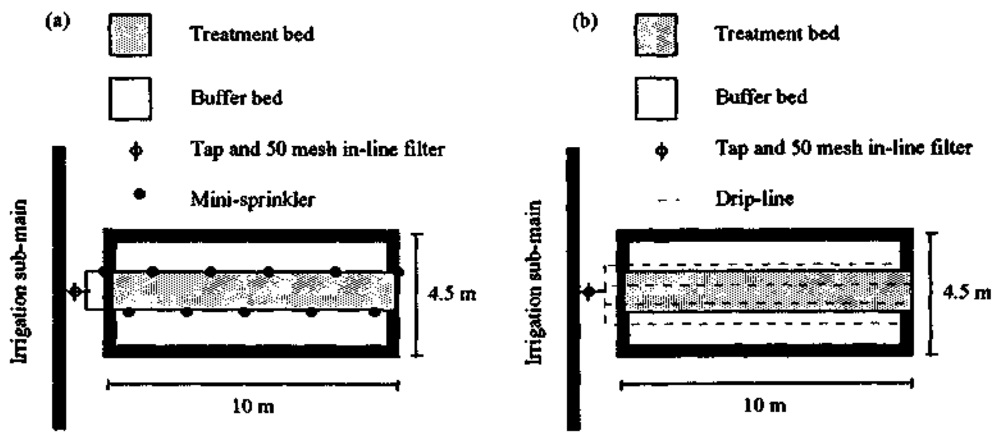


Figure 1. Individual plot irrigation system layouts for treatments watered by (a) mini-sprinklers and (b) drip-lines.

Tensiometers were installed 20 cm and 60 cm below the tops of the hills in a treatment row in each plot. LOCTRONIC® tensiometers were used, which consist of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum at the top of the tensiometer, while an electronic vacuum gauge attached to the syringe records the vacuum in the small air gap below the septum. Tensiometer readings were recorded around 8-9 am daily.

Critical Tensiometer Values (T) were used to trigger irrigations in this experiment. Irrigation was applied when readings for the tensiometers installed 20 cm below the tops of the hills were greater than the T individually set for each treatment. Five irrigation treatments were investigated:

1. Irrigated by drip-tape
2. Irrigated at T of 30 kPa for the latter part of the growing period
3. Irrigated at T of 45 kPa for the latter part of the growing period
4. Irrigated at T of 60 kPa for the latter part of the growing period
5. Irrigated at T of 80 kPa for the latter part of the growing period

Weather data, including rainfall, Class A Pan evaporation, maximum and minimum temperatures were recorded daily. The amounts of irrigation applied were calculated from data collected with a water meter at the irrigation pump.

At maturity, potatoes were dug by machine and hand harvested into bags on 9 November 1994 (132 DAP). Potatoes were graded into 5 weight classes; <80 g, 80-200 g, 200-350 g, 350-450 g, >450 g; counted and weighed. Dry matter contents were determined on 2 samples of 80-350 g potatoes for each plot.

Data analyses

All potato yield and quality parameters were analysed using standard analysis of variance.

Results and discussion

In discussing water use and growth of the potato crop, we have divided the growing period into 4 phases; (i) establishment and early vegetative growth $\cong$ 0-49 DAP; (ii) tuber initiation $\cong$ 50-69 DAP; (iii) yield formation $\cong$ 70-117 DAP; (iv) ripening $\cong$ 118-133 DAP. Because of a labour shortage, the separate irrigation treatments did nor commence until 76 DAP, well into the yield formation stage. During this first 76 days, all potatoes received 7 irrigations, averaging 33 mm. Only 39 mm of rain fell during this time, the bulk in one 25 mm event.

Values for the 20 cm tensiometers fluctuated between 0-30 kPa during the yield formation period in the drip irrigation treatment (Fig. 2). During this 6 week period this treatment received an average of 13 mm every 3 days (total 178 mm) Deep tensiometer data indicates no severe deep drainage occurrences. Sub-soil moisture steadily decreased over the yield formation period through to ripening. Deep tensiometer values ranged from around 5 kPa in the initial stages of yield formation, peaking at about 50 kPa at harvest time (Fig. 2).

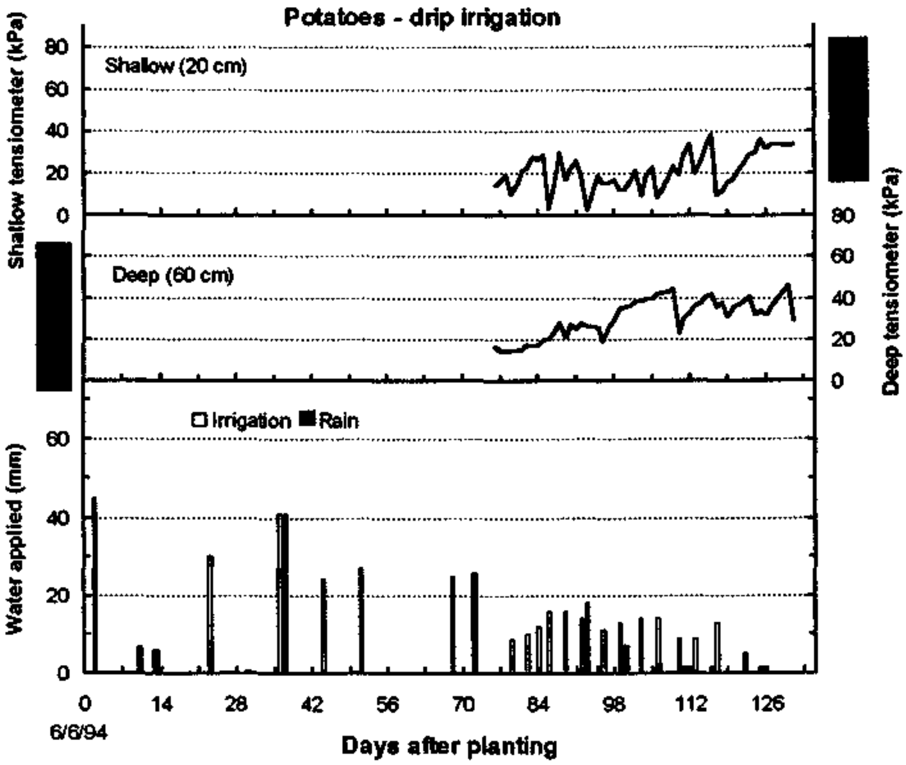


Figure 2. Fluctuation in tensiometer values with rainfall and irrigation for a drip-irrigated potato crop.

Values for shallow tensiometers in the 30 kPa treatment (Fig. 3) varied between 0 kPa and about 45 kPa. These plots were irrigated 6 times during the treatment period, receiving an average 32 mm per application (total 189 mm). The second irrigation of 37 mm at 112 DAP was followed by prolonged low values for shallow tensiometers. Deep tensiometer values indicate drainage occurred following irrigations 90 DAP and 112 DAP. For the bulk of the yield formation period, deep tensiometer values were between 20 kPa and 40 kPa.

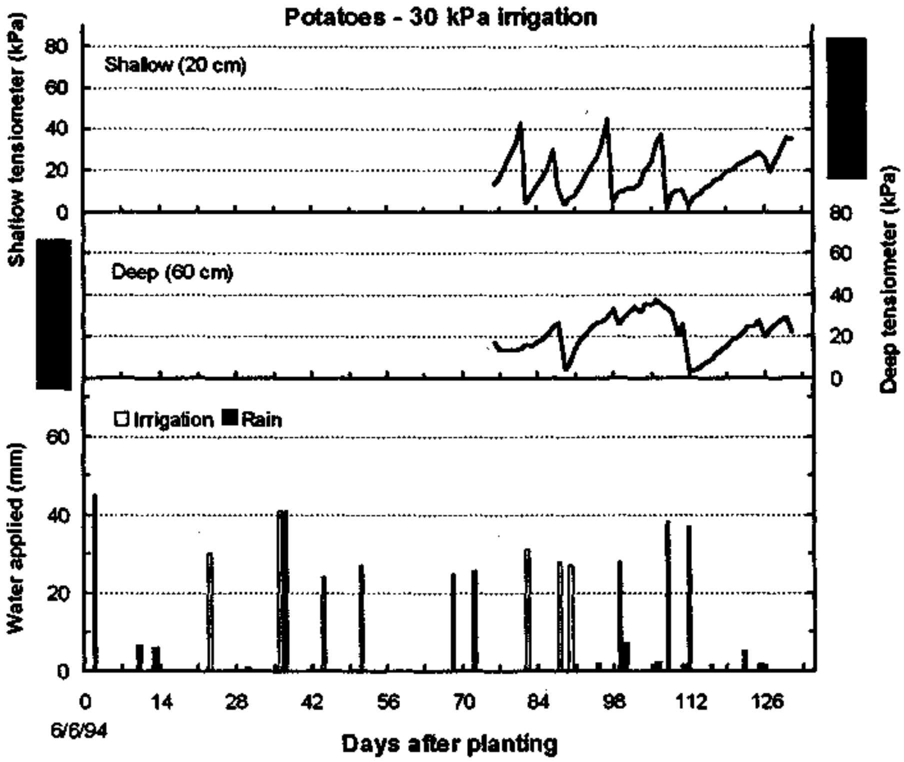


Figure 3. Fluctuation in tensiometer values with rainfall and irrigation for a potato crop irrigated when shallow tensiometer values reach 30 kPa.

The 45 kPa irrigation treatment 20 cm tensiometer values fluctuated between 0-45 kPa (Fig. 4), though not as frequently as those for the 30 kPa treatment (Fig. 3). The 45 kPa treatment was irrigated 5 times during yield formation, receiving a total of 158 mm. Fig. 4 suggests there was no excess irrigation during that time. Sub-soil moisture continued to decline until harvest, indicated by rising 60 cm tensiometer values.

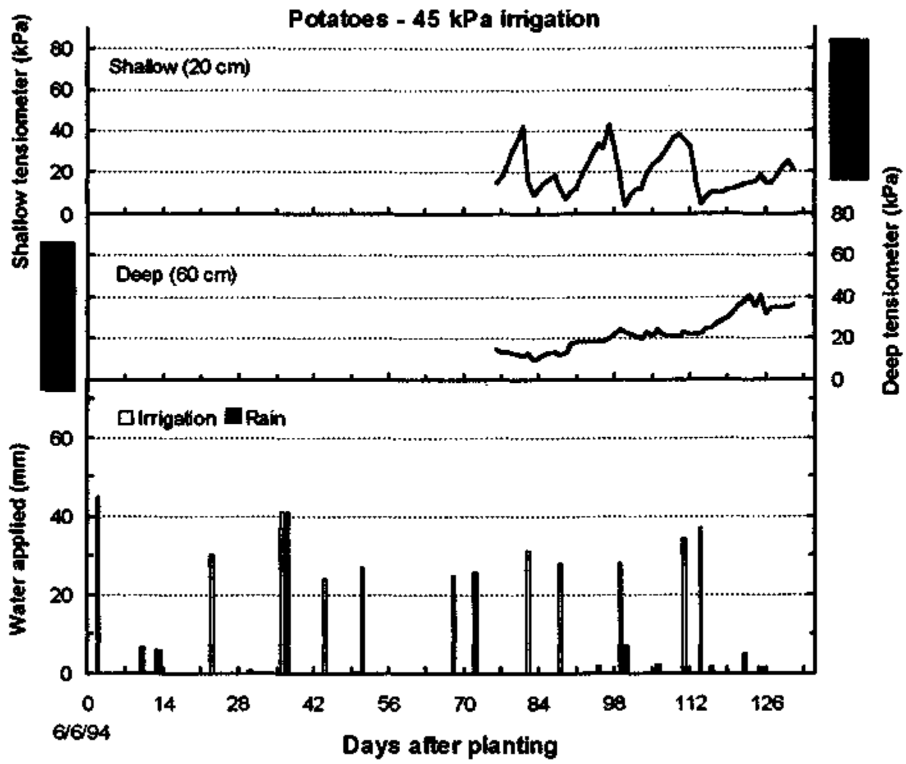


Figure 4. Fluctuation in tensiometer values with rainfall and irrigation for a potato crop irrigated when shallow tensiometer values reach 45 kPa.

Shallow tensimeter values for the 60 kPa treatment reached 55 kPa prior to irrigation at 87 DAP (Fig. 5). There was no deep drainage throughout the yield formation period; deep tensiometer values maintained the range 20-40 kPa. These plots received a total of 107 mm during the latter part of yield formation, with intervals of several weeks between waterings.

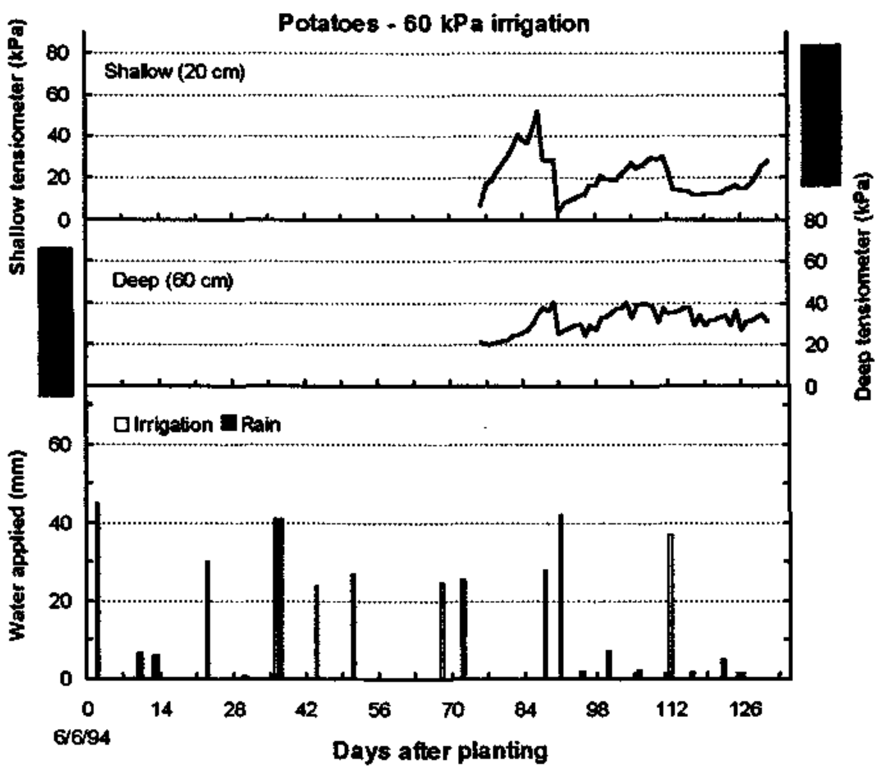


Figure 5. Fluctuation in tensiometer values with rainfall and irrigation for a potato crop irrigated when shallow tensiometer values reach 60 kPa.

Shallow tensiometer values from the 80 kPa treatment (Fig. 6) behaved similarly to those in the 60 kPa plots (Fig. 5). This treatment received 2 irrigations (78 mm and 36 mm respectively) during the yield formation period. The former irrigation resulted in deep drainage 90 DAP, shown by substantial dips in deep tensiometer values. Deep tensiometer values generally hovered between 30 kPa and 50 kPa.

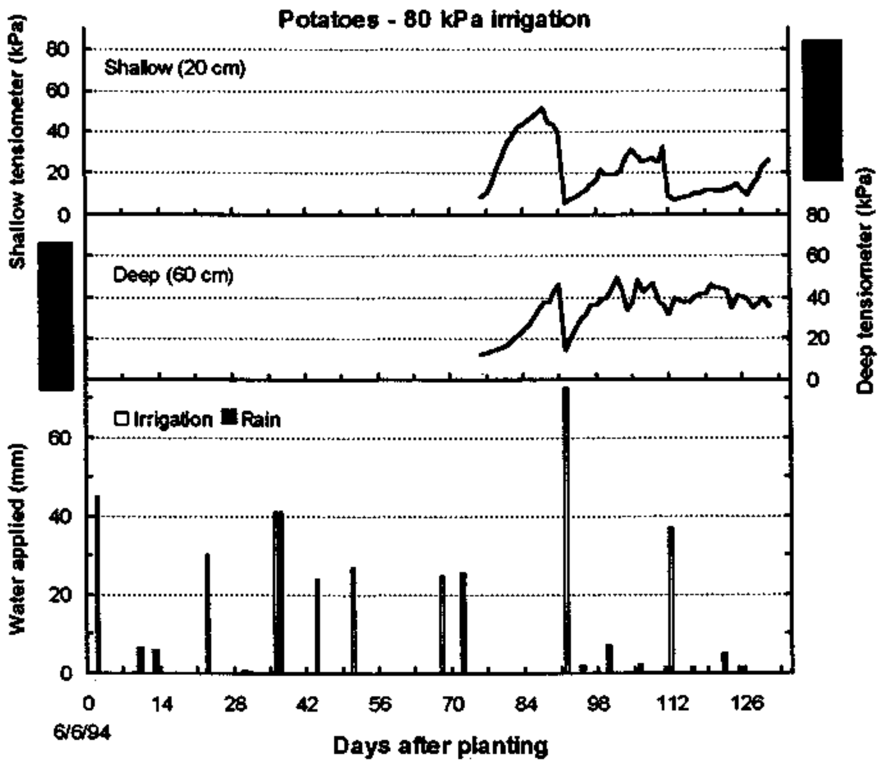


Figure 6. Fluctuation in tensiometer values with rainfall and irrigation for a potato crop irrigated when shallow tensiometer values reach 80 kPa.

Total potato yield was greatest for drip-irrigated plots (28.4 t/ha). The best performed sprinkler-irrigated treatments, watered when shallow tensiometers reached 30 kPa, yielded 25.6 t/ha (Fig. 7a). As critical tensiometer values and intervals between irrigations increased, yields declined. The 80 kPa treatment yielded 21.6 t/ha. Yields from both 60 kPa and 80 kPa treatments were significantly less than that from drip-irrigated potatoes.

Higher yields in better performing plots were due to increased production in heavier weight grades (Fig. 7a), particularly in the 3 grades >200 g. Shorter intervals between irrigations, and thus greater total irrigation, increased the proportions of initiated tubers that made larger size grades (Fig. 7b). The total number of tubers initiated and harvested were relatively similar across all 5 treatments.

There were no important effects of irrigation treatment on average sizes of potatoes within each size grade (Table 1).

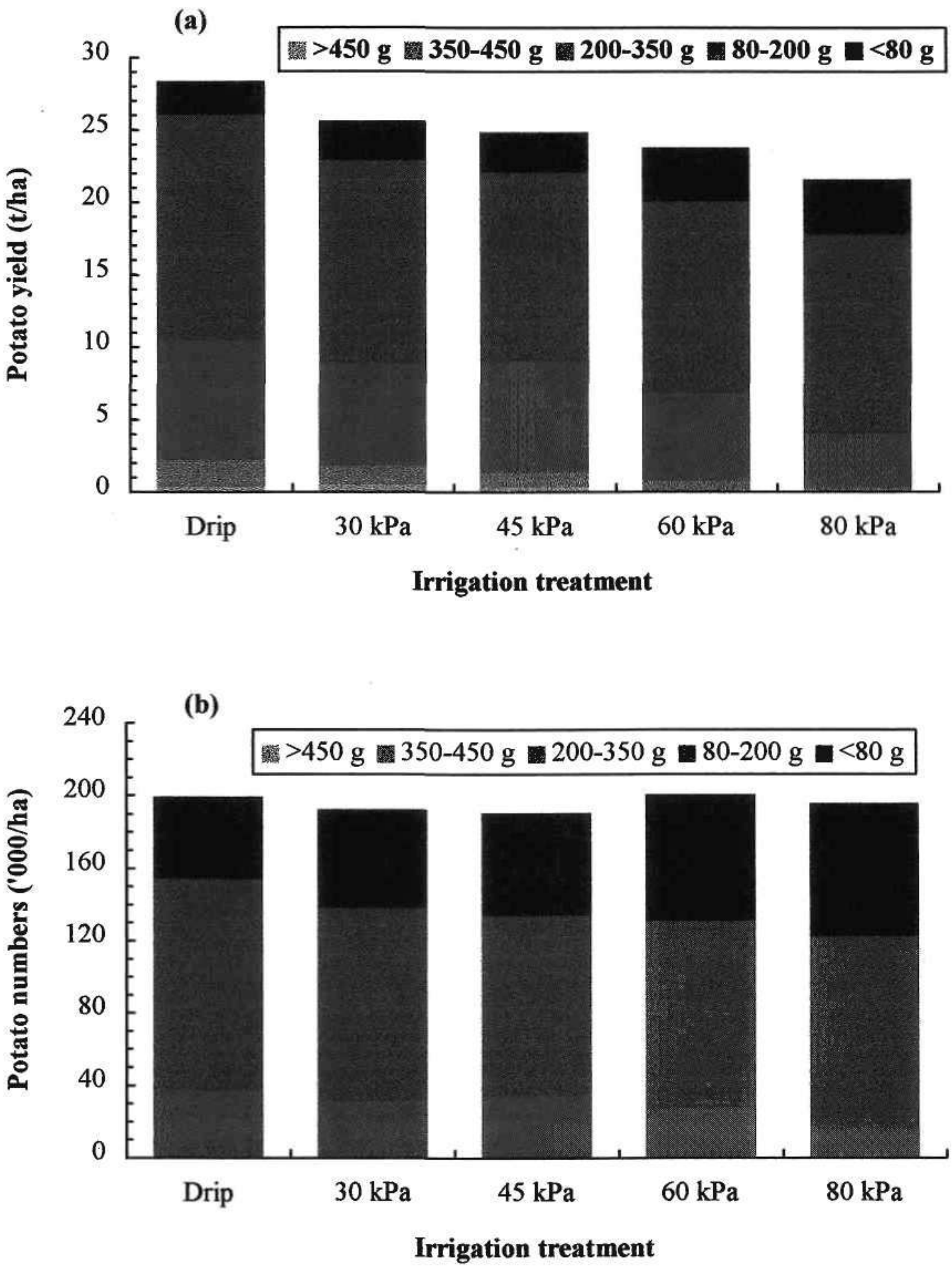


Figure 7. Increasing the critical tensiometer value for initiating irrigation reduced (a) the total weight and (b) the numbers of tubers in grades greater than 200 g in weight.

Table 1. Irrigation treatments had no effects on average tuber weights within size grades.

Treatment	<80 g	80-200 g	200-350 g	350-450 g	>450 g
Drip	50.13	134.45	253.72	376.03	486.56
30 kPa	51.37	131.20	257.87	382.10	526.39
45 kPa	49.18	129.74	248.86	378.17	556.72
60 kPa	54.12	126.36	238.30	374.60	501.06
80 kPa	52.00	128.62	244.71	393.38	000.00

Conclusions

Best yields in this experiment (≅28 t/ha) were substantially less than normally achieved in experiments at Gatton Research Station. We suspect this was due to poor quality water we were forced to use because of the prolonged drought. This may have particularly affected tuber initiation, as the total number of tubers harvested was around 25% less than recorded in previous experiments.

Higher yields from drip-irrigated potatoes may also have reflected inherent advantages of this system when using poor quality water. Leaching of salts away from drip lines is readily achieved, while leaves are not damaged by continual evaporation of high salinity water on their surfaces.

In this experiment, tuber quality declined as the critical value increased above 30 kPa. In previous experiments, a value of 40-45 kPa for triggering irrigation has been optimal. It may be that where poorer quality water is used, this critical tensiometer value needs to be reduced. Note that yield differences between 30 kPa and 45 kPa treatments (<1 t/ha) were minor.

Due to the late imposition of irrigation treatments, yield differences reflected tuber sizes rather than tuber numbers. No doubt, if irrigation stresses had occurred earlier, yield variation between treatments could have been more substantial.

This experiment confirmed the value of using tensiometers to schedule irrigation in potatoes. Using a critical figure of ≅ 40 kPa for tensiometers installed 20 cm below the top of the hill will maximise yields in a sprinkler-irrigated crop. In most instances, 25-35 mm of irrigation on any one occasion is sufficient, with a return interval of 5-7 days. In situations where poor quality water is used, the critical tensiometer value may need to be reduced and the irrigation quantities increased.

Future experimentation will be for demonstration purposes, confirming the validity of our current irrigation management advice.

Appendix 2. Report on 1994 onion experiment

Experiment Report No. P1052.01 6/6/94-15/11/94

Irrigation Scheduling in Onions

by Mick Webber and Craig Henderson
QDPI Gatton Research Station

Summary

We conducted an experiment investigating relationships between onion yields and irrigation regimes at Gatton Research Station during June-November 1994. Onions (cv Gladalan Brown) were grown using standard agronomy, with 5 irrigation treatments replicated 3 times in a RCB design. Plots were 4.5 m wide and 10 m long, with a total experimental area of 0.075 ha. One treatment was irrigated by drip tape; the other four used overhead mini-sprinklers, with irrigation commencing at different Critical Tensiometer values (T kPa). This value was obtained from tensiometers installed 15 cm below the soil surface in each plot. The T values were; 30 kPa, 45 kPa; 60 kPa and 80 kPa. Irrigation differences were applied from 35 days after planting (DAP) until the onions were harvested (162 DAP).

Onion growth in this experiment was reduced as the irrigation interval increased. Highest onion yields were in the 30 kPa and 45 kPa treatments, at around 77 t/ha. All irrigation treatments produced the same number of onion bulbs, however the higher yielding treatments had fewer picklers and more onions in the larger grades. The drip-irrigated treatment yielded poorly (68 t/ha) compared to the 30 kPa and 45 kPa treatments, possibly due to calcium deposits in emitters. Irrigation treatment did not significantly affect mean individual weight of onions, numbers of doubles, nor onion dry matter content.

This experiment confirmed the value of using tensiometers to schedule irrigation in onions. Using a critical figure of ≅40 kPa for tensiometers installed 15 cm below the soil surface will maximise yields in a sprinkler-irrigated crop. In most instances 20-25 mm of irrigation on any one occasion is sufficient, with a return interval of 5-7 days. In situations where poor quality water is used, the critical tensiometer value may need to be reduced and irrigation quantities increased.

Relevance to industry

In many regions, including the Lockyer Valley, irrigation demands regularly exceed the reliable capacity of the water supply, resulting in scarcity, or reliance on poorer quality water. In many vegetable enterprises, irrigation is a significant proportion of overall production costs. Onions are a major water user, requiring 4-6 ML per hectare per crop. Until recently, the frequency and amount of irrigation were relatively ad-hoc, based on tradition and producer experience, combined with superficial observations of plant or soil conditions.

Some vegetable producers use tensiometers or neutron probes to monitor soil water status and schedule irrigations. More recently, an electronic logging system based on capacitance probes, is being employed by larger scale enterprises. These methods have advantages and disadvantages, however tensiometers have the best immediate potential for use in onions in southern Queensland. Most water uptake occurs in the upper 0.3 m of the soil profile.

Matching irrigation to crop requirements maximises production by minimising plant water stress, nutrient deficiencies and some diseases, as well as preventing build-up of salinity problems. By preventing over-watering, problems with leaching of nutrients and pesticides into groundwater (and beyond the zone of usefulness) are reduced, as well as a decrease in disease levels. Monitoring producers' crops in the Lockyer Valley suggests there are substantial productivity and irrigation efficiency gains from improving irrigation in onions.

Objectives

This experiment investigated and demonstrated the relationship between onion yields and tensiometer values under various irrigation regimes. It also attempted to determine the efficiency of scheduling systems, by quantifying the amounts of applied water draining beyond the root zone during the onion growing period.

Materials and methods

The experiment was conducted on a black earth soil (*Ug5.15*) at Gatton Research Station (lat. 27°33'S, long. 152°20'E). The experimental design was a randomised complete block, with 5 irrigation treatments replicated 3 times. Each plot comprised 12 rows of onions 4.5 m wide and 10 m long.

The soil was prepared as per standard practice for onions. Cv. *Gladalan Brown* were planted on 6 June 1994, with 0.5 m between the rows and 0.005 m intra-row spacing. A total of 50 kgN/ha as urea was applied via irrigation water on 22-23 August 1994. A further 50 kgN/ha was applied as ammonium sulphate in the same manner on 12 September 1994. Weeds were managed by two applications of 0.1 L/ha and one of 0.5 L/ha GOAL® (oxyfluorfen) on 8, 18 and 25 July 1994 respectively. Occasional hand-weeding also took place as other weeds emerged. Leaf diseases were managed by applications of 3 kg/ha DITHANE® (mancozeb) on 11 August 1995 and 2.5 kg/ha RIDOMIL® (mancozeb/metalaxyl) on 30 August 1995. SUPRACIDE® (methidathion) was also applied on the same days at 0.75 L/ha to control insects.

The initial irrigations utilised solid set pipes and overhead sprinklers over the whole experimental area, for the first 5 weeks after planting. For irrigations during the latter part of the season, systems of mini-sprinklers or drip-lines were used to individually water each plot.. A schematic of plot layout is shown in Fig. 1, with 4 rows of onions per 'bed'. Each plot consisted of 12 rows of onions side by side, the central 4 rows were the treatment area, while the other 8 rows were buffer zones.

In the plots watered with overhead irrigation, lines of mini-sprinklers were installed down the 2 outer edges of the treatment beds, with 2 m between each sprinkler within a line. The sprinklers in the 2 lines were offset by 1 m, to give a staggered pattern down the bed (Fig. 1a). Each sprinkler was mounted on a 1 m high stake, and had an output radius of about 2 m and volume of 70 L/hr at 130 kPa operating pressure. Using this system, the irrigation was relatively uniform across the treatment bed, with no drift into neighbouring treatment beds. The application rate was around 20 mm/hr over the treatment beds. An electronic timing system was used to commence irrigation at 2 am on the appropriate days, to avoid windy conditions often prevalent during daylight hours.

Plots watered with drip-tape had tapes positioned on the top of the "treated" onion rows as well as the 2 adjacent buffer rows (Fig. 1b). We used "T-Tape Row Crop" with emitters every 0.2 m and an output of about 7.3 L/m/hr at an operating pressure of 70 kPa. This corresponds to an overall application rate of ≅9 mm/hr on a total area basis.

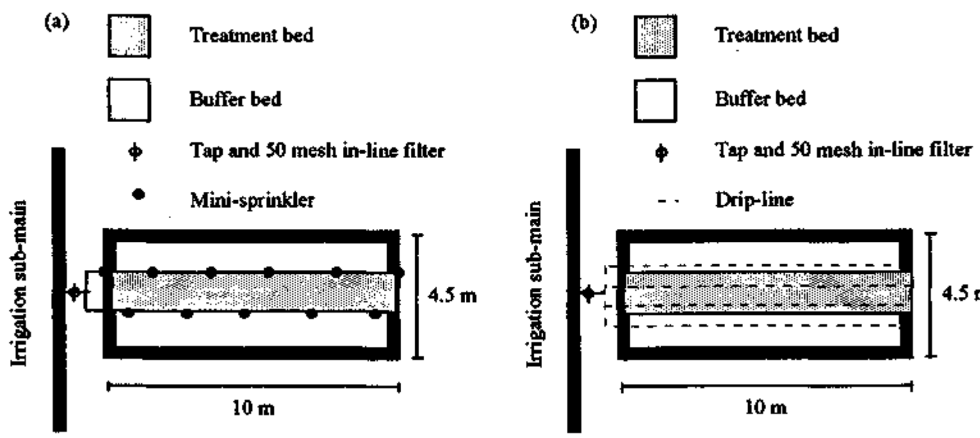


Figure 1. Individual plot irrigation system layouts for treatments watered by (a) mini-sprinklers and (b) drip-lines.

Tensiometers were installed 15 cm and 60 cm below the soil surface in a treatment row in each plot. LOCTRONIC® tensiometers were used, which consist of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum at the top of the tensiometer, while an electronic vacuum gauge attached to the syringe records the vacuum in the small air gap below the septum. Tensiometer readings were recorded around 8-9 am daily.

Critical Tensiometer Values (T) were used to trigger irrigations in this experiment. Irrigation was applied when readings for the tensiometers installed 15 cm below the soil surface were greater than the T individually set for each treatment. Five irrigation treatments were investigated:

1. Irrigated by drip-tape.
2. Irrigated at **T** of 30 kPa for the latter part of the growing period.
3. Irrigated at **T** of 45 kPa for the latter part of the growing period.
4. Irrigated at **T** of 60 kPa for the latter part of the growing period.
5. Irrigated at **T** of 80 kPa for the latter part of the growing period.

Weather data, including rainfall, Class A Pan evaporation, maximum and minimum temperatures were recorded daily. The amounts of irrigation applied were calculated from data collected with a water meter at the irrigation pump.

Onion heights were measured on 26 August 1994, 81 days after planting (DAP), 16 September 1994 (102 DAP) and 6 October 1994 (122 DAP). Onions were hand-harvested at maturity on 15 November 1994 (162 DAP). The onions were graded into 3 diameter size classes; picklers (<40 mm), #1 (40-75 mm), #1 large (>75 mm); counted and weighed. Dry matter contents were determined on a processed sample of 6 onions of #1 grade for each plot. Double onions from each plot were also counted and weighed.

Data analyses

All onion yield, growth and quality parameters were analysed using standard analysis of variance.

Results and discussion

The separate irrigation treatments commenced 35 DAP. During the first 35 days, all onions received 4 irrigations, averaging 20 mm. Only 16 mm of rain fell during this time, the bulk in one 9 mm event.

Values for the 15 cm tensiometers in the drip-irrigated treatment fluctuated between 0-20 kPa for the first 100 DAP. Values then varied between 20-60 kPa for the remainder of the growing period (Fig. 2). During the treatment period (18 weeks) these onions received 32 irrigations totalling 340 mm, averaging 11 mm every 3-4 days. Deep tensiometer readings for the drip-irrigation treatment indicate that sub-soil layers remained quite moist for the first 105 DAP, after which values fluctuated between 40 kPa and 80 kPa (Fig. 2).

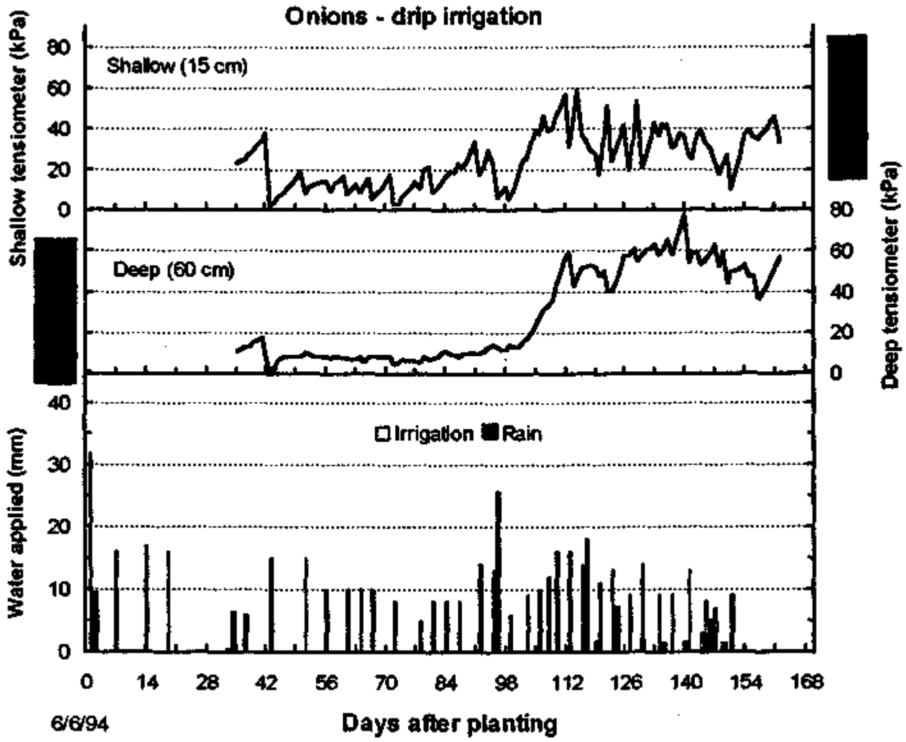


Figure 2. Fluctuation in tensiometer values with rainfall and irrigation for a drip-irrigated onion crop.

Values for shallow tensiometers in the 30 kPa treatment (Fig. 3) varied between 0 kPa and 30-40 kPa, peaking at around 55 kPa at harvest. It was irrigated 20 times over the treatment period, receiving an average 23 mm every 6 days (total 452 mm). Deep tensiometer values for the 30 kPa treatment indicate a prolonged period of high sub-soil moisture for about 105 DAP, with tensiometer values remaining <20 kPa. Drier conditions then prevailed for the remainder of the treatment period; with values ranging between 20-45 kPa (Fig. 3).

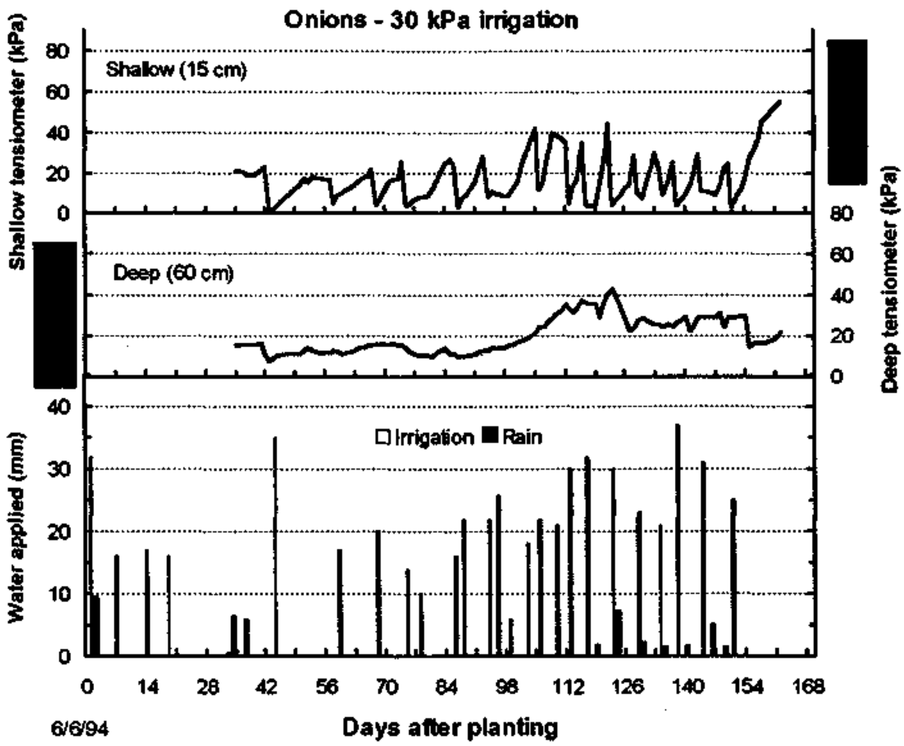


Figure 3. Fluctuation in tensiometer values with rainfall and irrigation for an onion crop irrigated when shallow tensiometer values reach 30 kPa.

The 45 kPa irrigation treatment (Fig. 4) 15 cm tensiometer values fluctuated between 0 kPa and 40 kPa for the first 74 DAP. Values then ranged between about 0 kPa and 50 kPa until harvest (Fig. 4). The 45 kPa treatment was irrigated 19 times during the treatment period averaging 22 mm every 7 days (418 mm total). Fig. 4 suggests few occurrences of excess irrigation during the cropping period, according to deep tensiometer values. Sub-soil moisture was high for 15 weeks after planting, then steadily declined over the remainder of the growing period. Matric suction peaked at approximately 55 kPa when the onions were harvested.

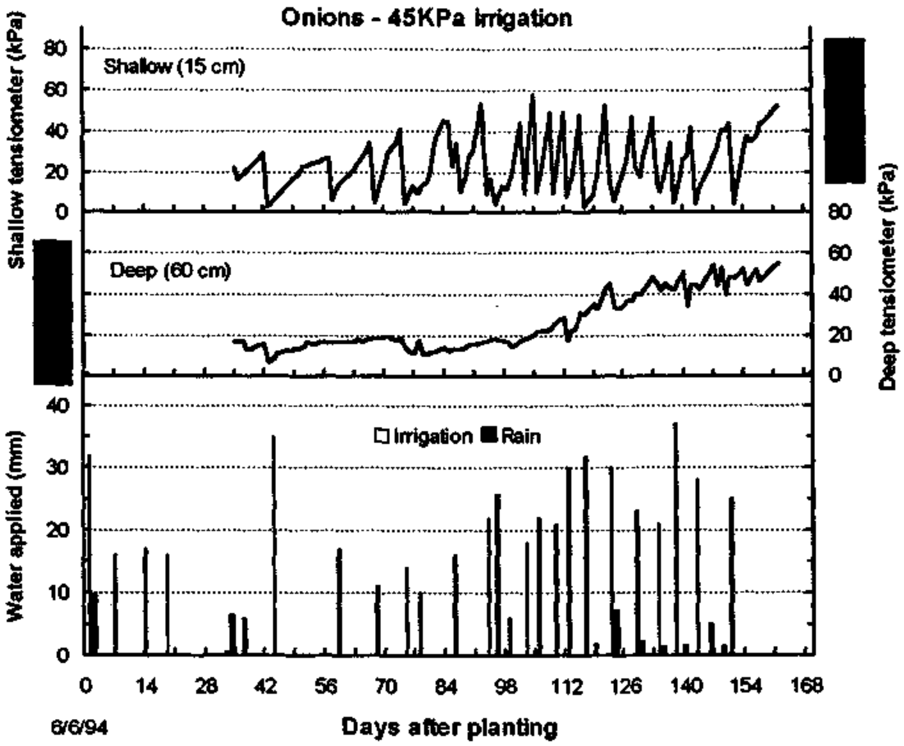


Figure 4. Fluctuation in tensiometer values with rainfall and irrigation for an onion crop irrigated when shallow tensiometer values reach 45 kPa.

Shallow tensimeter values for the 60 kPa treatment (Fig. 5) fluctuated between 0 kPa and 45 kPa for the first 12 weeks after planting, then ranged between 0 kPa and 55 kPa until harvest. This treatment received 14 irrigations averaging 26 mm every 9 days (367 mm total). Figure 5 indicates a steady decrease in soil moisture; (10-20 kPa) until 100 DAP; values then exceeded 25 kPa, peaking at around 55 kPa 147 DAP.

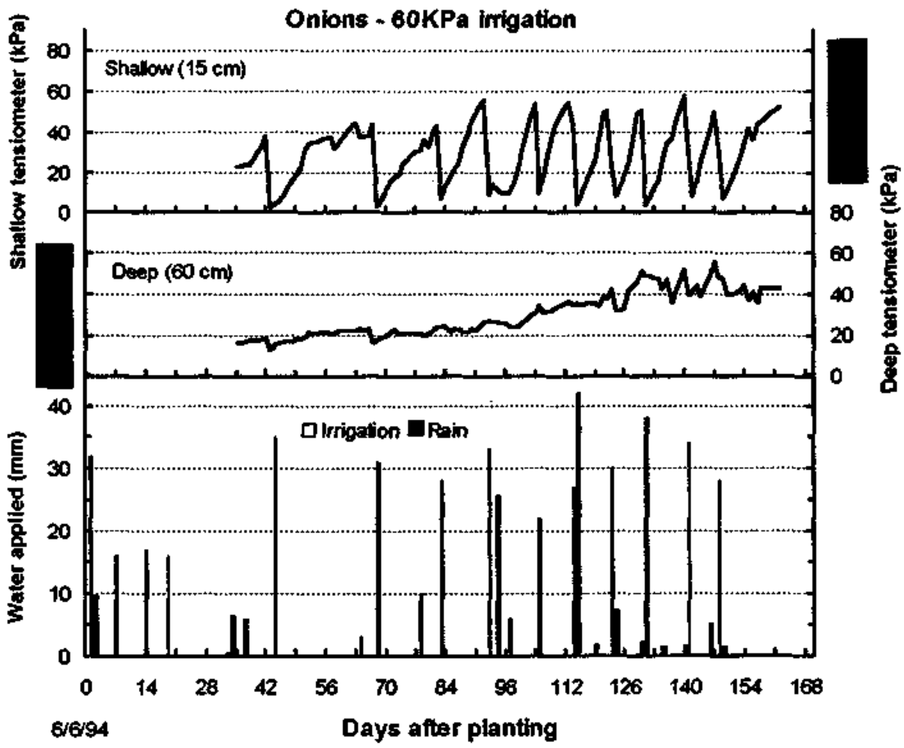


Figure 5. Fluctuation in tensiometer values with rainfall and irrigation for an onion crop irrigated when shallow tensiometer values reach 60 kPa.

Large fluctuations are evident for the shallow tensiometer values in the 80 kPa treatment (Fig. 6). There is a gradual rise in the shallow values (0-60 kPa) for the first 75 DAP. Readings regularly reached 80 kPa until 142 DAP. Values then ranged between 0 kPa and 50 kPa until harvest. This treatment received 9 irrigations over the treatment period, totalling 322 mm at an average of 35 mm every 2 weeks. As with the previous treatments, deep tensiometer values for the 80 kPa treatment remained low, well into the growing period. Figure 6 shows values under 20 kPa up to 120 DAP, after which higher values of 30-45 kPa occurred.

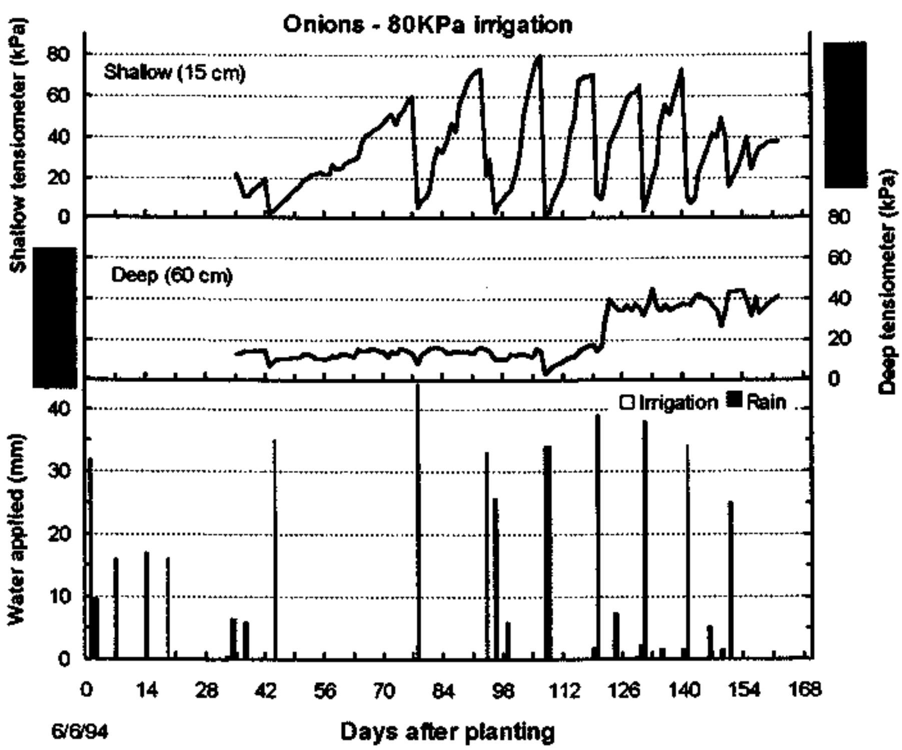


Figure 6. Fluctuation in tensiometer values with rainfall and irrigation for a potato crop irrigated when shallow tensiometer values reach 80 kPa.

Onion plants were shorter in the 80 kPa treatment compared to the 30 kPa treatment (Fig. 7). Differences were significant 81 DAP and 102 DAP.. Throughout the growing period there were consistent trends for shorter onions as the interval between irrigations increased.

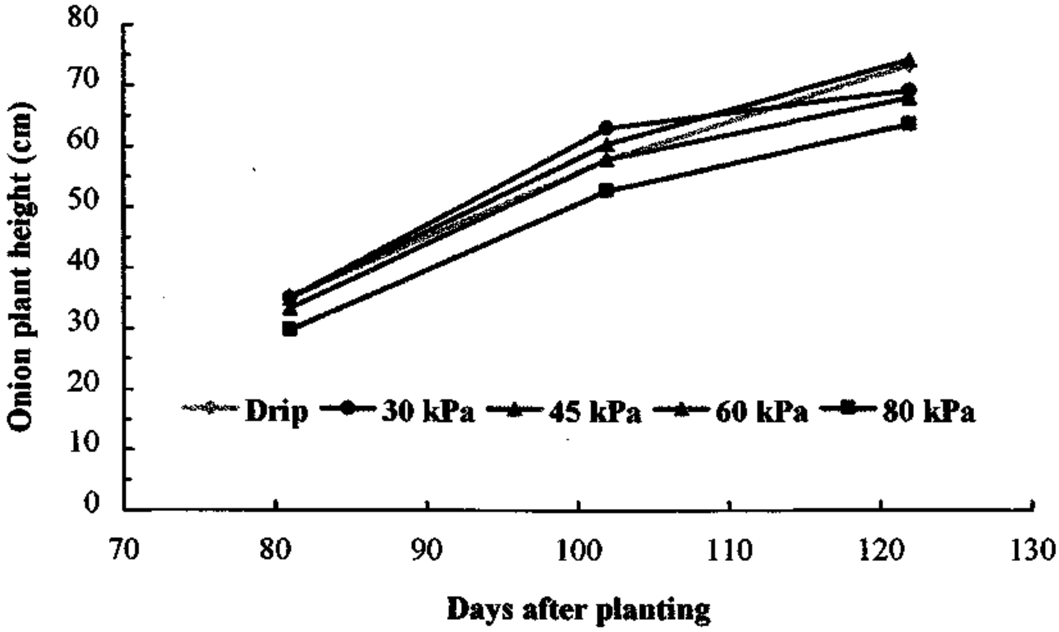
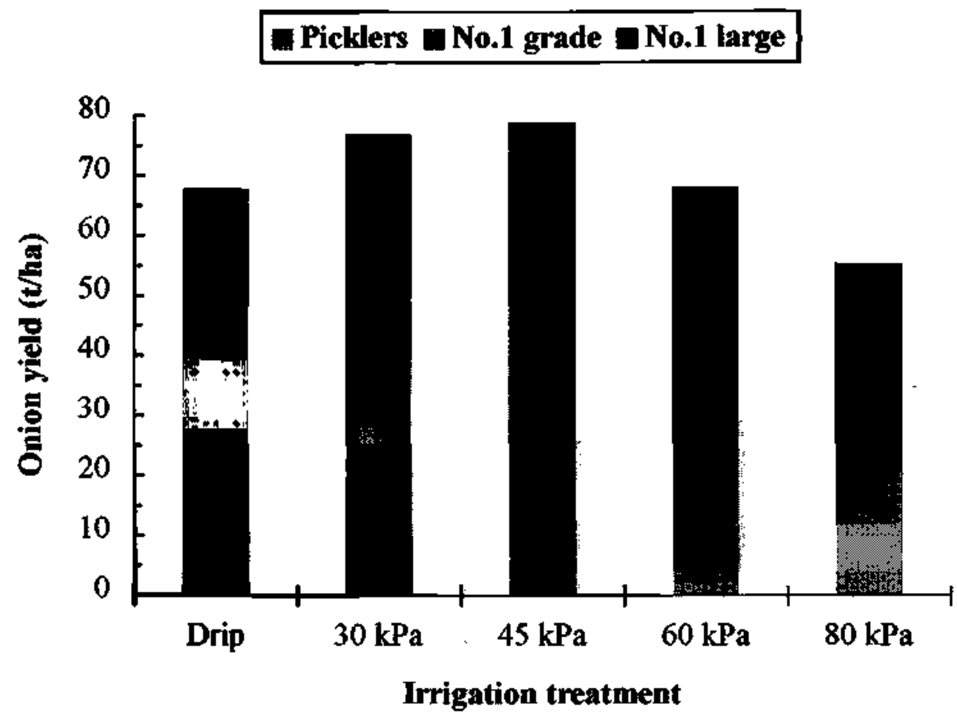


Figure 7. Increasing critical tensiometer value for initiating irrigation reduced sequential heights of onion plants.

Onion yields were greatest for the 30 kPa (76.9 t/ha) and 45 kPa (79.0 t/ha) The drip and 60 kPa treatment yields were similar at ≅68 t/ha. At 55 t/ha, yield of the 80 kPa treatment was significantly less than maximum. There were no significant differences in the total number of onion bulbs harvested from each treatment. However, the higher yielding treatments had more onions in the larger grades and fewer picklers (Fig. 8b). As a consequence, the 30 kPa and 45 kPa plots had the greatest yields of #1 grade and #1 large onions, and the lowest yield of picklers (Fig. 8a).

(a)



(b)

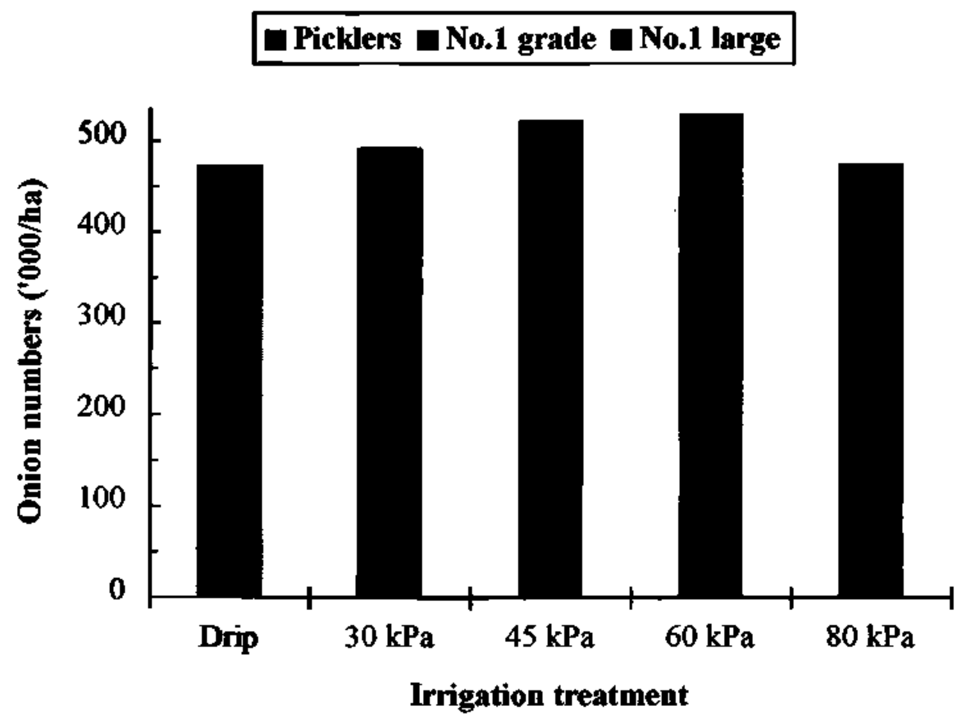


Figure 8. Increasing the critical tensiometer value for initiating irrigation reduced (a) yield and (b) the proportion of large onion bulbs.

Irrigation treatment had no significant effects on average individual weight of onions within each size grade, number of doubles, nor dry matter content of onions. The yield of doubles ranged from 0.9 t/ha for the 80 kPa treatment, to 1.8 t/ha for the 30 kPa plots, averaging 1.1 t/ha across the experiment. The general mean weight of picklers was 53 g, of #1 grade onions 120 g, and of #1 large onions 220 g. Dry matter contents varied from 8.7-9.2%, with a mean of 9.0%.

Conclusions

Maximum yields in this experiment (≅80 t/ha) were good considering the poor quality of irrigation water. In this experiment, onion yields and mean size declined as the critical value increased above 45 kPa.

We have found a shallow tensiometer reading around 40 kPa to be a useful value for initiating irrigation in many vegetable crops, including potatoes, brassicas, beans, etc.

The sub-optimal performance of the drip-irrigation system may have been due to clogging of emitters with calcium deposits. This resulted in uneven distribution across the bed, with subsequent poor performing sections of crop. This problem can be overcome by regularly flushing a weak acid solution through the system.

This experiment demonstrated the value of using tensiometers to schedule irrigation in onions. Using a critical figure of ≅40 kPa for tensiometers installed 15 cm below the soil will maximise yields in a sprinkler irrigated crop. In most instances, 20-25 mm of irrigation on any one occasion is sufficient, with a return interval of 5-7 days. In situations where poor quality water is used, the critical tensiometer value may need to be reduced and the irrigation quantities increased.

Future experimentation will be for demonstration purposes, confirming the validity of our current irrigation management advice.

Appendix 3. Report on 1995 onion experiments

Experiment Report No. P1452.03 23/3/95-3/10/95

Irrigation Scheduling in Onions

by Craig Henderson
QDPI Gatton Research Station

Summary

We conducted an experiment investigating relationships between onion yields and irrigation regimes at 2 different planting times at Gatton Research Station during March-October 1995. Onions (cv Golden Brown) were grown using standard agronomy, with 4 irrigation treatments replicated twice in a RCB design, repeated at 2 sowing times 12 days apart. Plots were 4.5 m wide and 10 m long, with a total experimental area of 0.15 ha. All treatments were irrigated by drip tape; irrigation commencing at different Critical Tensiometer values (T kPa). This value was obtained from tensiometers installed 15 cm below the soil surface in each plot. The T values were; 20 kPa, 35 kPa; 60 kPa and 75 kPa. Irrigation differences were applied from 35 days after planting until the onions were harvested (173 and 182 days after planting respectively).

In neither planting were total onion yields affected by increasing the irrigation interval from 4 days to 10 days. Yields averaged around 65 t/ha in Planting 1, and 80 t/ha in Planting 2. There were general trends for larger onions in the more frequently irrigated plots. However, there also appeared to be slightly more 'double' onions in these wetter treatments. There was a very high proportion of 'double' onions (circa 30-40%) in both plantings, which may have been due to a combination of genetic, climatic, nutritional and water management factors. Irrigation management did not affect the dry matter content of the onions, which ranged from 9-11%.

As in previous experiments, optimum production appeared to occur when onions were irrigated at values of 35-60 kPa for tensiometers installed 15 cm below the soil surface. Total amounts of water received (irrigation + rainfall) in these treatments were 5.7 ML/ha (≅13 mm every 5 days) and 4.5 ML/ha (≅13 mm every 7-8 days) respectively. In a situation where sprinklers are used, the amounts supplied and intervals between irrigations could probably be increased. In situations where poor quality water is used, the critical tensiometer value may need to be reduced and irrigation quantities increased. By using tensiometers, we were able to eliminate drainage due to excessive irrigation.

Relevance to industry

In many regions, including the Lockyer Valley, irrigation demands regularly exceed the reliable capacity of the water supply, resulting in scarcity or reliance on poorer quality water. In vegetable enterprises, irrigation is a significant proportion of overall production costs. Onions are a major water user, requiring 4-6 ML per hectare per crop. Until recently, the frequency and amount of irrigation were relatively ad-hoc, based on tradition and producer experience, combined with superficial observations of plant or soil conditions.

Some vegetable producers use tensiometers or neutron probes to monitor soil water status and schedule irrigations. More recently, an electronic logging system based on capacitance probes, is being employed by larger scale enterprises. These methods have advantages and disadvantages, however tensiometers appear to have the best potential for use in southern Queensland. Most water uptake in onions occurs in the upper 0.3 m of the soil profile.

Matching irrigation to crop requirements maximises production by minimising plant water stress, nutrient deficiencies and some diseases, as well as preventing build-up of salinity problems. By preventing over-watering, problems with leaching of nutrients and pesticides into groundwater (and beyond the zone of usefulness) are reduced, as well as a decrease in disease levels. Monitoring producers' crops in the Lockyer Valley suggests there are substantial productivity and irrigation efficiency gains from improving irrigation in onions.

Objectives

This experiment investigated and demonstrated the relationship between onion yields and tensiometer values under various irrigation regimes at two different planting times. It also attempted to determine the efficiency of scheduling systems, by quantifying the amounts of applied water draining beyond the root zone during the onion growing period.

Materials and methods

The experiment was conducted on a black earth soil (*Ug5.15*) at Gatton Research Station (lat. 27°33'S, long. 152°20'E). Experimental designs for both experiments were randomised complete blocks, with 4 irrigation treatments replicated twice. Each plot contained 12 rows of onions (4.5 m) wide and 10 m long.

The soil was prepared as per standard practice for onions. Cv. *Golden Brown* was planted on 23 March 1995 (Planting 1) and 4 April 1995 (Planting 2), with 0.38 m between the rows and later hand-thinned to 0.07 m intra-row spacing. Urea was applied at 50 kgN/ha via drip irrigation to both plantings on 12 May 1995, and 2 June 1995. Weeds were managed by occasional hand hoeing. Leaf diseases were managed by applications of 2.5-3 kg/ha DITHANE® (mancozeb) on 24 April, 11 May, 23 May, 5 June, 11 July, 27 July, 10 August and 17 August 1995, with 2.5 kg/ha RIDOMIL® (mancozeb/metalaxyl) sprayed on 7 September 1995. SUPRACIDE® (methidathion) was applied on 24 April, 23 May, 5 June, 11 July, 27 July, 10 August, 17 August and 7 September 1995, with ROGOR® (dimethoate) sprayed on 11 May 1995 to control insects.

Initial irrigations used solid set pipes and overhead sprinklers over the whole experimental area, for the first 3 weeks after sowing Planting 1 and the first 2 weeks after sowing Planting 2. For irrigations during the remainder of the growing periods, drip-lines were used to individually water each plot.. A schematic of plot layout is shown in Fig. 1, with 4 rows of onions per 'bed'. Each plot consisted of 12 rows of onions side by side, the central 4 rows were the treatment area, while the other 8 rows were buffer zones.

All plots had 2 drip lines positioned in the 'treatment' beds, as well as the near sides of the adjacent buffer beds (Fig. 1). We used "T-Tape Row Crop" with emitters every 0.2 m and an output of about 7.3 L/m/hr at an operating pressure of 70 kPa. This corresponds to an overall application rate of ≅9 mm/hr on a total area basis. An electronic timing system was used to commence and control duration of each irrigation.

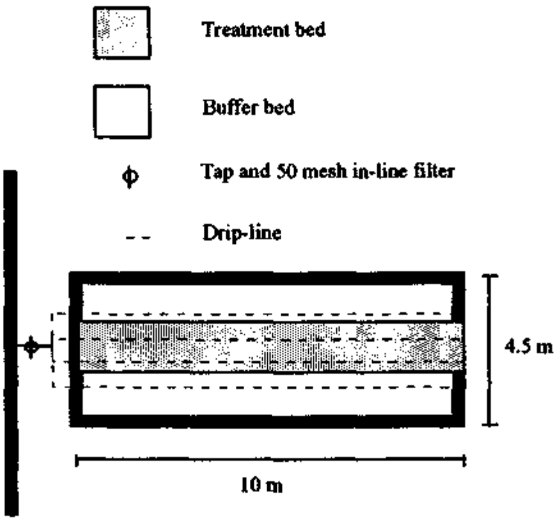


Figure 1. Individual plot irrigation system layouts.

Tensiometers were installed 15 cm and 60 cm below the soil surface in a treatment row in each plot. LOCTRONIC® tensiometers were used, which consist of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum at the top of the tensiometer, while an electronic vacuum gauge attached to the syringe records the vacuum in the small air gap below the septum. Tensiometer readings were recorded around 8-9 am daily.

Critical Tensiometer Values (**T**) were used to trigger irrigations in this experiment. Irrigation was applied when readings for the tensiometers installed 15 cm below the soil surface were greater than the **T** individually set for each treatment. Four irrigation treatments were investigated for each of the 2 planting times; these were:-

1. Irrigated at **T** of 20 kPa for the latter part of the growing period.
2. Irrigated at **T** of 35 kPa for the latter part of the growing period.
3. Irrigated at **T** of 60 kPa for the latter part of the growing period.
4. Irrigated at **T** of 75 kPa for the latter part of the growing period.

Weather data, including rainfall, Class A Pan evaporation, maximum and minimum temperatures were recorded daily. The amounts of irrigation applied were calculated from data collected with a water meter at the irrigation pump.

We measured onion heights in both plantings on 24 May, 7 June, 19 June and 13 July 1995. These dates correspond to 62, 76, 88 and 112 days after planting (DAP) in Planting 1, and 50, 64, 76 and 100 DAP in Planting 2. Onions were hand-harvested at maturity on 12 September 1995 (173 DAP) for Planting 1, and 3 October 1995 (182 DAP) for Planting 2. The onions were graded into 3 size grades; picklers (<40 mm diameter), No. 1 (40-75 mm), No. 1 large (>75 mm); counted and weighed. Dry matter contents were determined on a processed sample of 6 No. 1 grade onions for each plot. Double onions, seed heads and other off-types from each plot were also counted and weighed.

Data analyses

We analysed onion growth, yield and quality parameters using standard analysis of variance.

Results and discussion

Irrigation

Irrigation treatment differentiation began 26 DAP for Planting 1 and 35 DAP for Planting 2. During the pre-treatment period, Planting 1 was watered 6 times, averaging 22 mm per irrigation. This planting also received 40 mm of rain, the bulk occurring in one 32 mm event (Fig. 2). Planting 2 received one irrigation of 23 mm 2 days before planting, then 3 irrigations in the following 10 days at an average 23 mm. Planting 2 received 13 mm of rain in the pre-treatment period, most falling in a single 8 mm event (Fig. 6). During the irrigation treatment periods, both plantings received 80-90 mm of rain.

Planting 1

Values for the 15 cm tensiometers in the 20 kPa treatment fluctuated between 0-20 kPa for the bulk of the growing period, with occasional higher peaks of 40-60 kPa on a few occasions (Fig. 2). Irrigation was withheld from 155 DAP until the onions were harvested. Deep tensiometer readings for the 20 kPa treatment indicate that subsoil layers remained moist for the first 118 DAP. The subsoil then began to dry out, reaching 50 kPa around 140 DAP. Rainfall then reduced matric suction to below 20 kPa. The subsoil gradually lost moisture until onion harvest, reaching a final value of approximately 55 kPa (Fig. 2). During the treatment period (16 weeks) these onions received 32 irrigations totalling 368 mm, averaging 12 mm every 3.5 days.

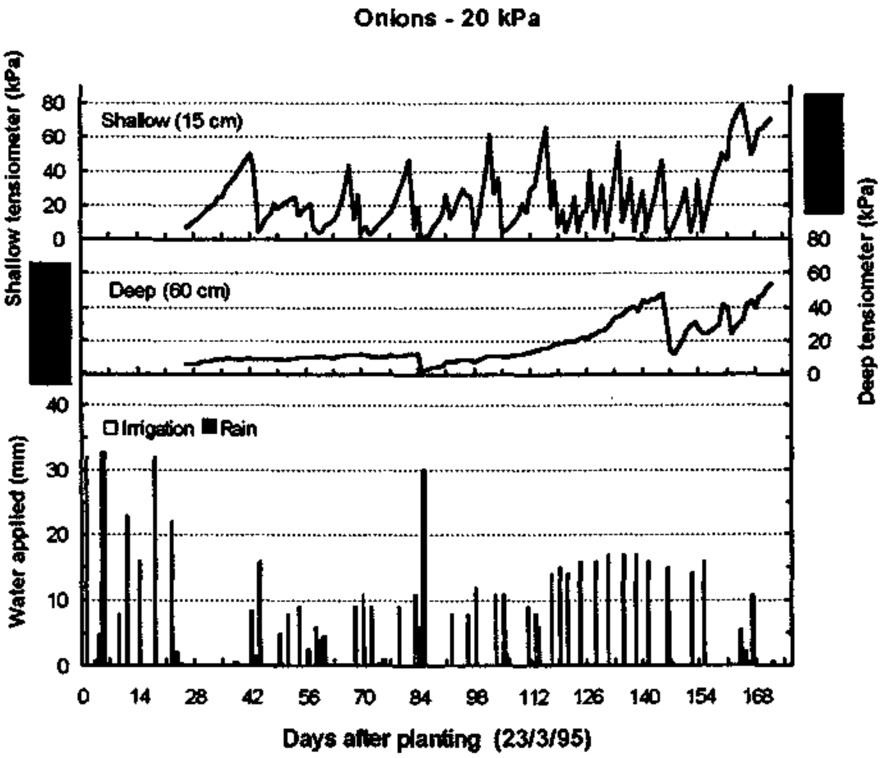


Figure 2. Fluctuation in tensiometer values for a drip-irrigated onion crop, watered when shallow tensiometer values reach 20 kPa (Planting 1)

Shallow tensiometer readings for the 35 kPa treatment ranged between 0 and 40 kPa during the growing period, with some peaks at 60 kPa. In the pre-harvest drying phase, tensiometer values reached 80 kPa (Fig. 3). The subsoil remained relatively moist for the first 112 DAP, with values less than 20 kPa. Values for the deep tensiometers then rose relatively steadily, to peak at around 60 kPa when the onions were harvested. This 35 kPa treatment received 25 irrigations during the treatment period; a total of 311 mm, averaging 12 mm every 4.5 days.

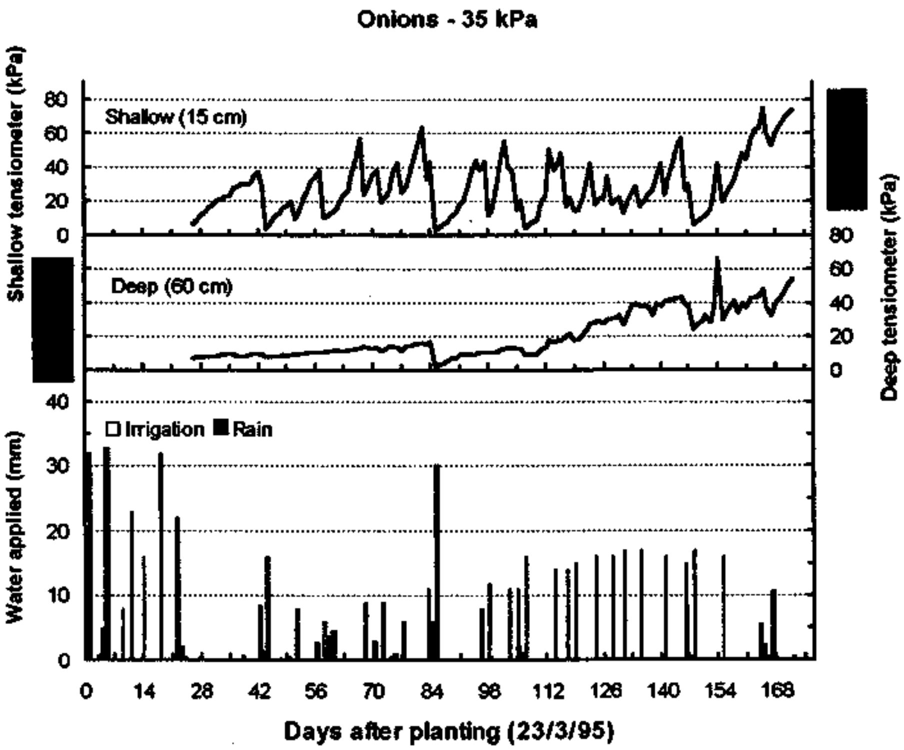


Figure 3. Fluctuation in tensiometer values for a drip-irrigated onion crop, watered when shallow tensiometer values reach 35 kPa (Planting 1).

The shallow tensiometer values for the 60 kPa treatment in Planting 1 rose to 60 kPa between irrigations, particularly during the latter half of the growing period (Fig. 4). Deep tensiometer values remained less than 20 kPa for the first 100 DAP, then steadily increased to 60 kPa when the onions were harvested. This treatment was watered 14 times during the treatment period, receiving a total of 199 mm of irrigation, averaging 14 mm every 8 days.

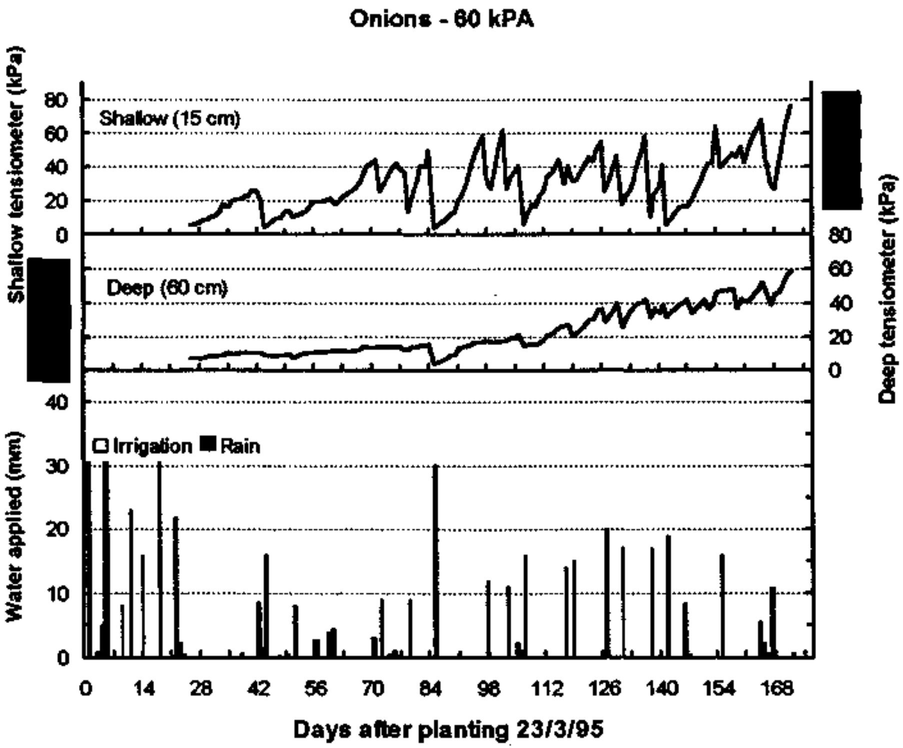


Figure 4. Fluctuation in tensiometer values for a drip-irrigated onion crop, watered when shallow tensiometer values reach 60 kPa (Planting 1).

Values for the shallow tensiometers in the 75 kPa treatment reached 60-75 kPa before irrigations in the first half of the growing period, but only rose to 50 kPa during the second half (Fig. 5). Values for the 60 cm tensiometers remained less than 20 kPa for the first 105 DAP, then rose to peak at 65 kPa before harvest. Irrigations at 149 DAP and 155 DAP re-moistened the subsoil to some extent, causing deep tensiometer values to dip below 20 kPa. This treatment was irrigated 13 times during the treatment period, totalling 158 mm at an average of 12 mm every 9 days.

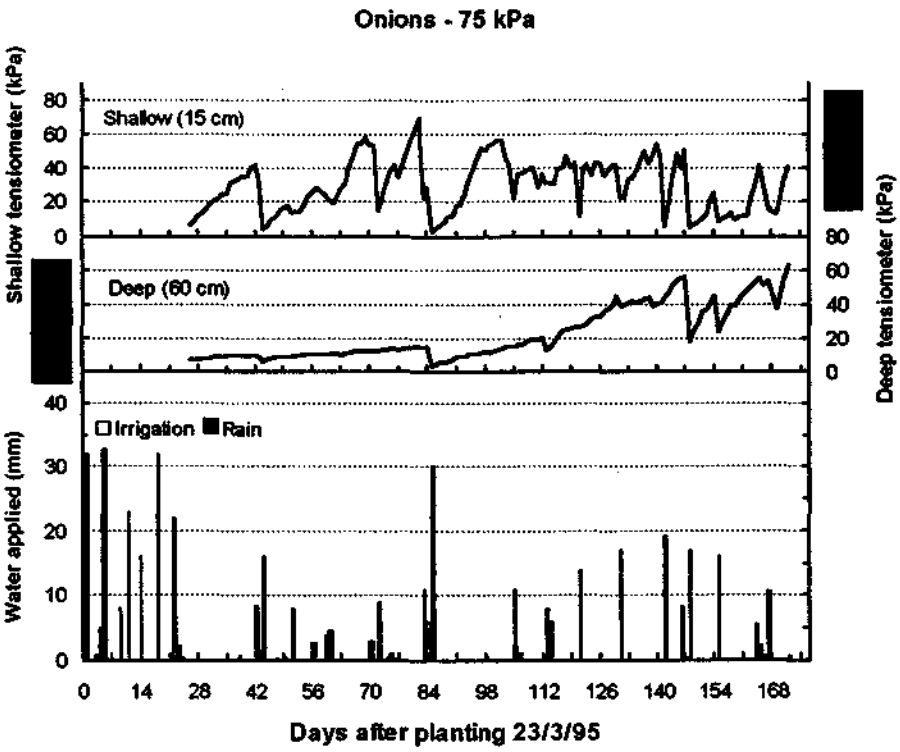


Figure 5. Fluctuation in tensiometer values for a drip-irrigated onion crop, watered when shallow tensiometer values reach 75 kPa (Planting 1).

Planting 2

Shallow tensiometer values in the 20 kPa treatment for Planting 2 fluctuated in the range 0-20 kPa for the growing period, with only very occasional higher peaks (Fig. 6). For the first 100 DAP deep tensiometer values remained below 20 kPa, after which they gradually rose to reach 60 kPa before the Planting 2 being harvested. This treatment received 35 irrigations over the treatment period of 19 weeks totalling 452 mm, averaging 13 mm every 3.5-4 days.

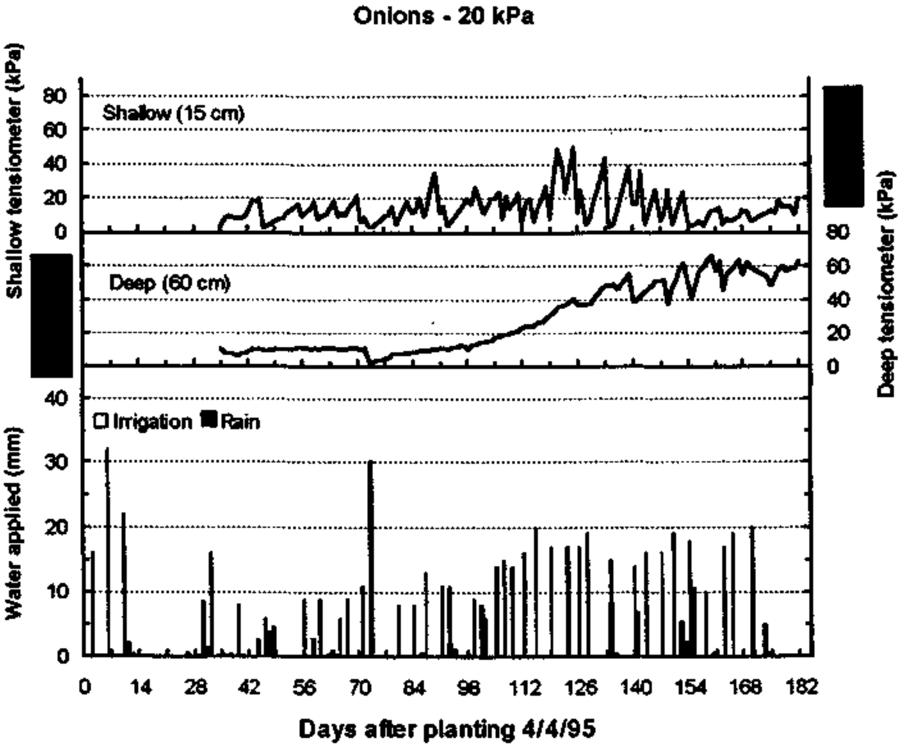


Figure 6. Fluctuation in tensiometer values for a drip-irrigated onion crop, watered when shallow tensiometer values reach 20 kPa (Planting 2).

Values for the 15 cm tensiometers in the 35 kPa treatment fluctuated between 0 and 40 kPa for much of the growing period, with many peaks of 60 kPa. Similar to the previous treatment, for the first 100 DAP deep tensiometer values remained below 20 kPa, after which they gradually rose to reach 50 kPa prior onions being harvested (Fig. 7). These plots were irrigated 31 times during the treatment period; a total of 407 mm averaging 13 mm every 4-4.5 days.

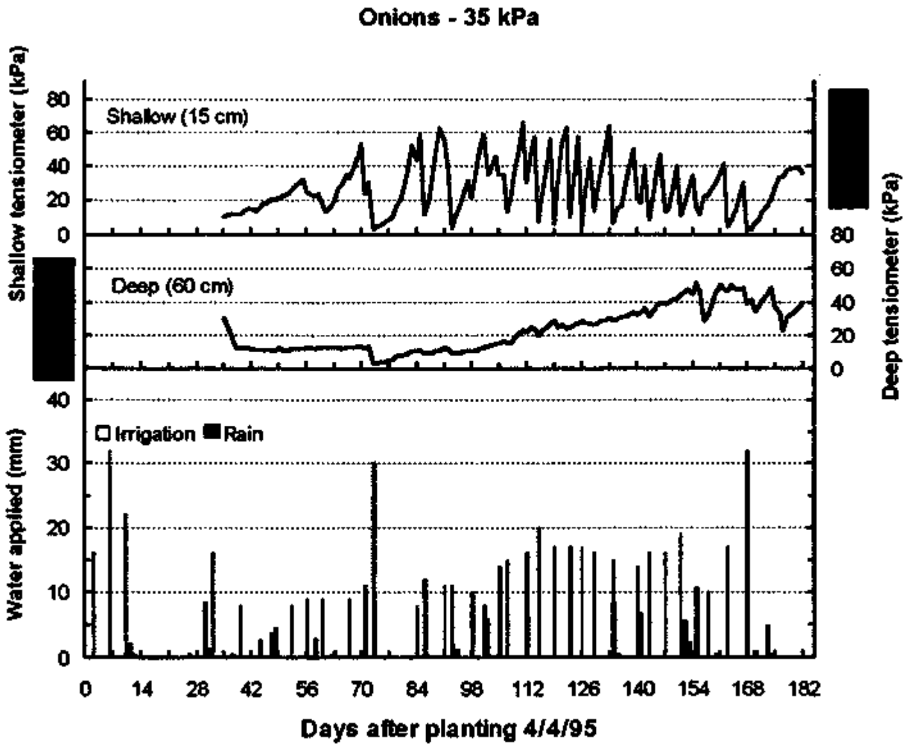


Figure 7. Fluctuation in tensiometer values for a drip-irrigated onion crop, watered when shallow tensiometer values reach 35 kPa (Planting 2).

Shallow tensiometer readings for the 60 kPa treatment fluctuated between 0 and 60 kPa during the growing period with an occasional peak at 80 kPa (Fig. 8). The deep tensiometers indicated the subsoil remained relatively moist right up to when the onions were harvested. This treatment received 21 irrigations totalling 276 mm, averaging 13 mm every 6-6.5 days.

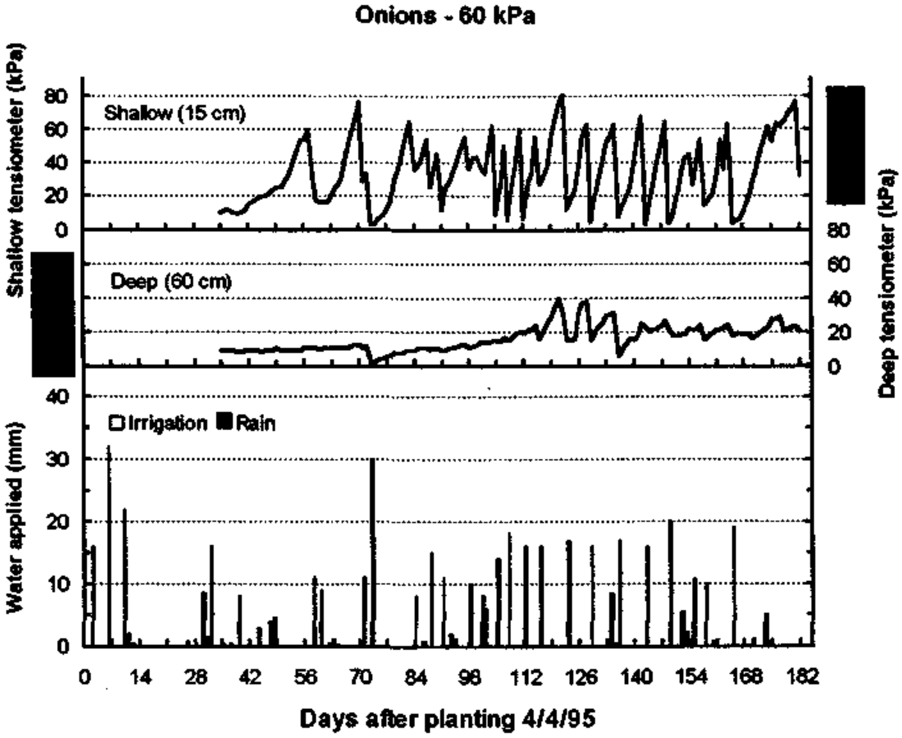


Figure 8. Fluctuation in tensiometer values for a drip-irrigated onion crop, watered when shallow tensiometer values reach 60 kPa (Planting 2).

The readings from the shallow tensiometers in the 75 kPa treatment rose to 70-80 kPa between irrigations for most of the growing period (Fig. 9). Whilst the deep tensiometer values remained below 20 kPa for the first 100 DAP, after that time they increased to a maximum of 70 kPa around 160 DAP, and remained relatively high until the onions were harvested. These plots were irrigated 19 times during the treatment period, receiving 270 mm, at an average of averaging 14 mm every 7 days.

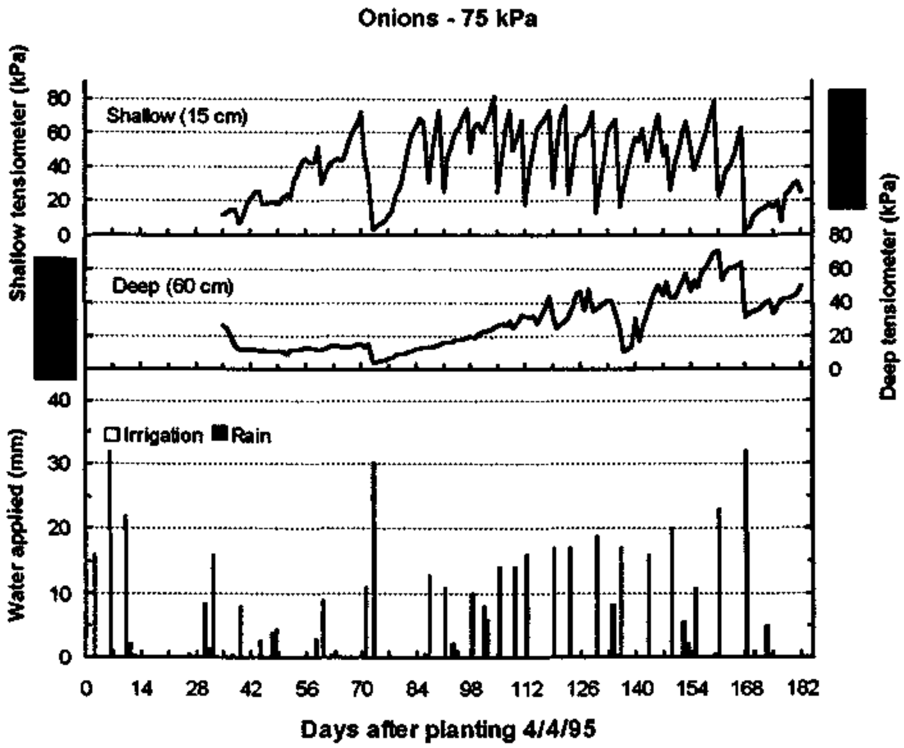


Figure 9. Fluctuation in tensiometer values for a drip-irrigated onion crop, watered when shallow tensiometer values reach 75 kPa (Planting 2).

Onion growth and yield

The different irrigation strategies did not significantly affect onion plant heights at any time of measurement in either planting (Fig. 10). There were consistent trends in Planting 2 for the onions in plots irrigated at a T of 35 kPa to be taller than those irrigated at T of 75 kPa.

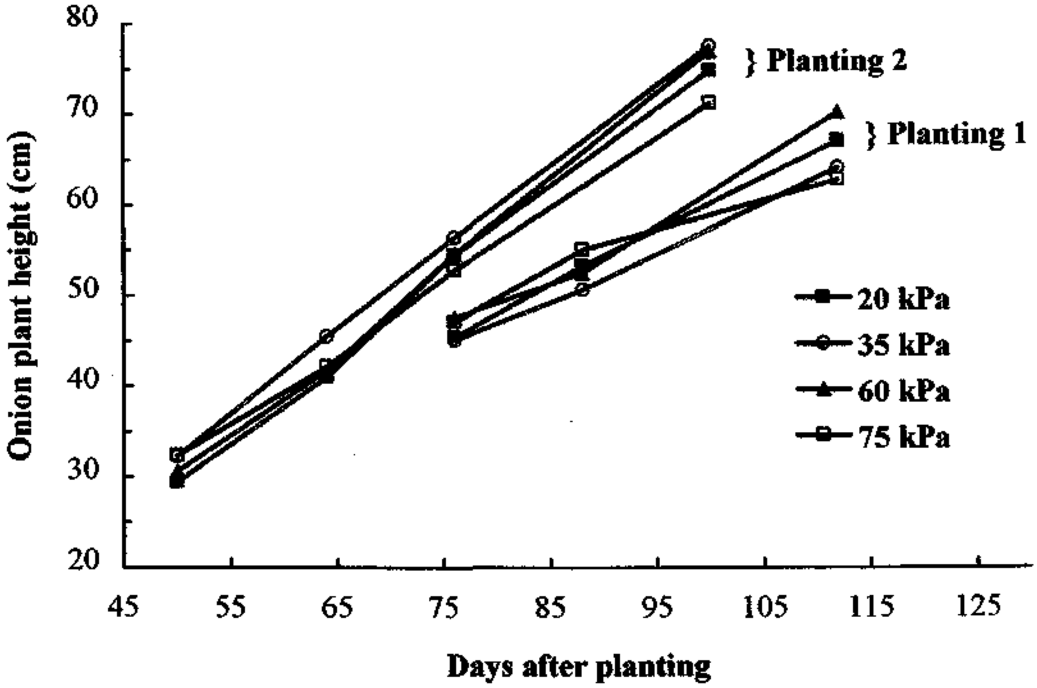


Figure 10. Changing irrigation strategies has no significant effects on the sequential heights of onion plants sown on 23 March 1996 (Planting 1) or 4 April 1996 (Planting 2).

In Planting 1, yields were maximised in the 35-60 kPa treatments, although the yield decline in the least irrigated plots was not significant (Fig. 11a). There were significantly greater yields of No. 1 and No. 1 large onions in the 35-60 kPa treatments, compared to onions irrigated at 75 kPa. This was because there were significantly more of those larger onions in the wetter treatments (Fig. 11b), while the 75 kPa treatment had more pickling grade onions. Average individual onion weights were 40 g for picklers, 125 g for No. 1 grade, 250 g for No. 1 large and 240 g for 'doubles'.

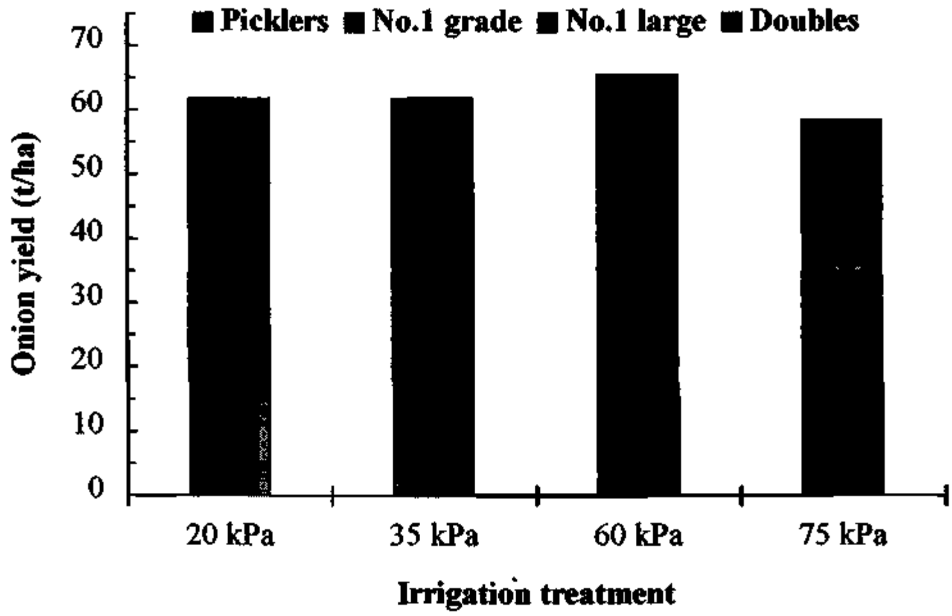
In Planting 2 the 20 kPa treatment gave the highest yields, with no significant differences between the other 3 treatments (Fig. 12a). However, there were slightly fewer total numbers of onions in the 35-60 kPa treatments, compared to the wettest and driest treatments (Fig. 12b). These differences in total onion numbers could not be attributed to irrigation, as differential watering would not affect the total numbers of bulbs harvested. Variations in numbers were therefore due to some random event outside the scope of this experiment. Further analyses of the data show consistent trends for a greater proportion of small onions in the drier treatments (Fig. 12b), ie. 20% picklers/No. 1 grade in 20-35 kPa plots, 25% in 60-

75 kPa plots. Average individual onion weights in Planting 2 were 45 g for picklers, 130 g for No. 1 grade, 285 g for No. 1 large and 265 g for 'doubles'.

In both plantings there was an extraordinarily high proportion of 'double' onions (circa 35-40%), mainly in the larger size bulbs (Figs. 11,12). In both plantings there were trends for a greater proportion of 'double' onions in the more frequently irrigated treatments. According to literature, some cultivars are more prone to doubling than others. It also seems to be exacerbated by high temperatures around sowing time, and high nitrogen and irrigation inputs.

Dry matter levels were 10-11% in Planting 1 and 9-10% in Planting 2, and were unaffected by irrigation management.

(a)



(b)

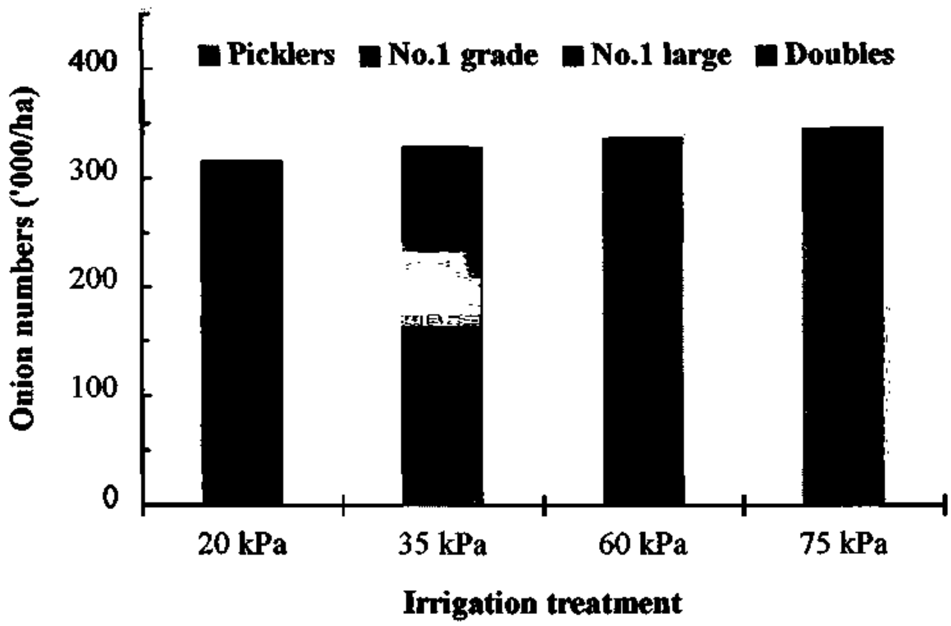


Figure 11. Increasing the critical tensiometer value for initiating irrigation slightly affects (a) yields and (b) numbers of onions in a range of size grades, in an experiment sown on 23 March 1996.

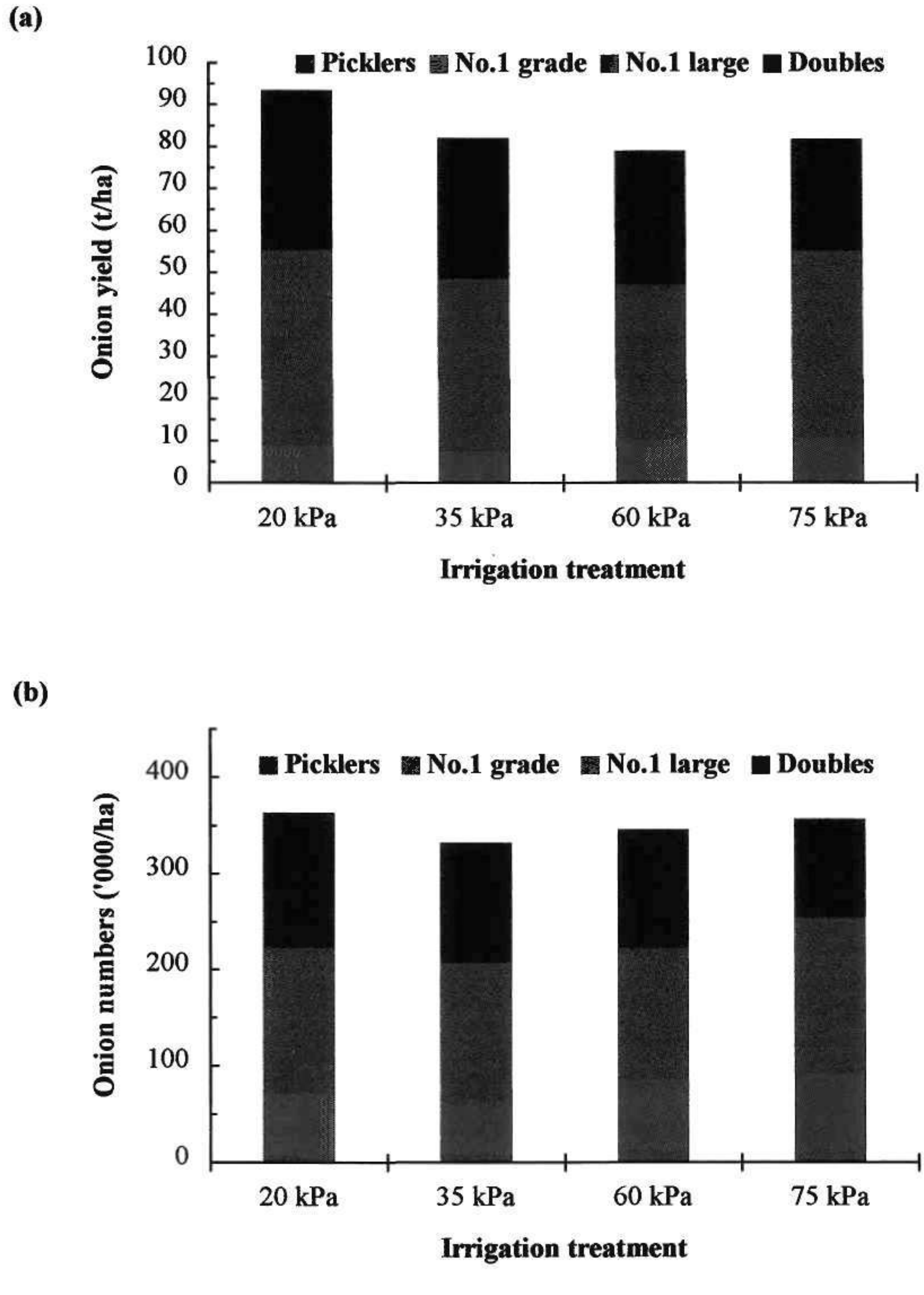


Figure 12. Increasing the critical tensiometer value for initiating irrigation slightly affects (a) yields and (b) numbers of onions in a range of size grades, in an experiment sown on 4 April 1996.

Conclusions

The higher yields in Planting 2 reflected slightly more onions, and marginally higher individual average weights in each size grade. From cultivar performance studies conducted at Gatton Research Station, yields of *Golden Brown* are known to decline as sowing dates are pushed earlier into mid-March.

Because of the extremely high proportion of 'double' onions in both experiments, conclusions on the implications of irrigation management on yields are difficult. Taking into account the inconsistent onion plant numbers in Planting 2, I still believe a tensiometer value of 35-60 kPa for triggering irrigation is optimum. The total amounts of water supplied (irrigation + rain) were 4.5 ML/ha to the 60 kPa treatment, increasing to 5.7 ML/ha for the 35 kPa treatment. Using drip irrigation, this involved 12-14 mm every 6-9 days in the former, increasing in frequency to every 4-5 days in the latter. In a situation where sprinklers are used, the amounts supplied and intervals between irrigations could probably be increased.

In previous experiments it has been shown that maximum onion yields are obtainable using a critical figure of ≅40 kPa for tensiometers installed 15 cm below the soil. The results from this experiment do not disprove that strategy. By using tensiometers, we were able to eliminate drainage due to excessive irrigation.

Future experimentation will be for demonstration purposes, confirming the validity of our current irrigation management advice.

Appendix 4. Example of report for Demonstrations F & G (potatoes)

Collaborative Monitoring of Irrigation Management in Commercial Potato Production, from May-October 1995.

A collaborative study conducted by:

Mr Craig Henderson, Senior Horticulturist, Gatton Research Station
Mr Mick Webber, Experimentalist, Gatton Research Station
Collaborating Potato Producer

Introduction

This study was part of a project demonstrating the use of tensiometers to manage irrigation in potatoes. We sought to show tensiometers indicating when crops require watering, and whether the amounts of water applied matched crop needs. Two sites were installed in the crop being monitored. At each site, a shallow tensiometer was placed 15 cm below the soil surface, with a deep tensiometer at 60 cm. The grower monitored the tensiometers on a regular basis, recording readings in a notebook. Amounts of irrigation and rainfall were also noted. Tensiometer sites were occasionally inspected and serviced by QDPI staff.

Results

Tensiometer, rainfall and irrigation data are shown in Figures 1 and 2. Because the 2 sites were irrigated independently, and responded somewhat differently, they are treated separately.

Between 40 and 70 days after sowing (DAS), irrigation of potatoes at Demonstration F was sufficiently frequent to keep shallow tensiometer values under 60 kPa, given the prevailing climatic conditions (Fig. 1). The combination of increasing crop leaf area and unseasonably higher evaporative demand during late July into early August (70-100 DAS) caused rapid increases in tensiometer values. The 8-10 day interval between irrigations during this period meant that shallow tensiometer values were around 70-80 kPa for several days prior to each irrigation. Slight stress on the potato crop may also be indicated by increases in the deep tensiometer values just before 100 DAS (Fig. 1). Rainfall and more frequent irrigation between 100 DAS and desiccant spraying reduced maximum tensiometer values during the latter bulking up and maturation period. Dips in deep tensiometer values following irrigations of around 30 mm suggest there may have been slight amounts of drainage following these water applications (Fig. 1). The quantities of water involved were probably not significant. In an ideal situation, around 25 mm, per irrigation would have been sufficient, on several of these occasions.

In contrast to Demonstration F, there were fewer intervals of 8-10 days between irrigations at Demonstration G, which seems to be reflected in the shallow tensiometer values (Fig. 2). Tensiometer values were only occasionally above 50 kPa, and rarely greater than 60 kPa. As with Demonstration F, there were a few occasions on which a minor amount of drainage may have occurred, however these would have been insignificant in comparison to the total quantities of water applied.

Comments

Between 6-20 weeks after planting, the potatoes at both sites received 72 mm of rain and 255-265 mm of irrigation. During the period from 9-15 weeks after planting, Demonstration F received 5 irrigations; averaging 25 mm per irrigation. Over the same period, potatoes at Demonstration G received 6 irrigations; averaging 20 mm per irrigation. It seems as though the timing of watering during this period had a substantial effect on the patterns of crop water use and hence shallow tensiometer readings. Given experiences with other potato crops, the irrigation regime at Demonstration F would only have had a slight impact, if any, on potato yields. The rapid rises in shallow tensiometer readings indicate a healthy, rapidly transpiring crop, with little limitation to growth. Demonstration G appeared to be close to an ideal watering pattern.

Overall yields measured by the producer were in then order of 40 t/ha for both blocks; good production for a commercial crop. There appeared to be a problem with brown centre (a precursor to hollow heart) in some of the Exton potatoes. The exact causes of this physiological disorder are not defined, however it can be associated with rapid tuber development, low temperatures and fluctuating soil moisture conditions. Some varieties are also more susceptible than others. It would be interesting to compare potatoes harvested from the 2 blocks, to determine if the slight changes in irrigation regime affected the incidence of brown centre.

The irrigation regimes in both blocks were relatively effective and efficient, particularly in the context of a limited water supply. Overall, the irrigation management of Demonstration G was probably close to a theoretical ideal, taking into account crop demand and soil water-holding capacities. Irrigation patterns would have resulted in no more than 15-20 mm of drainage during the growing period.

Acknowledgements

The collaborative efforts of the producers in conducting the day-to-day monitoring of the tensiometers and irrigation cycles are sincerely appreciated. Their commitment to the project maximised the information gained from the exercise. We hope that in return the collaborating producers gained some benefits as far as their approach to irrigation management in commercial potato crops is concerned.

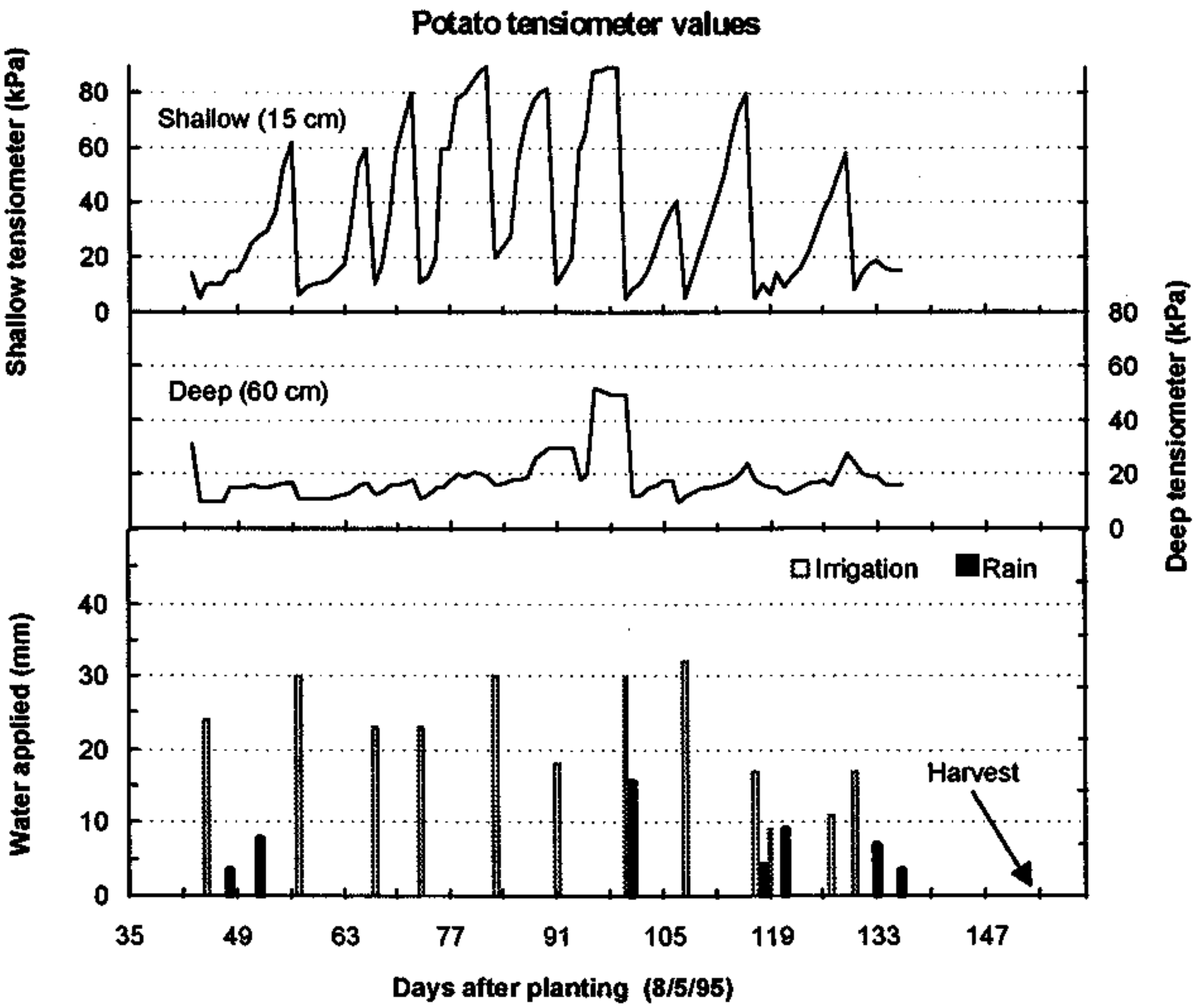


Figure 1. Changes in tensiometer values with irrigation and rainfall in a potato crop (Demonstration F).

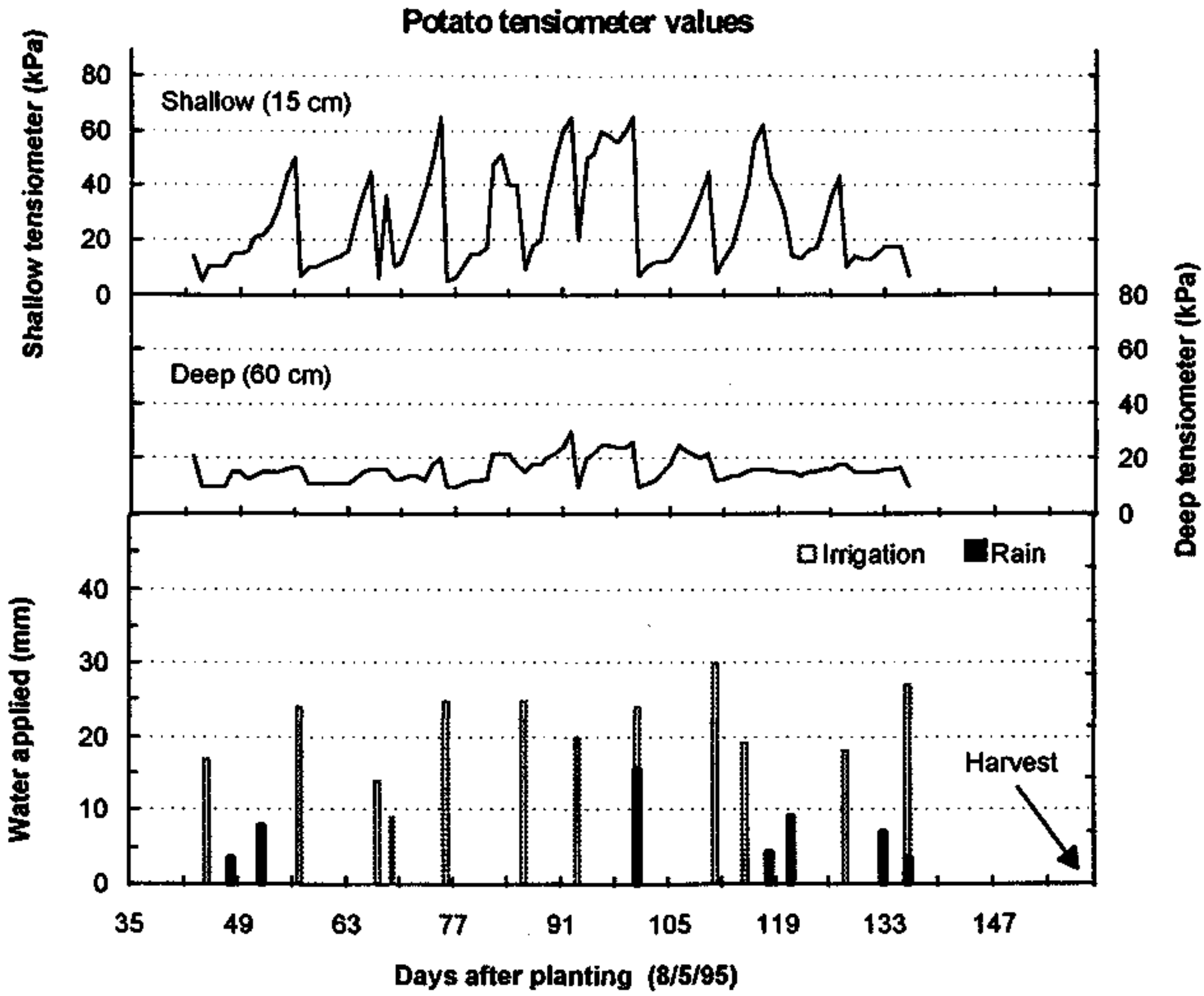


Figure 2. Changes in tensiometer values with irrigation and rainfall in a potato crop (Demonstration G).

Appendix 5. Example of report for Demonstration M (onions)

Collaborative Monitoring of Irrigation Management in Fresh Market Onion Production, from May-October 1995.

A collaborative study conducted by:

Craig Henderson, Senior Horticulturist, Gatton Research Station
Mick Webber, Experimentalist, Gatton Research Station
Collaborating Onion Producer

Introduction

This study was part of a project demonstrating the use of tensiometers to manage irrigation in fresh market onions. We sought to show tensiometers indicating when crops require watering, and whether the amounts of water applied matched crop needs. We installed 2 sites in the crop being monitored. Both sites were in close proximity, with Site A using JETFILL® brand tensiometers supplied by QDPI, and Site B using IRROMETER® brand tensiometers supplied by the collaborating producer. At each site, we placed a shallow tensiometer 15 cm below the soil surface, with a deep tensiometer at 60 cm. The producer monitored the tensiometers regularly during the growing season, recording readings in a notebook. Craig Henderson and Mick Webber regularly inspected and serviced the tensiometer sites.

Results

Average tensiometer, rainfall and irrigation data across the 2 sites, as well as individual data for each tensiometer, are shown in Figures 1 and 2 respectively. Between about 16 weeks after planting, and when the onions were harvested, values for both shallow and deep tensiometers at Site B, where the IRROMETER® tensiometers were used, were consistently higher. Rather than a difference in tensiometer brands, it is more likely that plant growth (either onions or weeds) and hence water use was greater at Site B. This demonstrated the importance of monitoring more than one site per crop, irrespective what equipment is used. The differences between the 2 sites do not substantially affect data interpretation. The following discussion will mainly refer to the average values shown in Figure 1.

For the first 9 weeks after planting, onion roots were only just starting to develop at the depth of the shallow tensiometer. During this period, all tensiometer values remained below 20 kPa. Only 2 irrigations of about 15 mm were applied during the 5 weeks following the heavy rain 4 weeks after sowing. The 10 day interval between water application (either irrigation or rain) during this initial period may have been too long, particularly given the sandy soil texture. The calculated average daily water use during this period, just over 1 mm/day, is somewhat less than expected. There would have been substantial deep drainage following the 30 mm of rain at 4 weeks after planting. This rain fell on a soil profile fully wetted by 25 mm irrigation the previous day. Drainage is indicated by dips in values for deep tensiometers.

From 10 weeks after planting until the onions were harvested, irrigation was much more frequent, and appeared to closely match crop demand. As expected in sandy soils, tensiometer values rose very rapidly once the profile started to dry. Readings for the shallow tensiometers rose from 15 kPa to 60 kPa within a few days (Fig. 1). It is unlikely that the onions suffered any significant water stress, as there were no prolonged periods where shallow tensiometer values were above 60 kPa. In addition, the deep tensiometers remained relatively static, at around 20 kPa for this latter half of the growing period. This suggests the crop was not having to take much water up from depth (frequently a sign of under-watering). Deep tensiometer values also indicate there was no excessive irrigation resulting in saturation of the subsoil, and subsequent excess drainage or leaching. During this 10 week period the onions received about 15 mm of water every 4-5 days, much closer to the expected requirements of a well-grown crop.

Comments

Irrigation of this crop can be separated into 2 distinct regimes; the first 10 weeks after planting, and from then until the onions were harvested. During the first period, the crop did not appear to use much water, and may have been slightly under-irrigated. During the latter half of the growing period, the onions received 70 mm of rain and about 180 mm of irrigation, with a mean daily water use of just over 3 mm per day. The irrigation frequency and quantity during this bulbing period were appropriate for onions growing on sandy soils.

Despite the relatively lengthy intervals between irrigations early in the cropping period, irrigation deficit was unlikely to have limited onion production. There was no evidence of excessive irrigation causing substantial through drainage or leaching.

Acknowledgements

I appreciated the collaborative efforts of the collaborating producer in regularly reading the tensiometers. I hope that he derived some benefit, with regard his approach to irrigation management in onions.

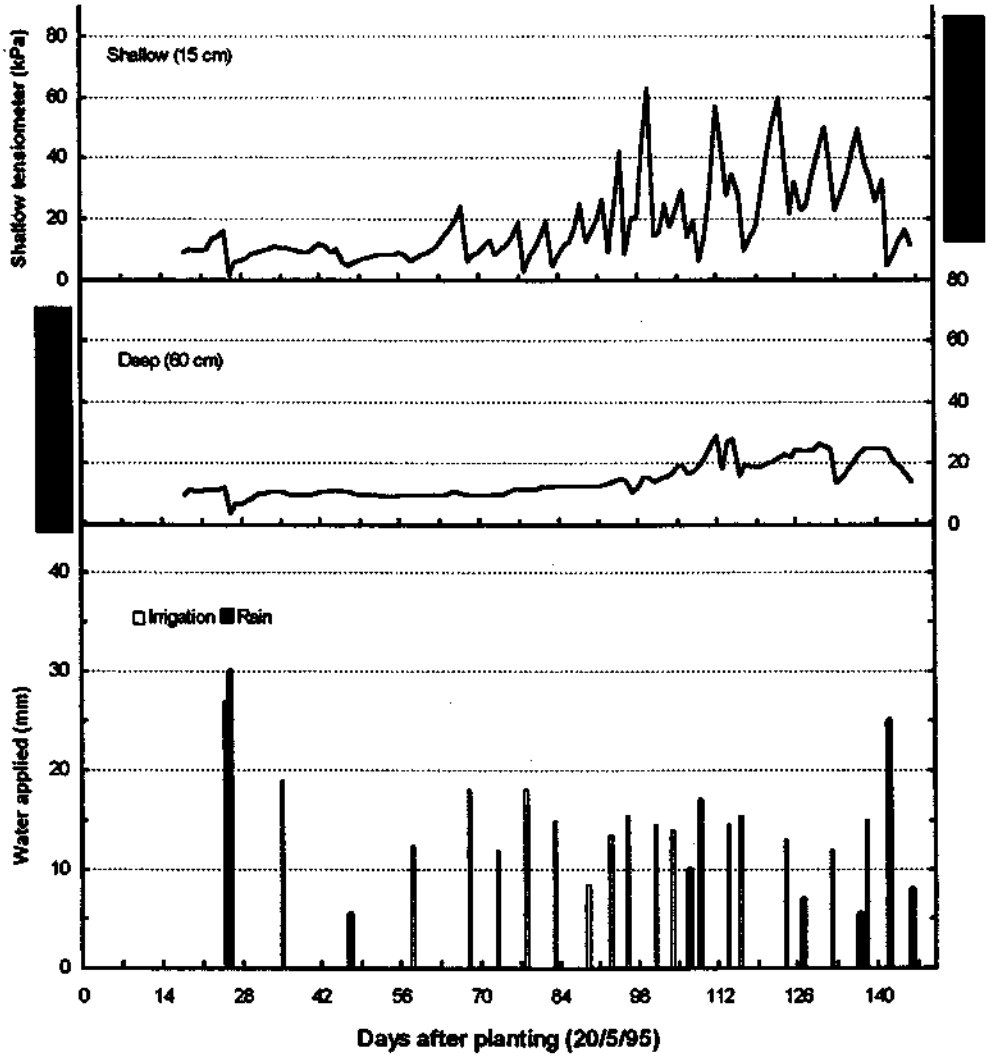


Figure 1. **Changes in average tensiometer values with rainfall and irrigation during the growing period of a fresh market onion crop.**

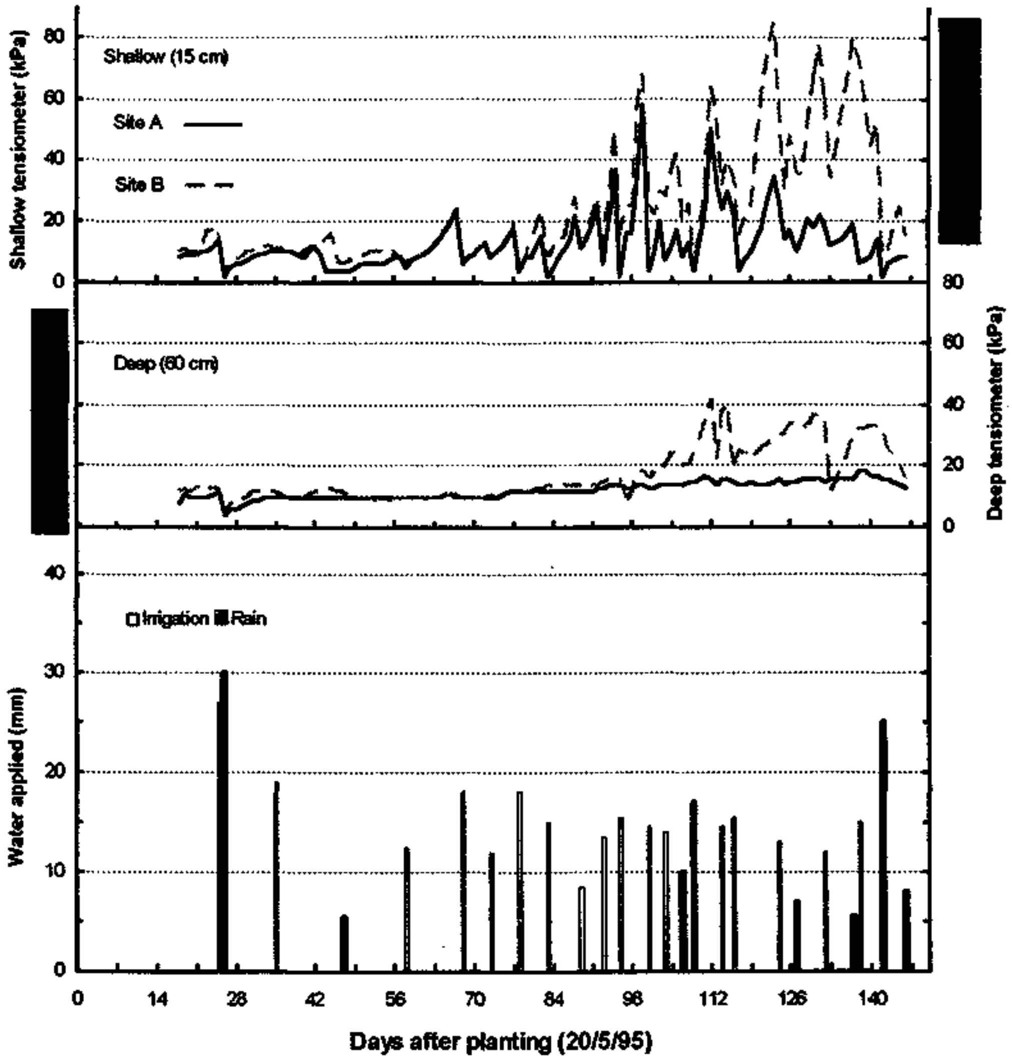


Figure 2. **Changes in individual tensiometer values with rainfall and irrigation during the growing period of a fresh market onion crop.**

Appendix 6. Irrigating Potatoes For Optimum Performance
(distributed to all collaborating producers)

Irrigating potatoes for optimum performance.

Summary

Potatoes are sensitive to water stress, and in most regions require regular irrigation for optimum production. In many current production areas, crops are not irrigated frequently enough, but are watered excessively at each irrigation. This leads to sub-optimal yields and water wastage. Potatoes are most sensitive to water stress during tuber initiation, and to a slightly lesser degree during tuber bulking. Potatoes are relatively shallow rooted; a well-grown potato crop in southern Queensland gets 85% of its water from the upper 40 cm of the soil profile.

Water stress during tuber initiation reduces the number of tubers set. Once this yield component is restricted, the loss cannot be regained by adequate watering for the rest of the growing period. Water stress during bulking results in smaller, often misshapen tubers. Diseases such as common scab, and physiological disorders such as brown centre, hollow heart, high stem-end sugar, etc. are exacerbated by poor irrigation patterns. Overall, experimental evidence has shown water stress during critical periods can reduce yields by more than 50%.

For optimum crop performance and efficiency of irrigation, a system of objectively scheduling irrigation is highly desirable. Although there are several methods of irrigation scheduling, using tensiometers to monitor soil water status is simple and relatively inexpensive. In southern Queensland, optimum production occurs if potatoes are irrigated when values for shallow tensiometers (ie. installed 20 cm below the surface of the potato hill) reach ≅40 kPa. Lower tensiometer values should be used in warmer conditions with high evaporative demand, or on sandier textured soils such as sandy loams. These critical levels are only guides; potato producers can develop different criteria for commencing irrigation as they become familiar with their irrigation and crop water use patterns.

A system of tensiometer installations can indicate the likelihood of plant stress, irrigation intervals and the adequacy of individual irrigations. Tensiometers give objective numbers defining soil and crop water status. These numbers, along with other factors that influence the need for watering (or withholding of water), will assist producers make their irrigation decisions. Factors that interact with irrigation include: disease incidence; crop nutrition; soil and water salinity; pesticide and fertiliser applications; availability of labour and water; cultivation, harvesting and field access requirements; etc.

The irrigation goal of successful potato producers is to optimise efficiency, crop performance and profitability, and assist in maintaining the quality of water resources.

Introduction

Often considered a field crop, potato plants are sensitive to water stress. High yields of quality tubers can only be obtained when potato crops are not stressed during their principal growth stages. In most areas where potatoes are produced in Queensland, this means regular irrigation is a standard practice.

Competition for water resources is becoming intense; pressure is being brought to bear on irrigators to use water more efficiently. The general community is concerned about pesticide and nutrient pollution of water. The cost-price squeeze common across all agricultural production is forcing producers to use their resources as efficiently as possible. Against this background, there is increased emphasis on irrigation management (and scheduling in particular) to optimise irrigation efficiency. In many instances, improved irrigation management can increase marketable yield, while reducing irrigation costs. It can conserve water, energy and fertilisers, with less risk of contaminating surface and groundwater with pesticides and nutrients.

Overseas, interstate and local investigations suggest there is potential for better irrigation management in Queensland potato production. Many producers probably do not irrigate frequently enough to maximise potato yields and quality, but apply excessive water at each irrigation. Experimental and commercial evidence indicates a high yielding potato crop needs consistently moist soil, avoiding large fluctuations in soil water content and excess drainage.

Research in the USA showed irrigation scheduling (based on evapotranspiration water budgeting), reduced water requirements by 40%, while maintaining tuber yields and quality. At Gatton Research Station, a potato crop yielded 41 t/ha where 370 mm of irrigation was applied; just 40 mm less irrigation during a critical period reduced yields by 20 t/ha.

This article describes irrigation requirements of potatoes, with particular reference to production in southern Queensland, although the principles are more widely applicable. It suggests a strategy on which to build a tailored irrigation management program for individual enterprises. The goal is to optimise irrigation efficiency, crop performance and profitability, and assist in maintaining the quality of water resources.

Potato plant growth and responses to water irrigation

In southern Queensland, potatoes generally take 16-17 weeks from planting until harvest; this varies with cultivar and seasonal conditions. The life of a potato plant can be divided into 5 growth stages:

(i) Planting to emergence (≅ 2 weeks).
(ii) Vegetative growth (≅ 4 weeks).
(iii) Tuber initiation (≅ 2 weeks)
(iv) Tuber bulking (≅ 6 weeks)
(v) Maturation (≅ 2 weeks).

The actual time for each growth stage also varies significantly with cultivar and seasonal conditions. Producers should dig up plants on a regular basis, to check plant and particularly tuber development. This is a significant part of any crop monitoring program.

Potato plants are sensitive to water status, with substantial declines in tuber yields and quality when subject to under or over-watering. The plant has a shallow, fibrous root system, with most roots in the top 30-40 cm of the soil profile. Potato roots have a limited ability to extract soil water. Potatoes recover more slowly from water stress than do other crops, such as cotton or sorghum. This is due to the physiology of potato plants (stomata operation, water uptake by roots).

For optimum yields, potatoes need to be irrigated when the crop has taken up 30-40% of the available water in its root zone. In Queensland, a well-grown potato crop gets 85% of its water from the upper 40 cm of the soil profile (measured from the top of the potato hill). In the alluvial soils of the Lockyer Valley, this means potatoes need irrigation (or rain) when they have used 25-30 mm of water from the soil profile.

Compared to other crops, potatoes are sensitive to water stress throughout their growing period. A worldwide research survey suggests potato yields decline by 11% for each 10% that irrigation is below optimum. The same survey showed yields and quality of potatoes were particularly sensitive to stress during tuber initiation and bulking. Using a theoretical example, a potato crop receiving 350 mm irrigation may yield 35 t/ha. If it received 10% less irrigation (35 mm), with the deficit spread evenly over the life of the potato crop, the expected yield reduction is around 4 t/ha. However, if that 35 mm deficit occurred entirely during the tuber initiation period, the yield loss is estimated at 10 t/ha, or about 25%.

The most important time to ensure potatoes are not subject to water stress is during tuber initiation. Although only a short 2 week period, it is when yield potential is determined. Water deficits during tuber initiation reduce the number of tubers set per plant. The number of tubers initiated during this phase places an upper yield limit - once restricted, any yield loss cannot be regained by improved watering during the rest of the growth period.

Water stress when tubers are bulking reduces tuber size (and hence yield), but also results in misshapen potatoes. Water stress can reduce dry matter and specific gravity of tubers. Good yields of high specific gravity potatoes are directly related to the amount of time tubers are bulking. Other aspects of potato quality tend to decline with increased levels of water stress during the tuber bulking period. Stress during early tuber bulking can increase the sugar content in the stem-end, adversely affecting processing quality. Diseases such as common scab (*Streptomyces spp.*) are increased by water stress during tuber initiation and bulking. Substantial water stress followed by irrigation can cause tubers to crack, suffer brown centre and hollow heart.

Although lack of water is the most common irrigation-related problem in potatoes, excessive irrigation can also cause difficulties, particularly during early growth, or when soil temperatures are cool. Over-watering reduces soil aeration, increases nutrient and pesticide leaching, and creates conditions favourable for disease development. Waterlogging following planting can delay emergence and promote seedpiece breakdown. In cool conditions, even otherwise optimal irrigation may reduce soil temperatures, predisposing tubers to powdery scab (*Spongospora subterranea*) infection, as well as inhibiting tuber initiation. Physiological disorders such as brown centre and hollow heart are exacerbated by over-watering.

The early vegetative stage, prior to tuber initiation and bulking, is less sensitive than the latter to water stress. Severe lack of water during the early vegetative stage will reduce the amount of leaf area developed. This can limit the ability of the potato plant to produce carbohydrate, for filling tubers during the rest of the growing period.

At maturity, soil water contents should be reduced (to ≅50% of available soil water), to promote firming of the skin and closure of lenticels (potato skin pores). This will reduce the risk of diseases such as bacterial soft rot (*Erwinia carotovora*). Moderate water deficits at maturity can enhance the specific gravity of tubers and reduce susceptibility to peeling or bruising during harvesting. However, excessive water stress at maturity can increase harvesting costs and tuber damage by causing machinery to work harder in dry soil. In clay soils, excessive drying and substantial soil cracking can enhance the risk of damage from potato tuber moth (*Phthorimaea operculella*) or skin greening.

Potato cultivars can vary in their responses to water stress at different growth periods. For example, cultivars that initiate fewer tubers per plant may be less sensitive to water stress during the tuber bulking stage.

Research results at Gatton Research Station demonstrate the importance of irrigation management in potato yields and quality. In an experiment with autumn-grown potatoes, the optimal treatment received 24 mm of irrigation every 4-5 days during the tuber initiation and bulking phases. A drier treatment was irrigated with 24 mm every 10 days. By stressing the crop at tuber initiation, the total number of tubers produced was dramatically reduced, particularly the #1 ((80-350 g) and large (>350 g) grades (Fig. 1). This was reflected in the overall yields (Fig. 2), with the stressed crop yielding 65% less #1 grade and 70% less large potatoes. Note that overall yields were depressed by purple top wilt virus, which was more severe on the water stressed potatoes.

In a second experiment with winter-grown potatoes, water stress treatments were not imposed until well after tuber initiation. In this case, both irrigation strategies yielded the same number of tubers overall, however the water stressed potatoes were smaller across all size grades. Thus the total yields for the optimally irrigated potatoes were 44 t/ha, while the crops stressed during tuber bulking yielded 32 t/ha.

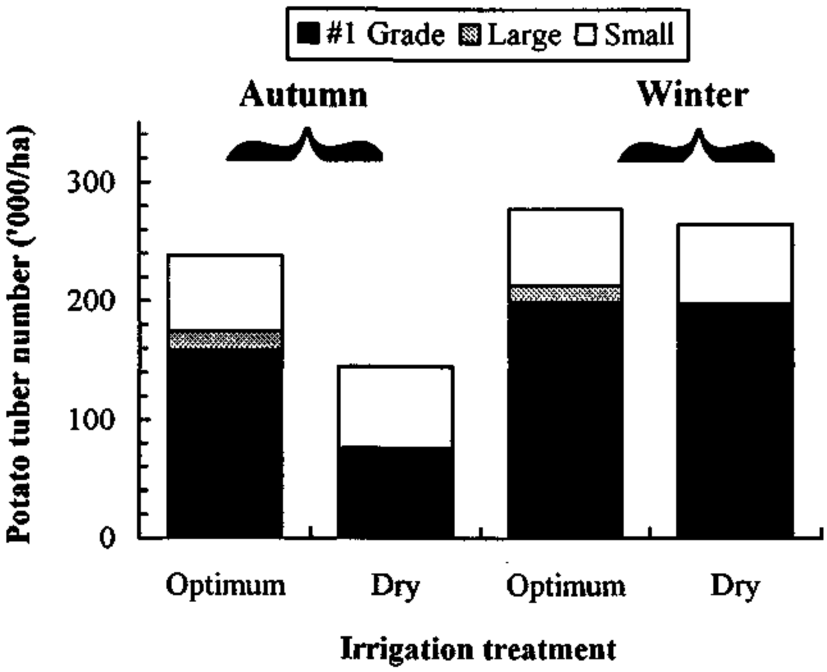


Figure 1. **In an autumn crop, water stress at tuber initiation severely reduced potato tuber numbers; in a winter crop, water stress during tuber bulking only reduced the number of large potato tubers.**

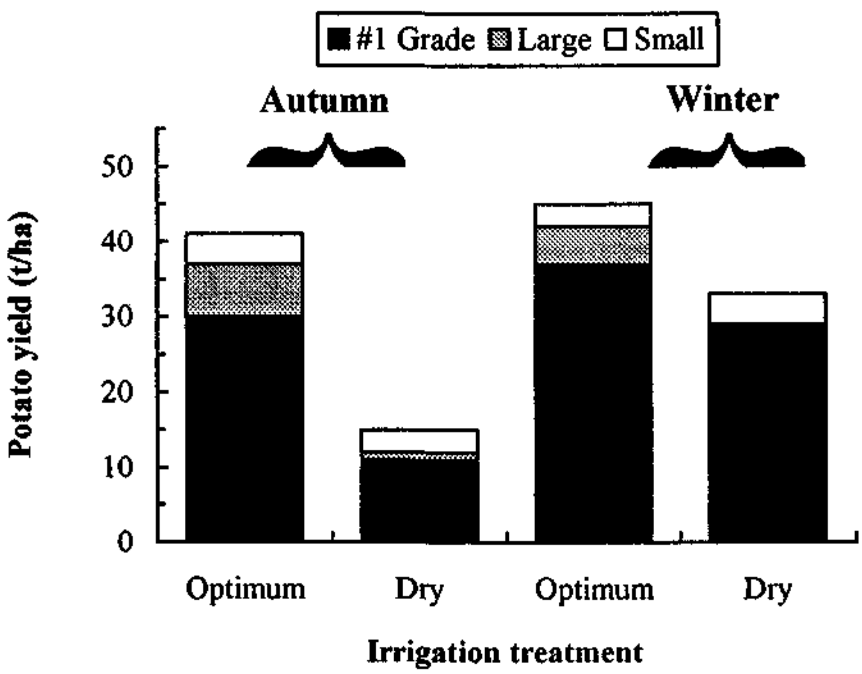


Figure 2. **In an autumn crop, water stress at tuber initiation severely reduced potato yields; in a winter crop, water stress during tuber bulking less dramatically reduced potato yields.**

Irrigation scheduling

Successful irrigation requires

(i) a water supply and irrigation system capable of delivering the required amounts of water when it's needed.

(ii) scheduling irrigation according to crop water use and soil water holding capacity.

Most potato crops in southern Queensland are irrigated with overhead sprinklers; either solid-set, hand-shift, travelling guns or lateral move systems. There is some use of drip irrigation, however this is not common. For optimum potato performance and overall irrigation efficiency, a system that can apply between 15-30 mm on a regular basis is necessary. During peak tuber bulking in warm conditions, irrigation may be required every 4 days for maximum potato production. On sandier soils, or where frosts are common, irrigation may be needed even more often. Hand-shift sprinklers or travelling guns may not be capable of applying small amounts at that frequency.

A range of equipment and techniques are available for scheduling irrigation in vegetable crops. Currently, the most common methods include assessing soil water status (using neutron soil moisture probes, tensiometers, or newly developed soil capacitance systems) or using a water budget to estimate crop water use and irrigation requirements.

Water budget systems based on estimates of evapotranspiration can work in potato irrigation, provided good pan and crop coefficients are available. Even so, such systems probably require occasional cross checking with direct soil monitoring devices, to ensure that water balance errors do not accumulate during the growing period.

Because most vegetables have the bulk of their roots in the top 30 cm of soil, any soil water monitoring device used for irrigation scheduling needs to concentrate on this part of the soil profile. Without intensive calibration, neutron probes are not very accurate at determining moisture contents in the upper 20 cm of the soil profile, although they are good at showing drainage beyond the root zone. New systems based on capacitance probes (eg. Enviroscan) work well at showing soil moisture contents at various depths. However, at $7-10,000 for an 8 sensor system, they are a substantial capital investment.

At Gatton Research Station, we use tensiometers as the most cost-effective method for monitoring soil water under shallow-rooted, quick-maturing vegetable crops. They are easy to install and use, give accurate, reliable readings, require little maintenance and are relatively cheap. One complication with tensiometer systems is determining the correct quantities (as opposed to frequencies) of irrigation to apply, to avoid excess losses through drainage beyond the root zone. Unlike the neutron probe, tensiometers do not measure the amount of water needed to refill the root zone. The quantity of irrigation applied at a given tensiometer reading relies on previous experience with the particular crop/soil type combination.

For information and descriptions of the use of tensiometers in vegetable crops, readers should refer to the QDPI booklet '*Water It Right - Irrigation using tensiometers*' or the Qld Fruit & Vegetable News article (September 23, 1993) '*Tensiometers in vegetables made easy*'.

Determining water stress by visual appearance of the potato crop, or using infrared thermometry to measure leaf canopy temperatures are not recommended. Neither method is sensitive, and allows levels of water stress sufficient to reduce yields and tuber quality.

Irrigation scheduling in potatoes

Following a water budget approach, a potato crop should only use 30-40% of the available soil water in its root zone before irrigating. On the alluvial soils of the Lockyer Valley, research has shown potatoes should be irrigated according to the following schedule:

(i) For the first month after planting (minimise irrigations between planting and emergence), irrigate after the crop has used ≅15 mm.
(ii) For the following month allow 20-25 mm water use between irrigations.
(iii) From then until the maturation stage, irrigate when the potatoes have used 30-35 mm.

For potato producers wishing to use tensiometers to schedule irrigation, a tensiometer site should include the following. One tensiometer is installed 20 cm below the surface of the hill, and another tensiometer 60 cm below the top of the hill (Fig. 3). Both tensiometers are placed midway between plants within the row, with at least 2 tensiometer sites per 5 ha of potato planting. Tensiometers should be read daily, or at least every 2 days, preferable at the same time each morning (best between 7 and 9 am).

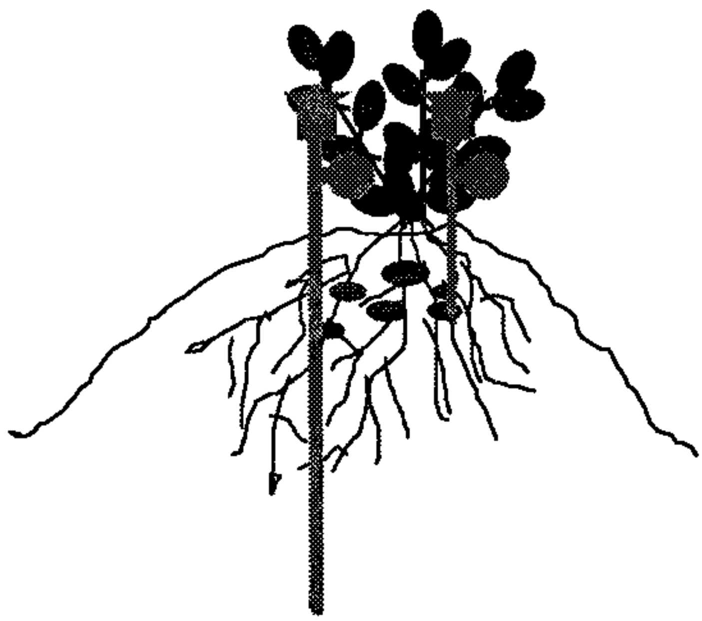


Figure 3. Diagrammatic representation of tensiometer placement in a potato row (section running the length of the row).

Overseas data suggests that for maximum production, potatoes should be irrigated when tensiometer values in the root zone reach 30-50 kPa, or when the potato crop has depleted 30-40% of available water. Our investigations in southern Queensland confirm that optimum production occurs if potatoes are irrigated when values for shallow tensiometers reach

≅40 kPa. Lower critical tensiometer values should be used in warmer conditions with high evaporative demand, or on sandier textured soils such as sandy loams. These critical levels are only guides; potato producers can develop different criteria for commencing irrigation as they become familiar with their irrigation and crop water use patterns.

As an example of how tensiometer information can be used, data from 2 potato producers' crops are shown in Fig. 4. Dips in shallow tensiometer values show where irrigation (or rainfall) has occurred.

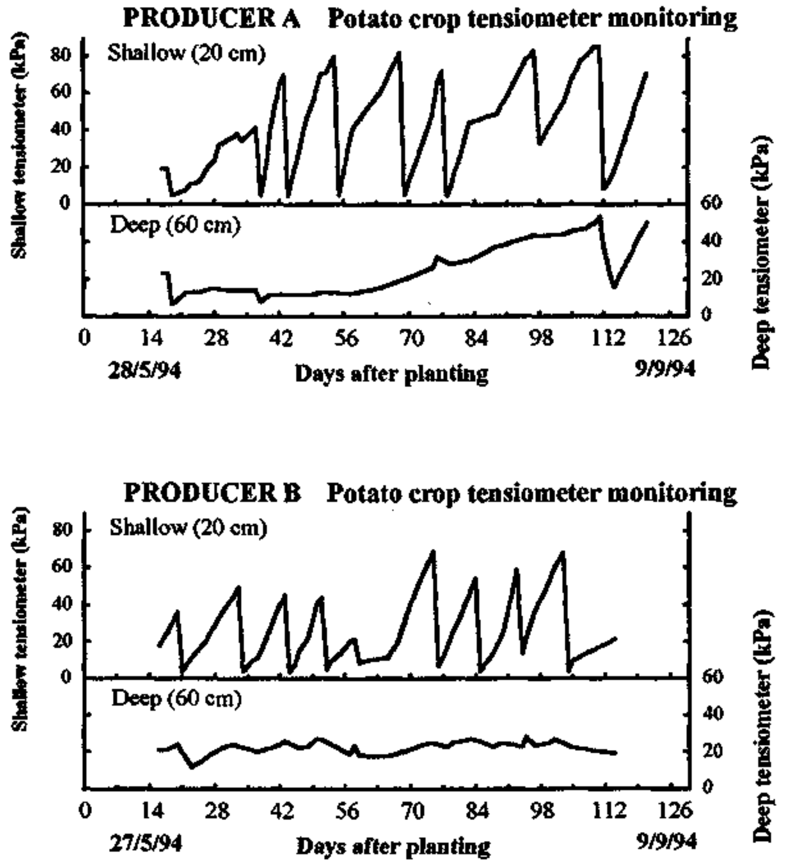


Figure 4. Tensiometer fluctuations in potato crops under 2 irrigation regimes.

Due to severe drought conditions, Producer A had limited water available, and was unable to irrigate as often as desired, particularly during the latter part of the tuber bulking period. This is confirmed by readings for the deep tensiometers, which gradually rose between 60 and 110 days after planting, indicating water uptake from deeper in the soil profile. This suggests the potatoes were not obtaining enough water from main section of the root zone (where the shallow tensiometers were located). Insufficient water was applied at each irrigation to refill the potato root zone, until a major irrigation about 112 days after planting (note the dip in both the shallow and deep tensiometer values at that time). The irrigation strategy adopted by Producer A was reasonable, given restricted water availability during the drought. Yields from this crop were still relatively good, indicating no severe or prolonged periods of water stress.

Tensiometer fluctuations shown for the potato crop of Producer B were close to ideal for an optimally irrigated planting. Note the shallow tensiometer values continually less than 50 kPa during the critical tuber initiation and early bulking periods. There were only a few days where tensiometer values were above 50 kPa during the rest of the growth period. The deep tensiometer values stayed around 20 kPa for the whole time the potatoes were in the ground. This indicated no substantial deep drainage of irrigation water, and no periods of extended water stress to the crop.

Interaction of irrigation with other agronomic factors

In Queensland, frequent irrigation for maximum yield results in large bushes with substantial leaf canopies. This may create a micro-climate more favourable for diseases such as *Sclerotinia, Alternaria*, etc. Potato producers need to take this into account in their pest management programs.

Too much available nitrogen at planting can delay tuber set and increase the number of small tubers. It is advantageous to have multiple N applications during the growing period, particularly on sandier soils with lower nutrient retention capacities. A nutrient monitoring program, involving pre-plant soil testing and in-crop tissue or sap testing is recommended to be used in conjunction with irrigation scheduling, in order to optimise crop performance and minimise leaching losses.

Potatoes are classified as moderately sensitive to soil salinity; overseas research suggests a 25% yield reduction where irrigation water has an electrical conductivity of 2.5 mS/cm. In practice, some producers have successfully grown potatoes with water of this quality, provided adequate leaching occurs.

Potato irrigation program

Where irrigation water is limited, the potato growing enterprise should maximise yields over a reduced area, rather than spread the limited water supply over larger areas. In humid regions with more frequent rainfall, producers may be more willing to risk the chance of timely rainfall. If irrigation per unit area is restricted, irrigation should cover the most critical periods (tuber initiation and bulking), with selection of cultivars more tolerant of water stress. Potatoes are more tolerant of stress during the early vegetative growth stage and late tuber bulking. Water deficits can be allowed immediately prior to and during maturation. This makes harvesting easier, improves the dry matter content of tubers, and makes full use of stored soil water. Soils should not be allowed to dry excessively during this period, otherwise harvesting becomes difficult, with bruising and tuber damage more likely.

Using criteria of irrigating to refill the potato root zones when shallow tensiometers reach 40 kPa, guideline irrigation sequences can be developed for cultivar/soil/climate combinations. For example, with Sebago potatoes planted at Gatton Research Station in July, the following program is our estimate of irrigation requirements for the growing period. For the first 2-3 weeks after emergence, irrigate with 15-20 mm per week, increasing to 25 mm per week during initiation and early bulking, and then 25-30 mm every 5 days until maturation commences. By using tensiometers, this baseline program of irrigation timing can be altered during the season to take into climatic variations and crop vigour. High levels of crop water use, and thus high yield potentials, can only be achieved if other agronomic factors, such as nutrition, pest and disease management are also optimised.

An average value for the total amount of irrigation required to produce an optimum potato crop in southern Queensland is ≅350 mm (ie. 3.5 ML/ha) on the ground. Producers may have to pump a greater water volume, to take into account evaporative losses and other inefficiencies in their irrigation systems. Obviously any rainfall would reduce requirements, although there may still be a need to irrigate for other purposes, such as frost control, fertiliser or pesticide incorporation. Irrigation regimes will also be affected by cultivar selection and agronomic practices.

Because of high fertiliser requirements, there are significant risks of groundwater contamination where excessive irrigation occurs in potatoes. In sub-humid and humid production areas, it may be important to leave a reserve of unfilled soil water storage, to act as a buffer against leaching rains. This can be achieved by growing potatoes after a deep-rooted crop (such as forage sorghum) used to dry out the soil profile, and/or deficit irrigation (not completely refilling the root zone at each irrigation).

As producers are aware, timing and amounts of irrigation are influenced by factors other than soil moisture and plant water requirements. Irrigation must be incorporated in the whole crop management program, taking into account; application of herbicides, fungicides, insecticides and fertilisers; cultivation; field access, harvesting, etc. The decision to irrigate is affected by the type of irrigation system used, the availability of labour, and the availability of water. The presence of foliar diseases such as Alternaria or Sclerotinia, may influence the irrigation pattern. Potato producers may wish to apply sufficient water to get a small amount of drainage at each irrigation. This is essential when using poor quality water; the saltier the water the more leaching is required at each irrigation. By irrigating to achieve a small amount of drainage beyond the root-zone, the interval between irrigations can be slightly extended. This is because (a) such a policy ensures the root-zone is completely filled and (b) some water will move back up into the root-zone from the subsoil via capillary action. In many situations this can be a viable irrigation strategy, provided the drainage is not excessive.

Conclusion

Yields and quality of potato tubers are highly dependent on irrigation practices. For optimum crop performance and efficiency of irrigation, a system of objectively scheduling irrigation is highly desirable. Although there are several methods of irrigation scheduling, using tensiometers to monitor soil water status is simple and relatively inexpensive. A system of tensiometer installations can indicate the likelihood of plant stress, irrigation intervals and the adequacy of individual irrigations. Tensiometers can give objective numbers defining soil and crop water status. These numbers, along with other factors that influence the need for watering (or withholding of water), will assist the producer make the final irrigation decisions.

Further reading

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Acknowledgements

Much of the research and development work on which this article is based was funded by the Queensland Fruit and Vegetable Growers and the Horticultural Research and Development Corporation. I thank both organisations for their valuable assistance. In the process of carrying out the R & D, we collaborated with QDPI personnel and potato producers, whose cooperation is gratefully acknowledged. Special thanks to Ken Jackson, John Kerr, Craig Wilson, Barry Stefan, Dudley Peck, Gary Jamieson, David Hood and Murray Hughes.

Appendix 7. Article on Tensiometers In Vegetables Made Easy (distributed to all collaborating producers)

Tensiometers in vegetables made easy

By Craig Henderson, Department of Primary Industries, Gatton Research Station

Introduction

Irrigation scheduling means knowing when and how much water a crop needs. The right decisions can increase yields and reduce wastage of irrigation water. In a recent experiment, irrigation scheduling improved marketable sweet corn yield by 4 t/ha and reduced the total irrigation by 75 mm. We have successfully used tensiometers in vegetables such as lettuce, brassicas, beans, sweet corn and potatoes. This article discusses general issues about using tensiometers in vegetables.

Tensiometers in theory

Tensiometers measure availability of soil water to plants. Common designs consist of 4 basic parts (Figure 1). In wet soil, the vacuum gauge displays 0 to 5 units (kPa or centibars). As the soil dries over several days, water moves from inside the instrument, through the porous ceramic tip, into the soil. The gauge reading steadily increases, to a maximum of about 90 kPa. When the soil is re-wet after rain or irrigation, water moves from the soil back into the tensiometer and gauge readings fall.

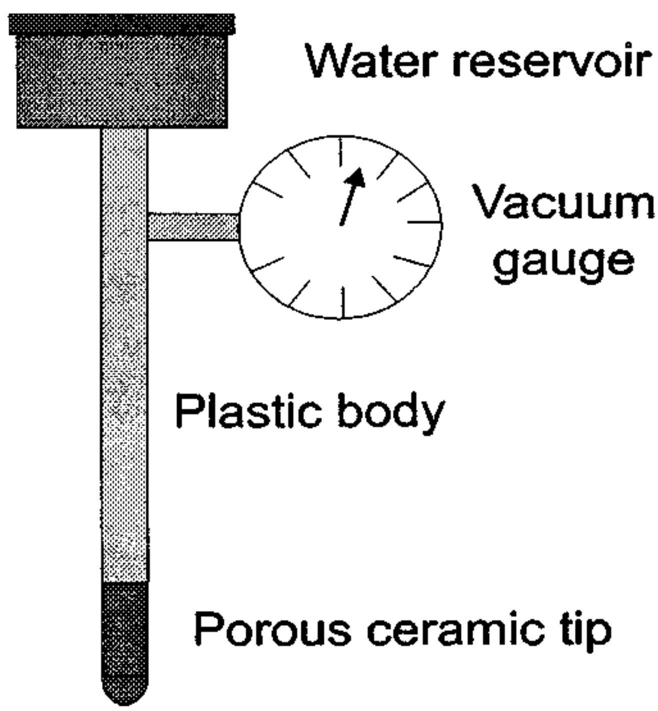

Figure 1. Design of a standard tensiometer.

In vegetables, a monitoring site consists of one shallow tensiometer installed in the major root zone, and one deep tensiometer below most of the roots (Figure 2). A crop planting should have at lease 2 monitoring sites. Shallow tensiometers should be placed within 10 cm of the crop row and midway between plants, although this can vary slightly. We install the shallow tensiometer with the tip 15 cm below ground. The deep tensiometer is located 45 cm below ground level for shallow rooted vegetables (e.g. onions, beetroot, lettuce, brassicas) and at 60 cm for other vegetables. Tensiometers should be installed after the crop is established, disturbing the plants and surrounding soil as little as possible.

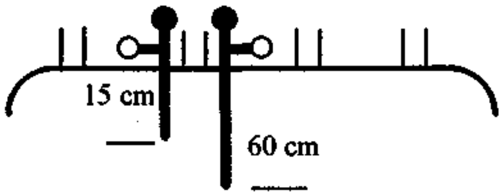

Figure 2. Profile of a typical tensiometer monitoring site in onions.

The shallow tensiometer indicates when to water, e.g. for winter lettuce at Gatton Research Station we irrigate at a value of 25 kPa. The deep tensiometer tells us whether we have applied the right amount of water. Deep tensiometer readings falling to less than 10 kPa within 2 days after irrigation suggest we have more water than the root zone could hold. Constant values after irrigation indicate we have filled the root zone. Readings continuing to rise immediately after irrigation mean we have added less water than the root zone could hold.

Tensiometers in practice

Although available for more than 50 years, tensiometers have not been commonly used in vegetables because of perceived problems with installation, maintenance, use and interpretation. These can be overcome by combining new tensiometer designs with simpler ways of using them. In much of the information about tensiometers, exacting procedures, (e.g. only using pre-boiled water to fill tensiometers; drilling precise installation holes, servicing tensiometers with a vacuum pump every few weeks are frequently stressed as essential. My feeling is that many of these procedures over-complicate tensiometer use. Since 1989, we have installed more than 1000 tensiometers using the following methods, with an overall failure rate of less than 5% (usually due to cracked tips). In the final analysis, there is no substitute for hands-on experience and familiarity.

Preparing for use

Assemble tensiometers and fill with good quality water (to which algaecide has been added). Leave them to stand in a bucket of water at least overnight, but preferably for 1 to 2 days. No water needs to be pre-boiled. Tensiometers are more reliable if an appropriate vacuum pump is available. Top up the tensiometers with more water if necessary. They are now ready to install.

Installing

Carry the tensiometers to the installation site with the tips either in water or wrapped in wet rags. Provided the ground is moist and well cultivated, the shallow tensiometer can simple be pushed into the soil to the appropriate depth (usually 15 cm). Don't push too hard! The tips are strong, but can crack under excessive pressure. Only experience teaches how hard is too hard; at $30 per tip, this is not a cheap lesson. If you encounter a hard soil layer, either take the tensiometer out and try somewhere else or use the deep tensiometer procedure.

To install the deep tensiometer, first make a hole to the required depth, keeping the excavated soil nearby in a pile. We have found a 50 mm (2 inch) auger the best tool. Place the tensiometer in the hole, over to one side. The next step is critical!

Good contact between the ceramic tip and the surrounding soil is very important. Take the most crumbly, moist soil from the dirt pile and pack it around the tip at the base of the hole. A piece of 10 to 15 mm diameter dowel is useful for packing. Do not over-compact the soil into plasticine, but remove any large air gaps. Continue replacing soil until the hole is filled. It does not matter which soil you use once you have packed the first 5 cm above the tip. Friable topsoil from a few metres away can be used to create a slight mound around the tensiometer; this minimises water draining down beside the tensiometer leading to false readings. Covers (made from silver/blue insulation foil) placed over the tensiometers minimise temperature fluctuations and algal growth. The gauge can be left exposed for easier reading. Covers are not essential, particularly where crop canopies develop quickly.

The tensiometers are now ready to operate. The vacuum pump can again be used to remove air bubbles. Tensiometers may take a few irrigation cycles to settle down, so do not take too much notice of the readings for the first few days. During this period, air gaps may appear in the tensiometer; simply refill with algaecide-treated water. Within a week of installation, readings should rise and fall with irrigation and rainfall. Check tensiometers early in the morning, at least twice a week (preferably every 1 to 2 days). Lightly tap the gauge before reading. Clearly mark tensiometer locations, or else they will fall victim to tractors, harvesters, rotary hoes etc.

Troubleshooting

No water in the tensiometer; gauge reads 0 kPa

There is either a crack in the ceramic tip or a faulty seal. Fill the tensiometer with water and apply suction with a vacuum pump. A stream of large bubbles will indicate the problem area; usually a cracked tip or a missing o-ring.

Air entering over several days; gauge registering more than 5 kPa

There is either a hairline crack in the tip, or a substantial air gap in the soil around the tip. Remove the tensiometer; if there are no obvious tip cracks then re-install the tensiometer. If the problem persists, replace the tip.

No change in readings over several days

The gauge may be faulty or blocked. Check the gauge is working by:

1. applying suction to the tensiometer with a vacuum pump, or

2. remove the gauge, rinse with clean water and suck it. If the needle does not move there is a problem with the gauge.

Tensiometer readings increase beyond 80 kPa then fall to 0 kPa, accompanied by air in the tensiometer

The soil has become too dry for the tensiometer to operate. After irrigation, refill the tensiometer and treat as if it had just been installed. If this happens frequently, consider whether you are under-irrigating. If you are happy with your irrigation, try installing the shallow tensiometer slightly deeper. This problem should never occur with the deep tensiometer.

How do I get into tensiometers?

A good 'grower starter pack' would include two 30 cm and two 60 cm tensiometers, a suitable vacuum pump, algaecide and a 1 m long 50 mm diameter auger (total cost less than $600). The best tensiometers have replaceable tips, gauges and reservoirs. If you can borrow equipment, even better.

Tensiometers should be installed at 2 monitoring sites in a single crop. Continue usual irrigation practices; get a feel for how tensiometers operate. Once comfortable with using them, make slight changes to your irrigation and observe what happens. For example, if deep tensiometer values always fall after irrigation, reduce the amount you apply.

Tensiometers are easiest to use in overhead-irrigated vegetables; flood, furrow and drip irrigation systems are more complex, because tensiometer positioning is more critical.

Anyone wanting more details information on tensiometers, or irrigation scheduling in general, can contact **Craig Henderson at Gatton Research Station 07-5462-1122.**