PT509

Irrigation managment for crisping potato growers in southern Queensland

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Qld Department of Primary Industries

Know-how for Horticulture™

PT509

This report is published by the Horticultural Research and Development Corporation to pass on information concerning horticultural research and development undertaken for the potato industry.

The research contained in this report was funded by the Horticultural Research and Development with the support of the Queensland Potato Crisping Grower Group and Smiths Snackfood Company.

Cover price: $20.00
HRDC ISBN 1 86423 593 4

Published and distributed by:
Horticultural Research & Development Corporation
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Gordon NSW 2072
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Acknowledgements

I wish to gratefully acknowledge the generous financial support from the Queensland Potato Crisping Group, and the Horticultural Research and Development Corporation. Special thanks to all the crisping potato producers, their partners and staff, who collaborated with us and were the key people in the whole project. They included; Gary Jamieson; Pat, John, Noel and David Keller; Lyle and Peter Grayson; Carolyn Taylor, David Vardy and Terry Banditt; John and Joe Foley; John Lennon; Brian Metcalfe and Ian Thomas; Gordon Fritz and Neville Cayley. Thanks also to Gary O'Neill, Northern Field Officer from Smiths Snackfoods, for his advice and assistance.

Craig Henderson

Dedicated to the memory of John Lennon, potato grower, colleague and gentleman.

Industry summary

Crisping potato producers in southern Queensland were concerned about irrigation management and its effects on yields and tuber quality. A project evaluating their irrigation strategies and demonstrating irrigation scheduling using tensiometers was initiated. We used commercial-scale demonstrations and producer collaboration to maximise interaction and the chance of adoption of proven technology. Eleven producers were involved in a total of 12 completed Demonstrations. Other Demonstrations were incomplete because of equipment failure, infrequent tensiometer readings, or most commonly, adverse weather.

Collaborating producers were provided with information on irrigating potatoes 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 for the life of the potato crop. QDPI staff maintained and serviced the tensiometers as required in most instances. At the end of each Demonstration, producers were sent a written report detailing findings for their individual situation.

Most of the collaborating producers were effective and efficient irrigators. Crops were watered when values for shallow tensiometers (installed 20 cm below the top of the potato hills) reached 50-60 kPa. This is within the acceptable range for optimum potato production. Only 2 of the 12 Demonstrations suggested significant periods of water stress in the monitored crops. Both these Demonstrations had lower yields than the group average. Using tensiometers enabled many producers to judge the value of intermittent rainfall, and thus extend the interval between irrigations, without stressing the potatoes.

Producers with hand-shift and travelling guns tended to irrigate less frequently than those with solid-set or linear-move systems. The former also applied more water at each irrigation. At one site, it was evident that the linear-move irrigator was applying water at an intensity that was too high for the soil to accept. Water was running off the hills and penetrating in the furrows; the potato hills thus remained dry for extended periods. By monitoring irrigation and soil water status, the producer evaluated whether modifications to his irrigator were effective.

In most situations, 25-35 mm of irrigation was sufficient to fill the root zone of well-grown potato 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 tuber yields or quality. In this project we found mean tuber yields consistently 10 t/ha greater than the fresh market average. Most of this increase can be attributed to more careful management of the potato crops; the relatively efficient and effective irrigation practices of the crisping group tends to bear this out. The relationship between irrigation management and the occurrence of low specific gravities and/or internal brown fleck is not clear, and warrants detailed investigation.

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).

Technical summary

A project evaluating irrigation strategiesof crisping potato producers, and demonstrating irrigation scheduling using tensiometers, was conducted from 1995 to 1996. We used commercial-scale demonstrations and producer collaboration to maximise interaction and the chance of adoption of proven technology. With moderately complex technology, this has proved more successful than using written information, media releases or even demonstrations at research institutions. Eleven producers were involved in a total of 12 completed Demonstrations (others were incomplete because of equipment failure, infrequent tensiometer readings, or adverse weather).

Collaborating producers were provided with information on irrigating potatoes and using tensiometers. At each Demonstration, 2 monitoring sites were installed in a representative paddock, with tensiometer values, irrigation, rainfall, and crop performance recorded for the life of the potato crop. At least 2 sites per crop were essential, to take into account natural variability and have confidence in the readings. QDPI staff maintained and serviced the tensiometers as required in most instances. At the end of each Demonstration, producers were sent a written report detailing findings for their individual situation.

Most of the collaborating producers were effective and efficient irrigators. Crops were watered when values for the shallow tensiometers (installed 20 cm below the top of the potato hills) reached 50-60 kPa. This is within the acceptable range for optimum potato production. Only 2 of the 12 Demonstrations suggested significant periods of water stress. Both these Demonstrations had lower yields than the group average. Using tensiometers enabled many producers to judge the value of intermittent rainfall, and thus extend the interval between irrigations, without stressing the potatoes. Producers with hand-shift and travelling guns tended to irrigate less frequently, and applied more water at each irrigation, than those with solid-set or linear-move systems. Using tensiometers enabled one irrigator to determine his current equipment set-up was not suited to his soil-type. In most situations, 25-35 mm of irrigation was sufficient to fill the root zone of well-grown potato crops that were not stressed.

In this project we found mean tuber yields consistently 10 t/ha greater than the fresh market average. Most of this increase can be attributed to more careful management of the potato crops; demonstrated by the effective irrigation practices of the crisping group. The relationship between irrigation management and the occurrence of low specific gravities and/or internal brown fleck is not clear, and warrants further detailed investigation. These disorders are both major issues in processing potato industries.

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 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 crisping potato producers, (although crisping producers are probably closer to optimum irrigation practices than fresh market producers). Current QDPI recommendations indicate about 4 ML/ha of irrigation are required for potatoes.

Many studies have shown that potatoes produce the 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).

Because potatoes 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, because of restrictive use conditions and lack of sensitivity (Jolly 1991).

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).

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.

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.

This project sought to improve irrigation management in crisping potato production, augmenting results from previous projects in other vegetables and fresh market potatoes. It focused on monitoring irrigation practices with collaborating crisping potato producers, demonstrating irrigation management techniques in commercial circumstances. These on-farm sites involved installation of tensiometers in contract 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 on the properties of all crisping growers in southern QLD who wished to participate.

The major focus of this project was evaluation and demonstration of the benefits of irrigation scheduling to crisping potato producers, extending current knowledge and assisting in its adoption, by using commercial-scale demonstrations and producer collaboration. This was in accord with the desire of producers for improved technology transfer, as expressed at the 1993 National Potato Conference (Salvestrin 1993).

Materials and methods

Almost all the crisping potato producers in southern Queensland participated in this project (Table 1). Several producers were involved in more than 1 Demonstration, or had additional sites above the 2 normally allocated per producer at any one time.

Table 1. Irrigation management demonstrations in crisping potato producers' crops 1995/96.

Producers	Location	Sites	Period	Status
Gary Jamieson	Tenthill	2	Jun.-Nov. 1995	Completed
Pat Keller	Lowood	2	Jul.-Nov. 1995	Completed
John Keller	Lowood	2	Aug.-Dec. 1995	Completed
Lyle Grayson	Tannymorel	2	Aug.-Dec. 1995	Completed
Carolyn Taylor	Killarney	2	Aug.-Dec. 1995	Completed
John Foley	Allora	3	Sep.-Dec. 1995	Completed
John Lennon	Yelarbon	2	Sep.-Dec. 1995	Completed
Brian Metcalfe	Clifton	2	Oct.-Dec. 1995	Completed
Gary Jamieson	Tenthill	2	Mar.-Apr. 1996	Completed
Lyle Grayson	Tannymorel	4	Mar.-Apr. 1996	Completed
John Foley	Allora	2	Mar.-Apr. 1996	Completed
John Keller	Lowood	2	Apr.-Jun. 1996	Completed
Gordon Fritz	Bundaberg	2	Jul.-Aug. 1995	Incomplete
Neville Cayley	Bundaberg	2	Jul.-Aug. 1995	Incomplete
Glen Zischke	Tenthill	2	Aug.-Sep. 1995	Incomplete
John Lennon	Yelarbon	4	Mar.-Apr. 1996	Incomplete
Brian Metcalfe	Clifton	2	Mar.-Apr. 1996	Incomplete
Pat Keller	Lowood	2	Mar.-Apr. 1996	Incomplete

Demonstrations were not completed because (a) there were insufficient tensiometer readings to enable a useful analysis, either due to equipment failure or not enough data, (b) heavy and lengthy periods of rain interfered with the cropping and monitoring program. The results described in this report only relate to the 12 completed demonstrations.

A typical demonstration involved the following sequence of operations. In collaboration with the producer, a representative crisping potato crop on the property was selected for monitoring. Two sites were installed in the potatoes as soon as possible after the final hilling or cultivation (to avoid damage to the equipment). At each site, a shallow tensiometer was placed 20 cm below the top of the potato hill, with a deep tensiometer at 60 cm. Generally, JETFILL® brand tensiometers were used at one site, and IRROMETER® brand tensiometers at the other. The intention was to compare these two brands for reliability, accuracy, ease of installation and use, and overall performance. 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 the potatoes were harvested.

At the start of each demonstration, producers were provided with 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). 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 own decisions on when and how much to irrigate their potatoes.

Where possible, potato yields and quality from the monitored paddock were recorded. 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 1 and 2.

Several group discussions were held at Crisping Group meetings, detailing project progress and interim findings. At a few sites, direct comparisons could be made with results from ENVIROSCAN® systems that were in operation in the same paddocks.

Results and discussion

Interpretation of results

Tensiometer, rainfall and irrigation values were plotted in a series of stacked graphs as shown in Fig. 1. 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. Where the 2 sites within the monitored paddock behaved similarly, mean values for the sites were plotted (as in Fig. 1). Occasionally the 2 sites had different responses, in which case values for the individual tensiometers were shown.

The example in Fig. 1 comes from a late Spring 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. 1).

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 estimating 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. 1, 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 on all the completed sites where information was available. 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 for 2 Demonstrations are given in Appendices 1 and 2. The following discussions summarise the findings from the full complement of completed Demonstrations.

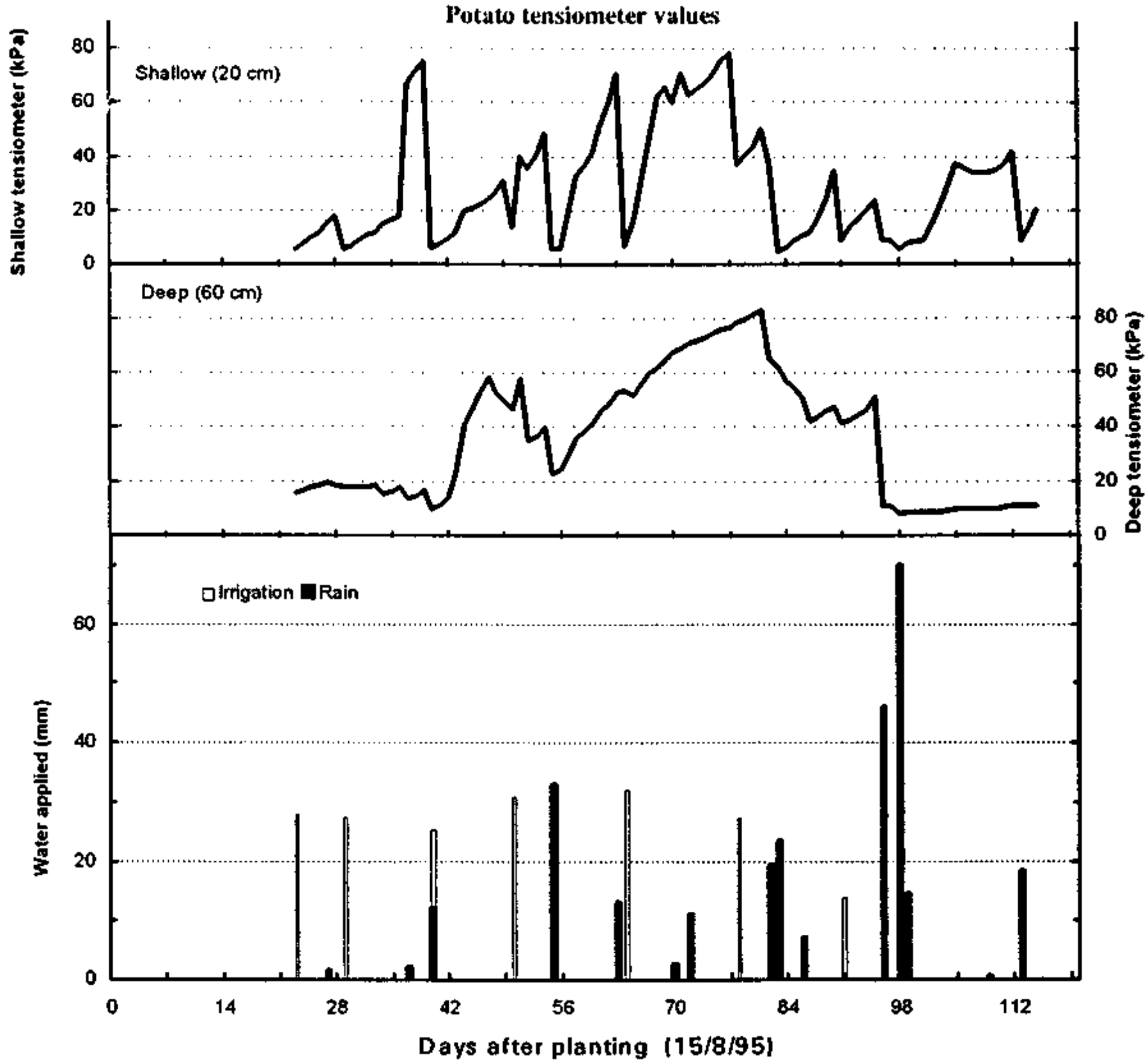

Figure 1. Example of average tensiometer changes and irrigation regime in an Atlantic crisping potato crop (Demonstration G).

Irrigation regimes and crop responses

In this study, crisping potatoes were grown on soil types ranging from sandy loams to light clays (Table 2). Climatic conditions also varied, from cool periods in the Lockyer Valley in late Winter, to summer heatwaves on the Darling Downs. Irrigation systems used to water the potatoes included hand-shift overhead sprinklers, solid-set sprinklers, and travelling irrigators (both guns and linear move). Rainfall during the periods the potato crops were monitored ranged from nil to amounts such that very little irrigation was required.

Table 2. Summary of environmental, management, irrigation, water balance and crop performance parameters for the 12 completed Demonstrations of irrigation management in crisping potatoes in southern Queensland. ***Note that to preserve anonymity of collaborating producers, the sequence of presentation is unrelated to the order shown in Table 1.***

Demo.	Soil type	Growing season	Irrigation system	Growing 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)	Potato yield (t/ha)	Tuber specific gravity	Time between tensiometer readings (days)
A	Loam	Autumn	Solid-set	0	40	7	22	25	3.1	-	-	2
B	Loam	Autumn	Hand-shift	240	40	7	25	25	-	-	-	3
C	Clay-loam	Autumn	Travelling gun	18	60	7	35	35	4.6	-	-	1
D	Sandy-loam	Autumn	Linear traveller	-	70	4	12	25	3.3	-	-	3
E	Clay-loam	Spring	Solid-set	86	40	12	30	30	4.3	37	1.075	1
F	Loam	Spring	Travelling gun	92	70-80	11	33	35	4.5	26	1.082	3
G	Loam	Late Spring	Hand-shift	125	60-70	13	30	30	3.0	30	1.082	3
H	Sandy-loam	Late-Spring	Linear traveller	138	50	6	14	25	4.5	30	1.077	1
I	Loam	Late Spring	Solid-set	138	50-70	5	15	25	5.5	36	1.073	1-2
J	Clay-loam	Late Spring	Solid-set	80	60	5-6	30	30	5.5	45	1.079	3
K	Sandy-loam	Late Spring	Linear traveller	53	60-70	5	30	25	6	32	1.075	4-5
L	Clay	Late Spring	Linear traveller	228	50	18	35	25-30	4.5	-	-	2

Notwithstanding this substantial variation in circumstances, most of the crisping potato crops were grown with relatively similar fluctuations in soil water status. In most instances, crops were irrigated when the shallow tensiometer values reached 50-60 kPa (Table 2). 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 tuber yields nor quality. In a well-grown potato crop, 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 the low or high value is chosen. However, extended periods with values over 50-60 kPa, particularly accompanied by steadily rising deep tensiometer values, should be avoided.

Of the monitored crops, only Demonstrations F and G had periods where potatoes may have been under significant water stress during sensitive growth stages. Interestingly, both these Demonstrations had slightly lower yields than those measured in the other crops (Table 2).

There were no clear correlations between soil type, growing season, and the tensiometer values at which the decision was made to irrigate. There was a slight trend for higher tensiometer values where hand-shift or travelling 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 E (Fig. 2), where the average irrigation interval was stretched to 12 days without the shallow tensiometer values rising above 40 kPa. Because rainfall was just sufficient to keep the root zone moist, using tensiometers enabled the producer to have confidence in the decision to delay irrigation. A more detailed discussion of this demonstration is given in Appendix 1. At Demonstration L, there was so much rain that only 2 irrigations were required for the whole of the growing period.

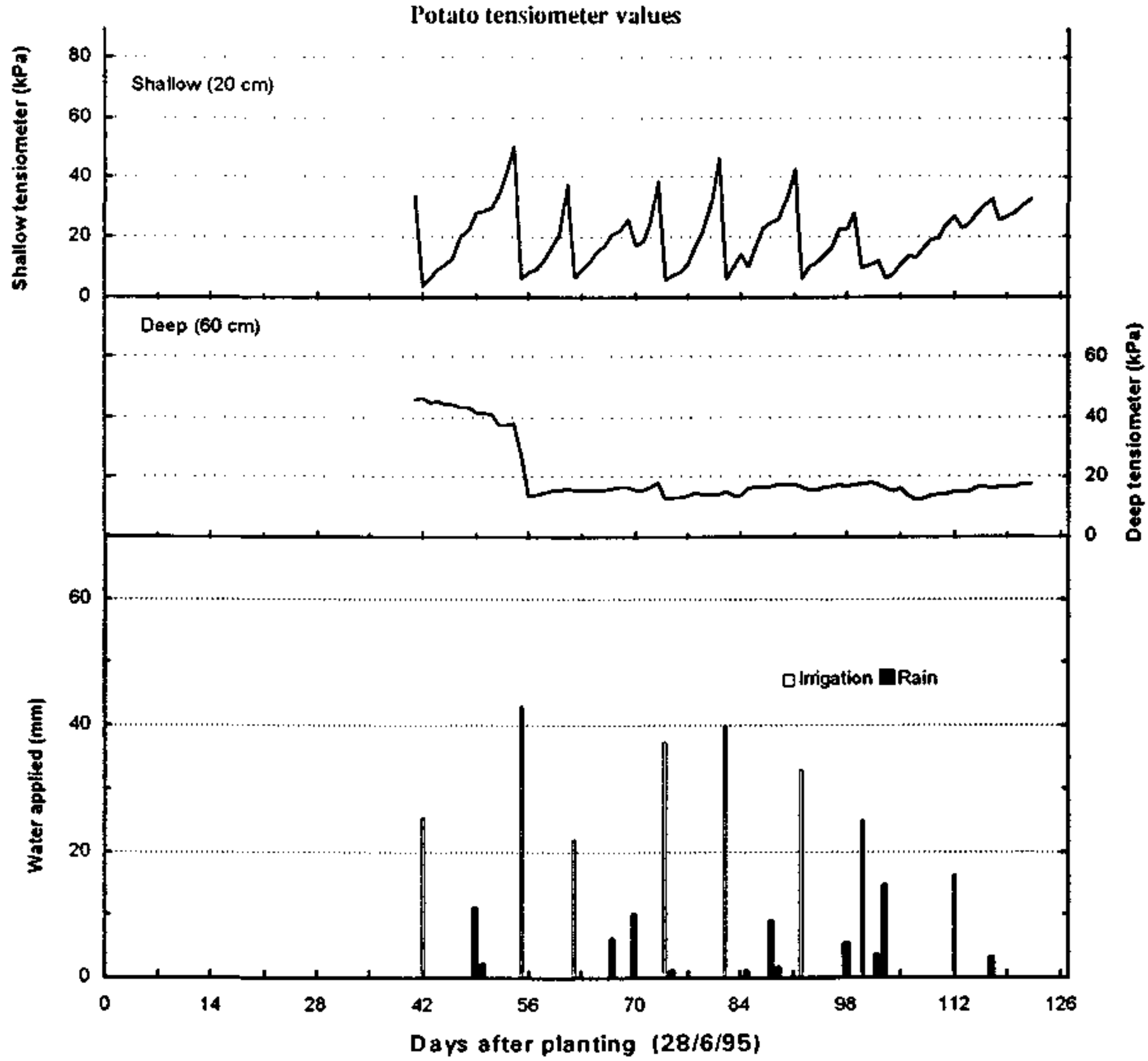

Figure 2. Average tensiometer changes and irrigation regime in a crisping potato crop (Demonstration E).

As expected, there were general trends for shorter intervals between irrigations on sandier soils, and in warmer growing conditions. This general rule is obviously affected by the frequency and quantity of rain.

Solid-set systems have the most flexibility in terms of frequency and amounts of irrigation applied (the average for solid-set systems in the monitored crops was 25 mm every 7 days). Because of the higher labour and operational requirements, hand-shift and travelling gun systems tended to put on 5-10 mm more water per irrigation than solid-set sprinklers, averaging 30-35 mm every 9-10 days. Interestingly, the linear move travelling irrigators were most variable, ranging from 15 mm to 35 mm per irrigation.

The case of the travelling linear move irrigator used in Demonstrations D and H is interesting, and shows the value of irrigation scheduling in pointing out other related problems. In summary, this sandy-loam soil is prone to developing surface crusts with low inherent infiltration capacities. This travelling irrigator applied a high intensity of water over a short time. It was noticeable that even after irrigation, shallow tensiometers installed in the potato hills were still indicating dry soil. Placement of further sets of tensiometers in the furrows, and observations in the field while irrigation was being undertaken, provided evidence as to what was occurring. During the high intensity irrigations, water was running off the hills and collecting in the furrows, where it would then penetrate the soil profile. Water would only move into the dry hills under capillary rise from the wet subsoil; this type of water movement was not particularly strong in this sandy soil. The producers' response to this situation was to try and reduce the intensity of irrigation by modifying the irrigator outlet jets. They also shortened the interval between irrigations and reduced the amounts of water applied at each irrigation. A more detailed description of Demonstration H is given in Appendix 2.

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 3.5-4 mm/day for good crops grown during cooler periods, increasing to 5.5-6 mm/day for crops grown in warmer weather. Most of the crisping potato crops fitted this scenario, although Demonstrations A, D, G, H and L were probably slightly below the expected values (Table 2). In conjunction with extended periods of high tensiometer readings, low water use values were an indication of 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 did not appear to be substantial issues in any of the crisping potato Demonstrations in this project. They have certainly been evident in other studies we have conducted with fresh market potato producers' situations (Jackson *etal* 1993, Henderson unpublished data).

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 25-35 mm of water storage available in the root zone of a well-grown potato 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. In all the Demonstrations there were very few instances of irrigation in excess of the root zone water storage capacity at the time. We determined there was one irrigation that resulted in 10-15 mm drainage at both Demonstrations K and L, and a few 5-10 mm over-irrigations at Demonstration C, where the travelling gun was used. In general the amounts of water applied by all the crisping potato producers were very close to optimal. At Demonstrations D, H and I, 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 studies with fresh market producers, we often found that although they were not irrigating frequently enough, when they did irrigate they often applied too much water, a significant proportion of which passed beyond the crop root zone. 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. We often found fresh market producers were applying 50-60 mm of irrigation in a single application, of which 15-25 mm was being wasted.

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 this 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 group tends to bear this out.

Tuber quality is very important in crisping potatoes. Processing companies are becoming more exacting in their requirements with regard tuber size and shape, absence of internal and external defects and specific gravity of the potatoes. Low specific gravities increase the cost of producing crisps, and producers are penalised on a sliding scale for delivering tubers with specific gravities less than critical levels. By optimising plant stands and as far as possible maintaining even growing conditions, without major fluctuations in soil water levels, most crisping potato producers are now digging tubers with good shape and size. At certain times of the year, notably in late Spring and early summer, many producers have significant problems with low specific gravities of tubers (Table 2). The other significant quality problem has been the appearance of internal brown fleck on some occasions.

The relationship between specific gravity and irrigation management is not clear. In experimental work with fresh market potatoes at Gatton Research Station, specific gravity was unaffected by irrigation management unless severe water stress was imposed. There is however some circumstantial evidence that specific gravity may be increased by withholding water toward the end of the growing period. There is probably a yield penalty associated with this strategy. Any decision to withhold irrigation would depend on the relative financial penalties for low specific gravities versus the income loss from lower yields. The impact of irrigation management on specific gravity probably warrants further attention.

The occurrence of internal brown fleck can be even more 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.

Producer collaboration

As with any group of people, the producers associated with this project varied in their level of interest in the project, and to 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 2-3 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.

Overall, the level of cooperation with the crisping group producers was very good, with positive and enthusiastic attitudes on all sides. This is important if such collaborative work is to succeed.

Although available for more than 60 years, tensiometers have not been commonly used in potatoes, 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 4 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.

In comparing the 2 models of tensiometer, 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 installed by either the crisping group or 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 the potato 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 or not to irrigate.

Extension/adoption by industry

The focus of this project was on demonstration of irrigation scheduling techniques to crisping potato 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.

Apart from one producer, every other member of the Crisping Potato Group in southern Queensland had an opportunity to participate in this project. Written reports (eg. Appendices 1, 2) 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. Updates on the progress of the project and findings to date were outlined at several Crisping Group general meetings. Some findings from our Demonstrations were included in a poster and paper presented at the Third Horticultural Industry Technical Conference (Henderson 1996).

Although most of the collaborating crisping potato 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 specific gravity, one of their main quality concerns. Another aspect is whether there is an irrigation interaction with the occurrence of brown fleck, particularly with regard nutrition (eg. calcium, boron). 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 opt to use tensiometers themselves, others will probably opt to use the services of consultants or processing company field officers 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.

Directions for future research

From this study, it was evident that most crisping potato produces were relatively effective and efficient irrigators. 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 showed that projects of this type can be useful where they are basically driven by the producer group, 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 individual 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.

The results of this project indicated that most crisping potato producers were reasonable to good irrigators. They have been exposed to the benefits of objective irrigation scheduling. In conducting this project, it became evident that there were 2 tuber quality issues that required attention, low specific gravities at certain times of the year, and the unpredictable occurrence of internal brown fleck. Specific gravity is very much a processing potato issue. In our studies of potato irrigation there did not seem to be a consistent response of specific gravity to gross differences in irrigation management. However, these experiments were conducted with fresh-market cultivars, and did not specifically investigate irrigation strategies late in the season, when it may be a more important influence on tuber dry matter. A project to pin down the factors that influence specific gravity in crisping potatoes, and developing techniques to optimise it in different environments would be very useful.

Internal brown fleck in potato tubers is an important issue for both fresh market and processing potatoes. In both instances 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. As with the specific gravity issue, 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.

Financial/commercial benefits

This project demonstrated to crisping potato 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 the crisping potato 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 crisping potato 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.

Other assumptions included; current on-farm price of $200/t; yields 30 t/ha; yield increase from scheduling of 5%, price increase (due to reduced dockages) of 5%, and 50-70% 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 producers is then $530/ha, and to society as a whole (taking into account increased price for raw product to the factory) $225/ha. The net present value of adoption of the research is around $360,000, and the return on research funds about 30:1. This analysis ignores the marketing, resource use and environmental benefits referred to earlier.

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Appendix 1. Example of written report for Demonstration E

Collaborative Monitoring of Irrigation Management in Crisping Potato Production, from July-November 1995.

A collaborative study conducted by:

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

Introduction

This study was part of a project demonstrating the use of tensiometers to manage irrigation in crisping 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 20 cm below the soil surface, with a deep tensiometer at 60 cm. The collaborating producer 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 Craig Henderson or Mick Webber.

Results

Tensiometer, rainfall and irrigation data are shown in Figures 1 and 2. Because the 2 sites were irrigated similarly, and responded in a relatively common manner, comments generally refer to the mean values.

Monitoring commenced around 25 days after sowing (DAS). Irrigation of potatoes was invariably conducted once mean values for shallow tensiometers reached 40 kPa (Fig. 1). Intermittent, light rain during the main growing period meant irrigation intervals varied from a minimum of 6 days to a maximum of 13 days. Deep tensiometer values showed a full root-zone profile after 43 mm of irrigation at 38 DAS. For the rest of the growing period, the deep tensiometer values remained constant at around 15-18 kPa, with no significant dips in readings. This indicates no root-zone water stress, nor significant deep drainage of excess irrigation water, during the growing period.

Site B consistently received slightly less irrigation than Site A (Fig. 2). The shallow tensiometer at Site B also reached slightly higher values immediately prior to irrigation that Site A, although differences were not substantial. Such variability in both irrigation and tensiometer values are not unexpected, given the size of the paddock. Note that the high readings for the deep tensiometers immediately after installation (Fig. 2) are due to dry soil being placed around the tips during the installation process.

Comments

Between 6-17 weeks after planting, the potato crop received 86 mm of rain and 233-253 mm of irrigation. Irrigation consisted of 8 applications; averaging 30 mm every 12 days. The timing of rain in relation to irrigation enabled the intervals between applications to be longer than would normally occur in this crop. It is likely that objective monitoring with tensiometers increased confidence in delaying irrigation. This enabled saving in pumping costs and labour to the producer, without sacrificing crop performance.

Overall yields were around 37 t/ha; good production for a commercial crop. The quality of tubers was of a high standard; except for slightly low specific gravity, which resulted in slight dockage on payment. This was a consistent problem with Atlantic potatoes on the producer's farm.

Taking into account the tensiometer information, the irrigation regime in this crop was as close to a theoretical ideal as encountered in several years of monitoring. There were no indications of crop stress, no indications of excess drainage, resulting in an high yielding, high quality potato crop.

Acknowledgements

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

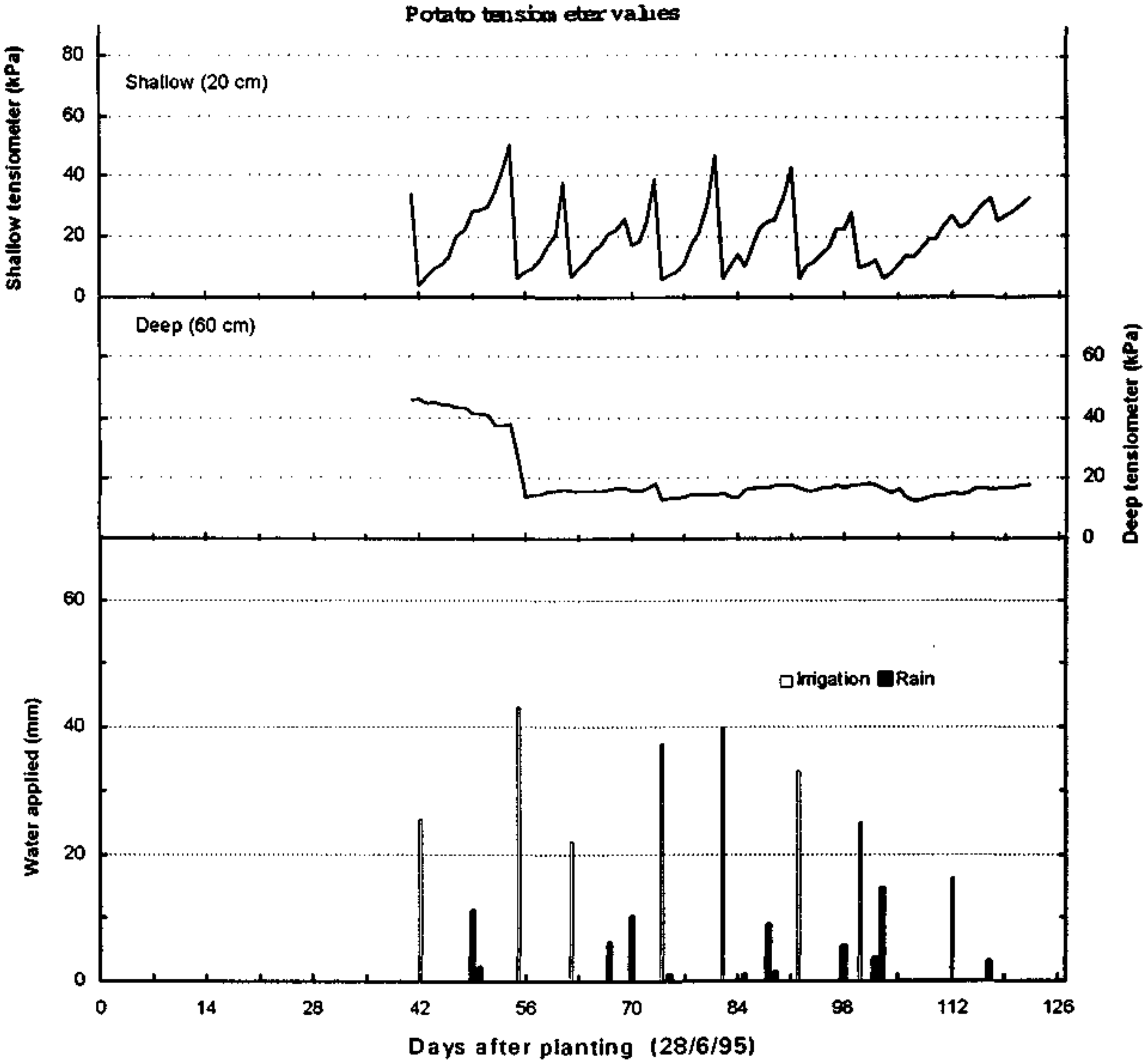


Figure 1. Average tensiometer changes and irrigation regime in a crisping potato crop.

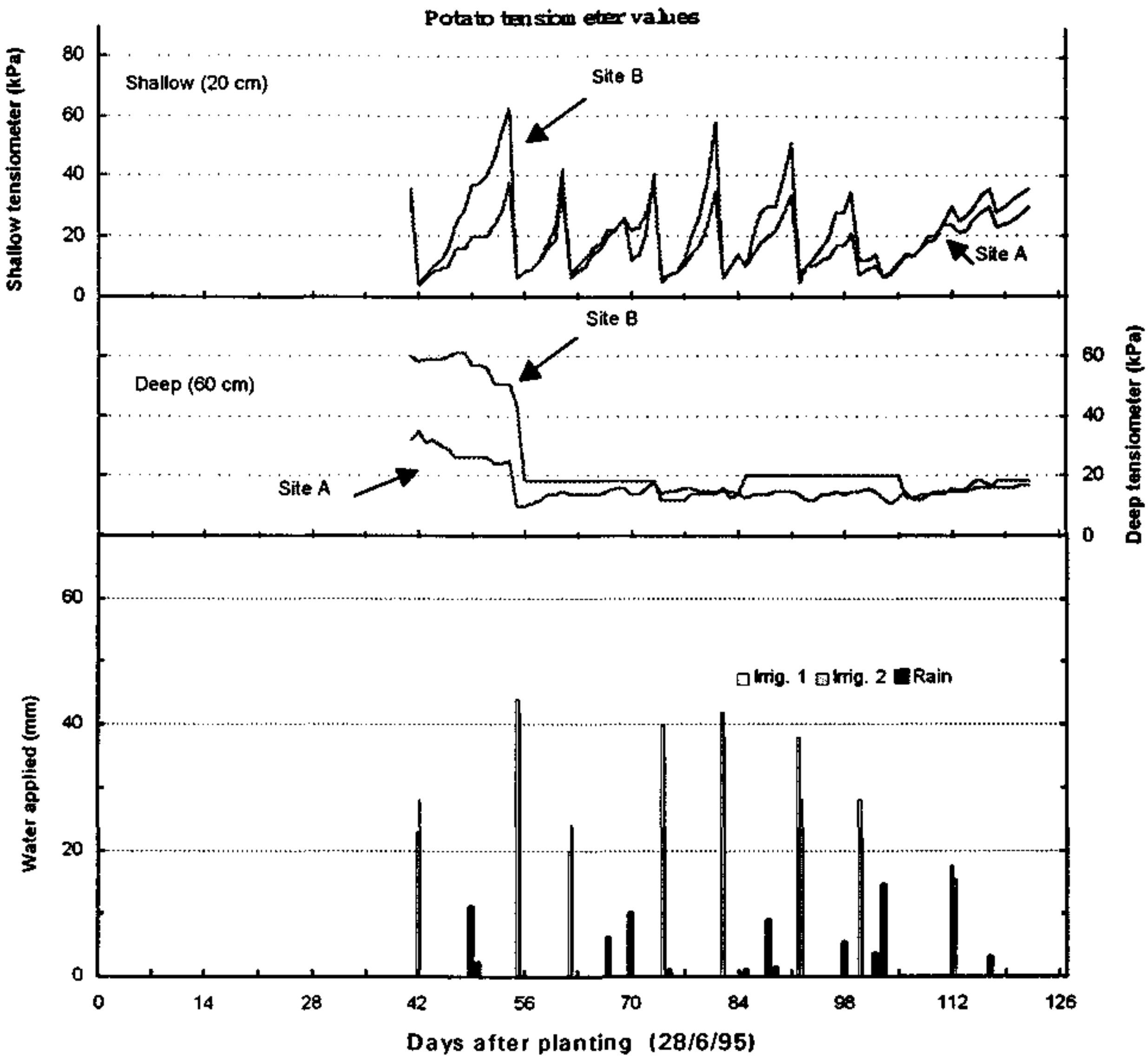


Figure 2. Individual tensiometer changes and irrigation regimes at 2 sites in a crisping potato crop.

Appendix 2. Example of written report for Demonstration H

Collaborative Monitoring of Irrigation Management in Crisping Potato Production, from September-December 1995.

A collaborative study conducted by:

Craig Henderson, Senior Horticulturist, Gatton Research Station
Collaborating Crisping Potato Producers

Introduction

This study was part of a project demonstrating the use of tensiometers to manage irrigation in crisping 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 a crop of Atlantic potatoes being monitored. At each site, a shallow tensiometer was placed 20 cm below the soil surface, with a deep tensiometer at 60 cm. An additional site was installed in a crop of fresh-market Sebago potatoes, with tensiometers at 15 cm, 20 cm and 60 cm. Part way through the growing period, additional sites were installed in the furrows of the Atlantic potato crop, at the same depths, and adjacent to, sites in the potato hills. The collaborating producers 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 Craig Henderson.

Results

Tensiometer, rainfall and irrigation data for the Atlantic crisping potato crop are shown in Figures 1 and 2. The 2 sites were irrigated similarly, and responded in approximately the same manner, although deep tensiometers at Site 2 gave slightly higher readings than at Site 1. Unless otherwise indicated, comments on the Atlantic potato crop refer to mean values in Fig. 1, rather than individual site values in Fig. 2.

Monitoring began around 7 weeks after planting (WAP). Heavy rainfall one week later saturated the soil profile to the depth of measurement (Fig. 1). Despite rainfall and irrigation over the ensuing fortnight, values for both shallow and deep tensiometers beneath the potato hills continued to rise, indicating drying soil conditions. Between 9-12 WAP, mean shallow tensiometer values fluctuated between 40 kPa and 60 kPa, notwithstanding 24 mm of rain and 86 mm of irrigation over the 3 weeks. Rainfall of 20 mm and 15 mm at 12 WAP re-wet the hill, but did not penetrate to 60 cm. During the next fortnight, tensiometer values again rose steadily to 60 kPa, until 32 mm of rain fell about 14 WAP. Monitoring ceased once heavy rainfall started 15 WAP.

Tensiometers installed in the furrows consistently responded more rapidly to irrigation (with lower average values), than corresponding tensiometers within potato hills. In conjunction with field observations, this suggested water was running off potato hills during irrigation, concentrating and penetrating in the furrows.

Values for deep tensiometers within the hills steadily increased as the growing period progressed, with no significant dips to indicate penetration of water beyond the potato crop root-zone. Dips in readings for deep tensiometers in the furrows, although not to very low values, may suggest slight deep percolation from water concentrating in furrows after rainfall. There was no drainage associated with excess irrigation at any time during the monitoring period.

During the period 54-107 days after planting, the crop received an average 14 mm irrigation every 6.5 days (total 112 mm), and 138 mm of rainfall. Assuming 20 mm of that rainfall drained beyond the root zone, this indicates an average crop water use of 4.5 mm water per day, slightly below expected water use for that time of year. Because water was not penetrating the potato hills, potato plants were extracting water from deeper in the soil profile, as well as from underneath the furrows. Because of slightly drier than desirable conditions in the main potato root-zone, the potatoes may have undergone stress during the hotter parts of the day, and just before each irrigation. Nevertheless, water use values suggest stress was not substantial, with slight effects on crop production. In more extreme climatic conditions, the failure of irrigation to properly wet the hills may have more detrimental effects on water use, nutrient uptake, crop production and tuber quality. Following heavy rainfall at 15 WAP, water use probably slowed dramatically. This rain may have increased leaf disease and started crop senescence.

Tensiometer values in the Sebago crop reflected a more usual pattern of readings (Fig. 3). The shallowest tensiometer showed the quickest rise after irrigation, as the crop (and evaporation) extracted water from this depth most rapidly. Readings for the tensiometer installed 20 cm below the top of the hill remained relatively low for the first 4 weeks after monitoring commenced. They then rose to a peak of 40 kPa, prior to rain at 11 WAP. Until monitoring ceased 3 weeks later, this tensiometer reached values of 50-60 kPa immediately before irrigation or rainfall. Deep tensiometer values indicated moist subsoil conditions for the whole period of monitoring. There were no sudden dips to indicate drainage following irrigation or rainfall. During the period 49-102 days after planting, the Sebago potatoes also received an average 13 mm irrigation every 6.5 days (total 104 mm), and 138 mm of rainfall.

Comments

The timing of rain in relation to irrigation enabled intervals between applications to be longer than normal in this crop. Field observations and tensiometer data confirmed that infiltration of water into the potato hill was substantially less than the rate of application. This resulted in run-off from the top of the hill into the furrow, where it collected and penetrated. As a consequence, the hill remained somewhat unresponsive to irrigation, and drier than expected following irrigation. This crop was watered with a travelling irrigator, with an intensity of output greater than this soil can currently absorb. The collaborating producers are modifying the irrigator to achieve a longer, less intense application period. Tensiometer data indicated that less intense rain was more readily penetrated potato hills.

In this crop, potato plant growth, yields and tuber quality were probably not substantially affected by poor penetration of irrigation water into the hills. In circumstances where there was less rainfall and greater evaporative demand, tuber quality and yields may be adversely affected by dry hill conditions. Given the drought situation and problems with irrigation application, the watering strategies in this crop were effective and efficient. Tensiometer values for the Sebago crop were OK, with very few periods of readings above 40-50 kPa. Likewise, shallow tensiometer values for the Atlantic crop were also reasonable, particularly taking into account the difficulties of wetting up hills. Although there were extended periods of values >50 kPa, values >70 kPa (that show moderate-severe water stress) did not eventuate. Deep tensiometer values in the Atlantic block suggested significant water uptake from deep in the soil profile, suggesting potential crop stress in adverse situations.

Yields were around 30-31 t/ha for both the Atlantic and Sebago crops. This is reasonable-good for a commercial Atlantic crisping potato crop, although higher production could be expected. Water stress, caused by the irrigation difficulties discussed earlier, may have slightly reduced production. Due to circumstances, harvesting of the crop was delayed for around 3-5 weeks after potatoes were ready to be dug. Saturated, hot soil conditions during this period no doubt reduced tuber yields and quality. In some instances these conditions can cause significant amounts of brown fleck. At 1.077, specific gravity was poor-moderate for crisping potatoes, resulting in payment dockage. This value is probably unrelated to the irrigation pattern; we have not found any consistent effect of watering on specific gravity, except in conditions of severe water stress. Low specific gravities were a common problem in southern QLD potatoes during this time.

During the period irrigation in this crop was monitored, the application rate of the travelling irrigator was greater than the potato hills could absorb. As a result, water ponded and penetrated in the furrows, with the hills remaining drier than expected following irrigation. This may have slightly reduced crop yields, however this problem could be exacerbated in seasons with less rainfall or greater evaporative demand. Notwithstanding these difficulties, irrigation was efficient, with no indications of drainage due to excess application. Potato yields were moderate-good, under difficult conditions, however for some unknown reasons specific gravity of tubers was well down.

Acknowledgements

The collaborative efforts of the producers in conducting the day-to-day monitoring of the tensiometers and irrigation cycles are sincerely appreciated. By reading the tensiometers relatively regularly, they increased the information gained from the exercise. We hope that in return our collaborators gained some benefits as far as there approach to irrigation management in crisping potato crops is concerned.

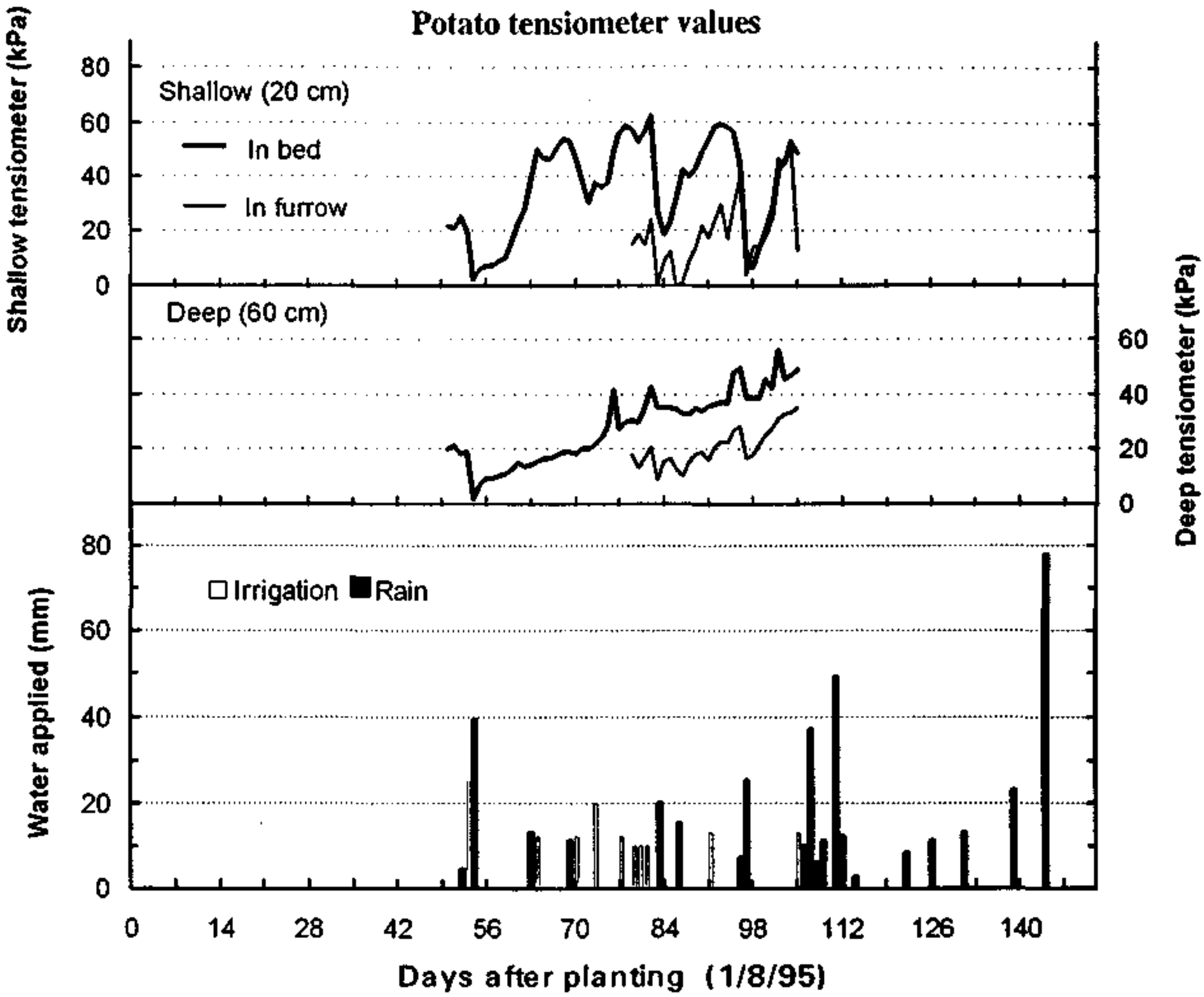


Figure 1. **Average tensiometer changes and irrigation regime in an Atlantic crisping potato crop.**

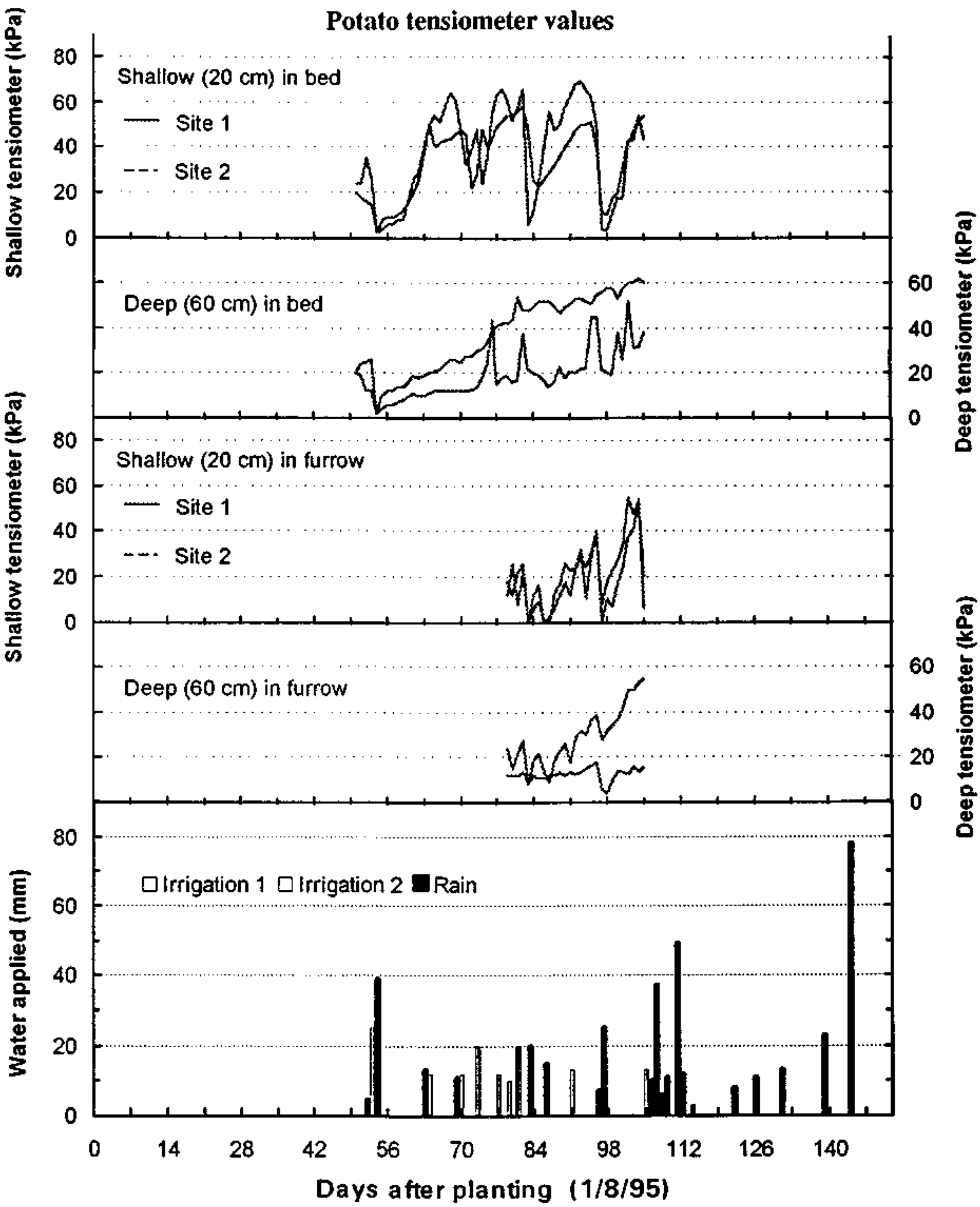


Figure 2. Individual tensiometer changes and irrigation regime at 2 sites in an Atlantic crisping potato crop.

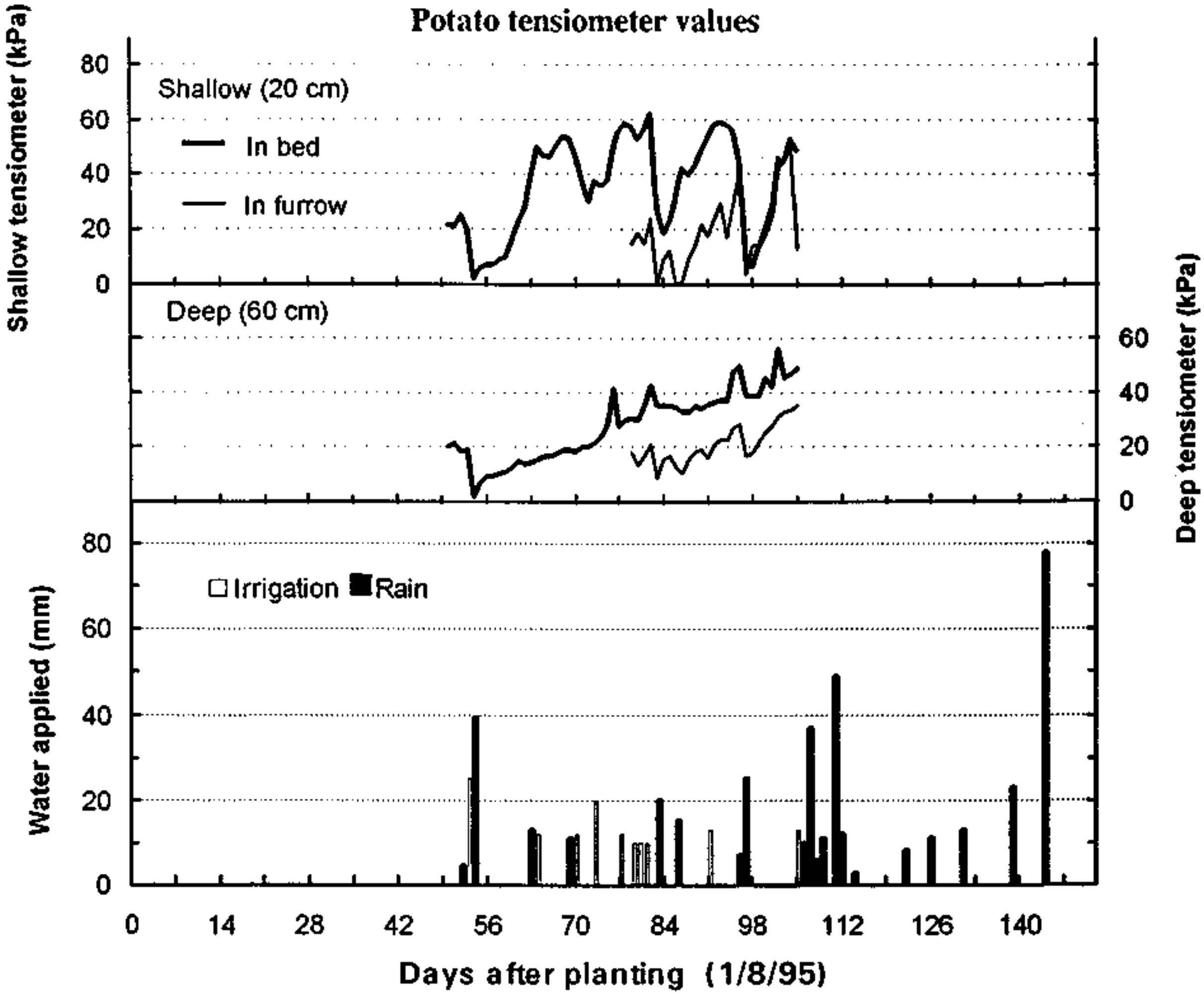


Figure 3. **Average tensiometer changes and irrigation regime in a Sebago fresh market potato crop.**

Appendix 3. 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.

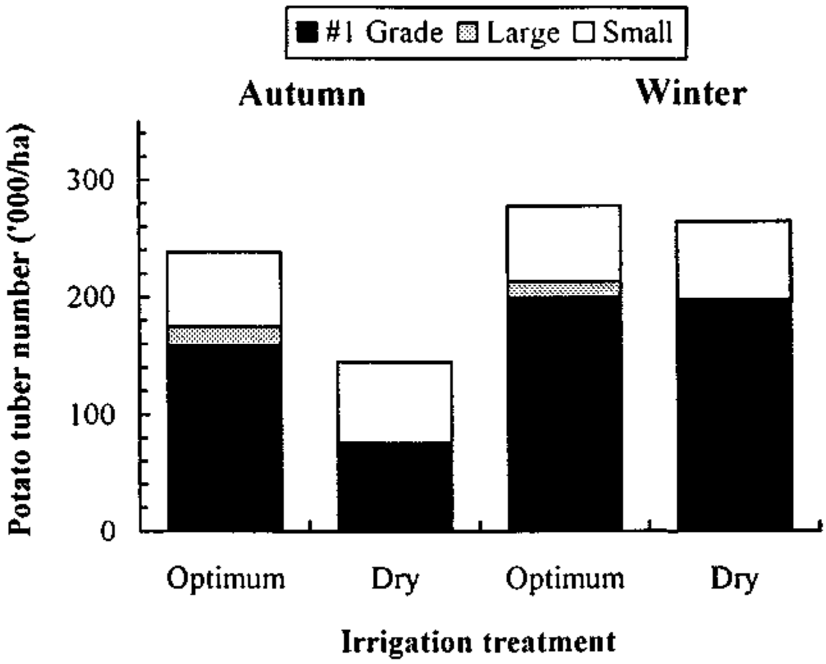


Figure 1. In an autumn crop, water stress at tuber initiation severely reduced potato tuber numbers; in a winter crop, water stress during tuber bulking only reduced the number of large potato tubers.

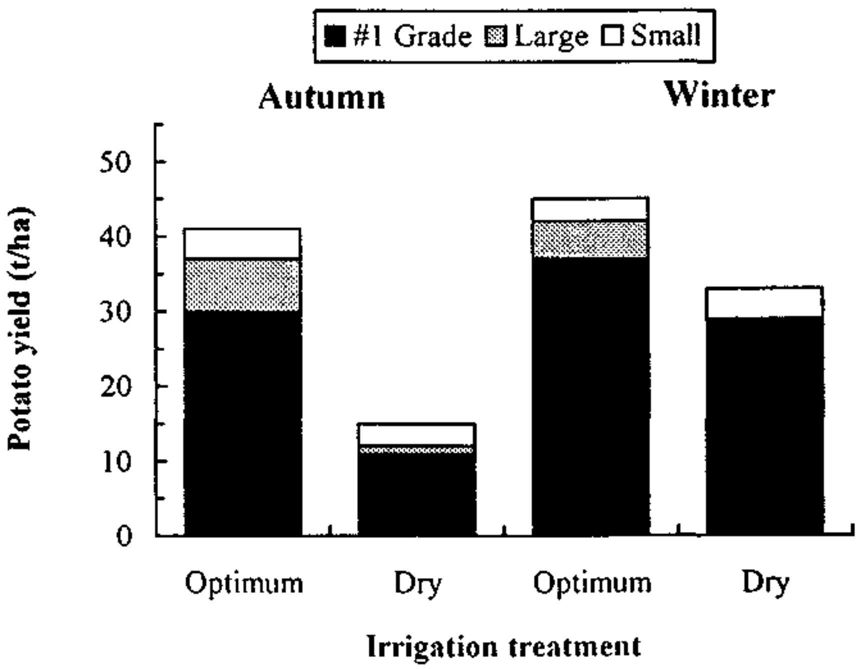


Figure 2. In an autumn crop, water stress at tuber initiation severely reduced potato yields; in a winter crop, water stress during tuber bulking less dramatically reduced potato yields.

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).

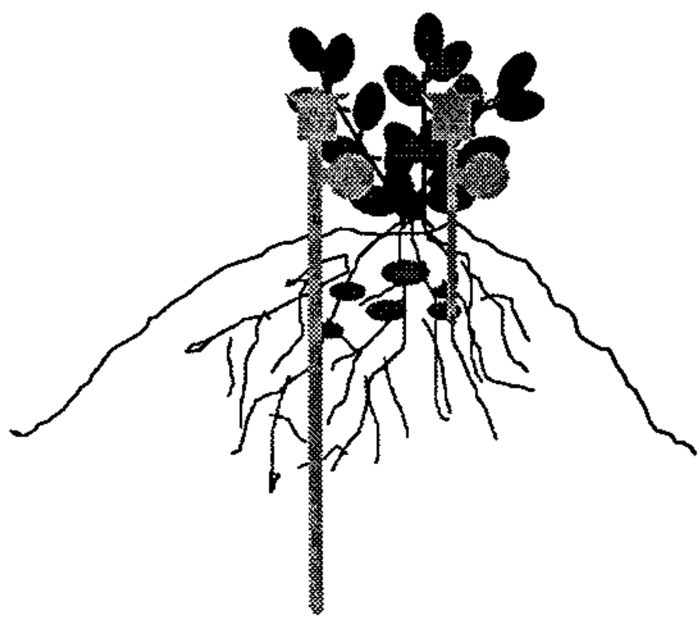
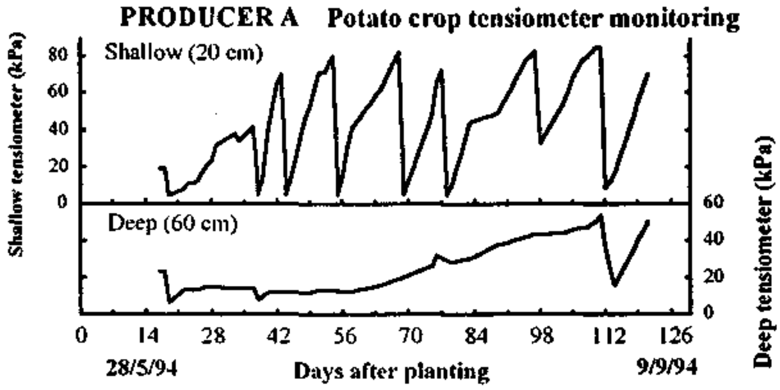


Figure 3. Diagrammatic representation of tensiometer placement in a potato row (section running the length of the row).

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.



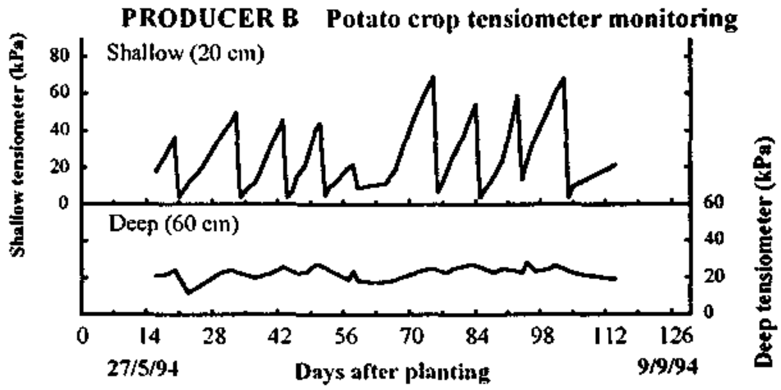


Figure 4. Tensiometer fluctuations in potato crops under 2 irrigation regimes.

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 4. 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.

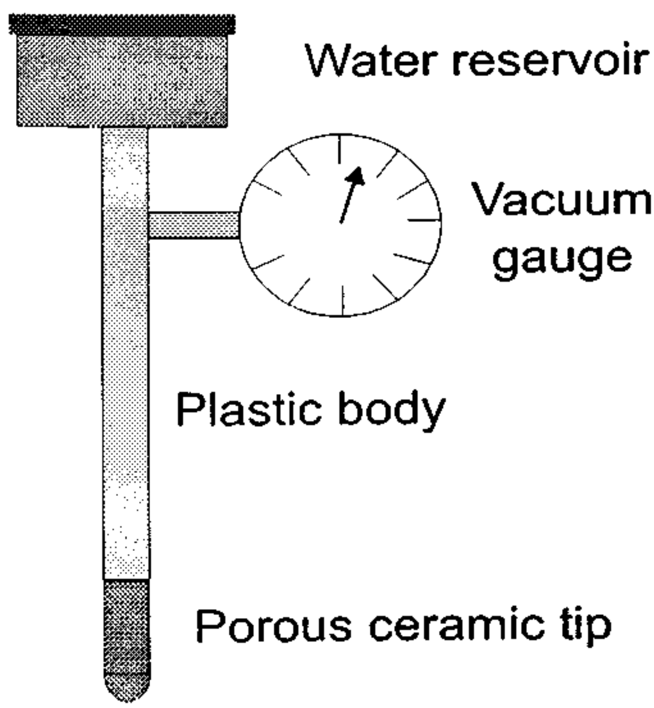

Figure 1. Design of a standard tensiometer.

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.

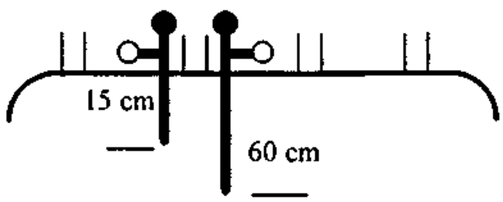

Figure 2. Profile of a typical tensiometer monitoring site in onions.

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.**