VG022
Irrigation scheduling for shallow rooted vegetables

Craig Henderson
QLD Department of Primary Industries

HAL

Know-how for Horticulture™

VG022

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

The research contained in this report was funded by the Horticultural Research and Development with the financial support of Queensland Fruit & Vegetable Growers.

Cover price: $20.00
HRDC ISBN 1 86423 592 6

Published and distributed by:
Horticultural Research & Development Corporation
Level 6
7 Merriwa Street
Gordon NSW 2072
Telephone: (02) 9418 2200
Fax: (02) 9418 1352
E-Mail: hrdc@hrdc.gov.au

HRDC

HORTICULTURAL
RESEARCH &
DEVELOPMENT
CORPORATION

Partnership in
horticulture

Industry and technical summary.

Between August 1990 and November 1993, we evaluated various methods of irrigation scheduling, including using tensiometers, neutron moisture meters (NMM) and heat dissipation probes, in a range of vegetable crops. We analysed experimental data and monitored producers' crops to determine irrigation regimes for optimum irrigation efficiency and crop performance. In several of the later experiments, we compared overhead sprinklers, surface drip tape and sub-surface drip tubing as application systems. The intensive research involved 14 experiments; including green beans (3), sweet corn (2), lettuce (3), broccoli (3), cabbage (1) and potatoes (2). Irrigation frequencies ranged from watering every 2 days, to watering once every 10-14 days.

Our experiments showed that in vegetables irrigated for maximum production, 60-85% of water use is from the top 20 cm of the soil profile (even when vegetables have fully developed root systems). Prior to full root system development, the proportion of water uptake from these surface soil zones is even greater. Thus, when monitoring soil water status for irrigation scheduling in vegetables, it is critical to obtain measurements from the upper 20 cm of the profile. To achieve the necessary measurements with NMM required precise and repeated calibration. This was tedious, time consuming and unlikely to be acceptable to most producers. For research purposes, the NMM was very useful for understanding crop water use patterns and general water balances. As newer electronic soil water monitoring systems (based on capacitance or heat dissipation probes) become commercially available, the NMM will probably become displaced technology. From a practical standpoint, we found irrigation scheduling using tensiometers to be effective under various soil and environmental conditions, for the range of vegetable types previously mentioned. Newer tensiometer models are easy to install and use, give accurate, reliable readings, require little maintenance and are relatively cheap.

Based on project results, we developed a range of irrigation regimes for optimum production in lettuce, broccoli, cabbage, green beans, sweet corn and potatoes. We determined values for tensiometers (installed at 15-20 cm below the soil surface) that indicate when irrigation is required. These were 15-25 kPa for lettuce, 35-50 kPa for broccoli, 40-60 kPa for cabbage, 40-50 kPa for green beans, 50-60 kPa for sweet corn and 40-50 kPa for potatoes. These are only initial guidelines, with the lower values more appropriate for warmer weather conditions, sandier textured soils, or cultivars sensitive to water stress. Irrigation managers would have to adjust these values, on the basis of experience with their individual conditions.

In our project we found no difference in irrigation efficiency or crop performance between well-designed sprinkler systems and surface drip tape systems. In a commercial situation, where sprinkler systems are usually less efficient, operated in more adverse conditions, and drip emitters are more widely spaced than in the system we used, there may be more significant water savings switching from sprinkler to drip irrigation. Our experience with the sub-surface irrigation tubing showed it to be less reliable, less water efficient and resulting in lower crop yields than the other application methods. This was probably due to the type of tube used, rather than an inherent problem with the general system.

Recommendations.

Extension/adoption by industry.

During this project, updated research summaries have been regularly sent to both the Queensland Fruit and Vegetable Growers (QFVG) and the Horticultural Research and Development Corporation (HRDC). These research summaries have been published in the HRDC Research Reports via the Good Fruit and Vegetables magazine. In addition, QFVG intends publishing a current research booklet in 1994, which will include information on the conduct and results from this project. As a result of the publicity generated by publication of these research summaries, individual producers and producer groups have contacted me for more detailed information, which I have provided where possible.

Information and results from the project have been regularly included in general articles for newspapers and magazines such as Queensland Country Life, Country Living Magazine, Rural Times, Toowoomba Chronicle, Gatton Star, Fruit and Vegetable News.

I wrote a general article on electronic soil water monitoring systems which was published in the 6 May 1993 edition of QLD Fruit and Vegetable News. This article outlined the pros and cons of such systems for horticultural producers, detailing the issues they should consider prior to purchase. I also wrote an article on the use of tensiometers for irrigation scheduling in vegetables, (included as Appendix 1 in the Technical Report). This was published in the 3 September 1993 edition of QLD Fruit and Vegetable News. I plan to submit a more extensive combined article on irrigation scheduling techniques to Good Fruit and Vegetable magazine in 1994. It is my intention to write extension articles on irrigation scheduling for specific crops during 1994. As a result of an exercise monitoring producers' crops in 1992, I co-authored an article on limitations to high potato yields in the Lockyer Valley, which was published in the 1993 issue of Potato Australia. This article included a significant section on irrigation scheduling and general irrigation management.

Information on irrigation for specific vegetable crops is currently being included in extension packages being prepared by QDPI. To date, sections for lettuce and potatoes have been completed. Other crops will be included as extension information is reviewed by specialist teams, as part of an overall extension program.

During this project I have developed and conducted displays on irrigation scheduling and the Gatton College's EXPO 11 and EXPO 12 Horticultural Field Days. I have also run field days at Gatton Research Station and on producers' properties, promoting the use of tensiometers in irrigation scheduling. These have involved crops such as lettuce, broccoli, cauliflower, potatoes, green beans and lucerne, at sites in the Lockyer Valley, Granite Belt, Warwick and Gympie districts. I have given seminars on irrigation scheduling to scientists, public sector extension personnel, private consultants and producer groups in Queensland (and Tasmania), as well as to Gatton College students.

In response to the publications, field days and seminars, several producers requested assistance in setting up irrigation scheduling systems, particularly with regard using tensiometers in the most effective manner. Where possible, I helped these producers establish workable systems, in order to promote examples of successful adoption of our research findings. I am aware of numerous producers in southern Queensland, particularly lettuce, broccoli and potato growers, who are now regular users of tensiometers in their irrigation management programs. As packaged information for specific crops is developed and published during 1994, there should be a broader adoption by producers.

The QFVG has agreed to fund a development/extension/demonstration project on irrigation management in potatoes and onions, which will incorporate and expand upon the information we gleaned from the recently completed study. This will particularly focus on farm demonstration and operation of irrigation scheduling, to hasten the adoption in the targeted areas. Although primarily aimed at potato and onion producers, other groups should also embrace this technology and/or concept.

Based on my experiences with 2 electronic soil water monitoring systems, I have held several discussions with personnel from companies developing these technologies. They are attempting to address many of the shortcomings we experienced, including issues such as power sources, instrument reliability, software flexibility and data interpretation. I believe people from these companies also now recognise the vital importance of on-going technical support for potential users. In many instances where producers have purchased similar equipment in the past, it has ended up being consigned to the back shed because of poor after-sales follow-up. I will continue to provide feedback to Australian companies developing soil water monitoring equipment, to improve both their marketing potential and the usefulness of their products to the end-user. In discussions with the broader horticultural community, my feeling is that people have become more aware of the existence and potential of these irrigation management systems, but are also more appraised of the limitations and possible problems.

I believe that over the next 2-5 years, electronic soil water monitoring systems will only be used by a select group of producers; those who have a high degree of management skill and technological expertise, and who have a strong desire/need for precision irrigation management. This need may be generated by a scarce water resource, a high input-output production system, or strong community pressure for accurate monitoring of water use and flows into and out of the production system. In the longer term, monitoring/control systems will become more widely adopted and integral components of horticultural production. Australian companies, who are currently at the forefront of these technologies, are well placed to capture a major proportion of this expanding market. This is provided they continue to modify, improve and develop their systems to better meet the needs of potential users.

During this project I had discussions with growers and advisers who expressed interest in the concept of sub-surface irrigation. The potential benefits and problems were considered; in most instances vegetable growers indicated they would not be implementing such systems in the immediate future. I am not aware of any Australian vegetable producers irrigating with sub-surface systems at > 10 cm below the soil surface. Many growers with standard drip tapes are burying them 2-5 cm below the surface with good results. In current intensive vegetable production systems, which rely on fine seed-bed preparation before each crop, there would appear to be little potential for deeper sub-surface irrigation systems. If permanent-bed or minimum tillage systems become more common for vegetables in the future, sub-surface irrigation may be more viable, particularly in deeper-rooted, longer-season crops such as sweet corn.

As part of my scientific responsibility, I will write scientific articles on results from various results from the project, mainly focussing on the irrigation requirements of vegetable crops, and the comparative performance of irrigation application systems. Articles on irrigation management in sweet corn and lettuce are well underway.

Directions for future research.

Over the next decade, the efficient use and preservation of water resources will become an increasingly important issue in the horticultural and wider communities. Effective irrigation management is an essential component of water resource utilisation. The next few years will see increased use of objective irrigation scheduling in horticultural crops. Producers will be looking to use various methods, including tensiometers, neutron moisture meters, computer models or electronic soil water monitoring systems as part of their irrigation management strategy.

In terms of success and adoption of such technology, I suggest that HRDC would get greatest benefit from investing in projects that have a substantial component that involves objectively monitoring techniques in on-farm situations. Systems are then evaluated under real-life operational conditions and stresses, rather than the more controlled and supposedly higher expertise environments of dedicated research facilities. Using on-farm studies mean the benefits and shortcomings of particular systems can be more readily evaluated, while HRDC is not investing in the purchase or day-to-day management of systems. In addition, other growers feel more confident with the results, because test conditions are more closely aligned with their individual situations. The objective evaluation would be conducted by a third party, independent of the equipment supplier or producer, but would obviously require strong cooperation, communication and commitment between the parties. Specific comments on evaluation of expensive, electronic and/or complicated technology are included in the companion report for Project VG134.

Overseas literature suggests occasional improvements in irrigation efficiency from the use of sub-surface drip systems. These generally involve the use of standard drip tape with periodic emitters, rather than the leaky pipe which we evaluated. Nevertheless, I believe that there is still merit in the leaky pipe concept, provided the shortcomings mentioned in the technical report can be overcome. The use of recycled rubber for manufacture is environmentally desirable, while continuous water emission along the length of the pipe may have agronomic advantages.

In a horticultural context, it is unlikely that deep sub-surface systems will provide optimum irrigation in current vegetable production systems. They may be appropriate in perennial crops, turf or amenity horticulture situations. A cheap leaky pipe product may compete with conventional drip tape in standard drip irrigation in vegetables, either under plastic mulch or in shallow burial systems. Comparisons between cheap, shallow leaky pipe and standard drip tapes, in terms of crop performance and irrigation efficiency may be a valid HRDC project. Further research into deep (i.e. > 10 cm) sub-surface irrigation in vegetables should only be funded as a component of a larger project looking at alternative vegetable production systems. Such systems should involve permanent installation of the pipe, as retrieval and re-installation at depth is too expensive and damaging. Thus a potential project would probably investigate minimum cultivation / permanent bed production systems.

Given that various irrigation scheduling strategies have been around for a long time, it is surprising that there is not more widespread adoption. I believe this is because the technology has been presented in packages that are neither comprehensive, nor easy to understand or operate. There are also often specific regional or district issues that mean that the general technology package may not be suitable for immediate application to an individual producer. Unless producers are willing to experiment, learn and gradually adapt technologies to suit their own needs, then they will often fail to persevere.

In order to enhance adaptation of irrigation scheduling methods, I suggest there is a need for more regional evaluation and particularly demonstration of technologies for particular district production systems. In this way, the technology can be better integrated into the overall farm operation, enhancing the likelihood of adoption. These demonstration type projects could be jointly operated by interested producer and community organisations, equipment suppliers, private consultants and general funding agencies. The emphasis should be on adapted regional solutions to regional problems.

Where successful irrigation management models have already been developed for specific crops or locales, it obviously makes sense to see whether these systems can be successfully adapted to new crops (with similar biologies, water needs). It probably makes more sense to successfully develop and promote standard (possibly 'out-of-date') technology that is adopted and <u>used</u> by the target group, than to continually fund research into 'new' technology that does not have an 'adoption' focus.

Financial/commercial benefits.

This project has developed systems for scheduling irrigation in vegetables using tensiometers, that are effective and relatively inexpensive. Compared to employing a consultant using a neutron probe (around $ 1000-2000 per site per crop), or $ 6000-15000 for 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, may benefit from more intensive, expensive, irrigation management systems, in conjunction with expert counsel from an irrigation adviser (public or private). However, for the vegetable producer looking at objective 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 across the various vegetable enterprises should result in (i) increased yields and produce quality; (ii) lower relative irrigation costs; (iii) more efficient use of water resources; (iv) conservation of water and land quality through less leaching of fertilisers and pesticides; (v) potential for less pesticide use; (vi) potential for higher profits or expanded markets with improved and consistent product quality. Producers have recognised that they need to meet these objectives, not just for their own economic survival, but also because of broader community expectations.

I conducted a simple analysis on the benefits of an irrigation scheduling strategy to potato 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 (e.g. 4 tensiometers per 5 ha paddock, monitoring 3 times per week). The returns to the producer are quoted on a per tonne of produce basis. It assumes that increases in yields are offset by a reduction in the area planted, so as not to cause a glut and reduce prices. The analysis also 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.

Current on-farm price is assumed to be $ 200/t; yields 25 t/ha; irrigation costs $ 40 /ML. With no yield gains, irrigation scheduling with tensiometers would cost the producer about $ 1.60/t of potatoes produced. With a 10% yield increase, the producer would have a net profit increase (after irrigation scheduling costs are taken into account) of $ 6.93/t; a 20% increase $ 14.04/t; and a 40% increase $ 25.20/t. Based on our experimental results, a conservative yield increase of 20%, with only 30% adoption of the technology, would increase the profitability of potato producers in Queensland by a total of $ 410,000 per annum. This analysis ignores the marketing, resource use and environmental benefits referred to earlier.

Although higher green bean and sweet corn yields than are currently being achieved are certainly possible with improved irrigation management, yield benefits from irrigation scheduling in other vegetables are likely to be less dramatic (in the order of 5-15%). However, even in those crops where actual yield gains are relatively low, other economic and environmental advantages will still be considerable. There is absolutely no question that improved irrigation scheduling would be beneficial to individuals, districts and regions, in terms of better economic returns, resource utilisation and environmental conservation.

Following discussions with suppliers of electronic soil water monitoring systems in Australia, both their equipment and the technical support offered have been enhanced. By becoming more aware of essential operating guidelines and needs of prospective clients, these Australian companies have/will continue to develop more commercially acceptable products for both national and international markets. By outlining issues that potential users should consider before such capital and time investment, this project has helped ensure that systems are more likely to be a value-for-money input into irrigation management (rather than an expensive toy, unused after an initial dabble).

By trying to focus both equipment suppliers and horticultural producers on the effective operation of electronic soil water monitoring systems, I hope this project has enhanced Australia's prospects of successfully manufacturing and utilising these leading-edge technologies. This would improve the commercial performance of the new electronic manufacturing/service enterprises and the competitiveness of our horticultural industries.

An Australian company has commenced manufacture of a recycled-rubber drip tube in Australia, with improved specifications and at a much cheaper price compared to the product we tested. They have rapidly expanding markets, both within Australia and internationally. With Australian manufacture, a much higher proportion of profits are retained within this country, with enhanced probability of successful export. In conjunction with results from our project, the company have been able to develop better operational guidelines, and target more appropriate market segments. This has also improved their actual and potential sales, now reaching the magnitude of millions of dollars in the past 18 months.

Our project determined that the AGRI-GRO system was inappropriate for intensive vegetable production. As a result, horticultural producers will not waste money and time on a product that will be of no benefit in their operation. In contrast, the AUstralian manufacturers have now developed a superior product that may be more commercially viable in perennial situations. In addition, they are also manufacturing a pipe that may directly compete with standard drip tape. Relative costs and performance will determine whether the leaky pipe is more commercially acceptable to producers; this project has assisted in developing a product that is at least competitive. As much of Australia's standard drip tape is imported, a competitive import replacement would benefit the national economy.

Technical Report

Irrigation scheduling

for

shallow-rooted vegetables

Queensland Fruit and Vegetable Growers

DPI QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES SOUTH EAST REGION

HRDC

Introduction.

As demands of water resources for rural, residential, industrial and recreational uses increase, the need for efficient irrigation management becomes more urgent. Effective irrigation scheduling and water delivery/application systems are integral components of irrigation management.

Irrigation scheduling is the science/art of determining when and how much water a crop needs. With high value vegetables, most efficient use of irrigation water occurs when crops are irrigated as infrequently as possible, while still maintaining maximum yields. Such an irrigation strategy maximises the probability of storing and utilising rainfall between irrigations.

Under-watering can reduce production and quality by restricting photosynthesis, vegetative and reproductive development. Water stress can adversely affect nutrient uptake and disease incidence. Depending on water quality, under-irrigation may increase salinity and sodicity in the root zone due to lack of leaching. Irrigation in excess of crop and soil requirements wastes money and can cause both production and environmental problems. Excessive drainage can lead to rising water tables and secondary salinity, with potential for leaching of nutrients and pesticides into both surface and groundwater resources. Over-irrigation can have deleterious effects on the availability and uptake of nutrients, causing either deficiency or toxicity problems. Wet conditions favour the incidence of some plant diseases, e.g. those caused by *Pythium spp.* and other 'damping off' organisms. In severe circumstances, over-watering can result in extended periods of waterlogged, anaerobic conditions, with consequent harmful effects on plant growth and development.

In recent decades there have been substantial advances in technologies for assessing plant water requirements. These include methods that either; (i) use mathematical models to estimate plant water use, evaporation, drainage and runoff from weather, crop and soil parameters; (ii) objectively measure a soil water variable, most commonly water content or water potential; (iii) objectively measure a plant parameter that indicates its current water status. Some technologies combine several methods into a package.

Methods in group (i) commonly involve an estimate of potential evapotranspiration (ET) using daily weather data (e.g. Penman-Monteith equations, Class A Evaporation Pan data), modified by crop growth stage and soil water availability functions, to calculate actual ET over a given time period. Such methods are not frequently used in vegetable crops, although some procedures do use modified versions, to determine daily water allocations via drip irrigation systems.

A summary of methods for determining soil water status was outlined by Campbell and Mulla (1990). Apart from describing techniques, they noted practical advantages and disadvantages for each method. Techniques for measuring soil water <u>content</u> included; gravimetric sampling; neutron probes; gamma-ray attenuation; time domain reflectometry; thermal conductivity; soil capacitance. Methods for determining soil water <u>potential</u> included; mechanical and electronic tensiometry; pressure-plate apparatus; thermal conductivity; electrical resistance; filter paper techniques; thermocouple psychrometers.

Similarly, methods for assessing plant water status were summarised by Hsiao (1990) and included; estimates of plant water potential using thermocouple psychrometry and hygrometry; dyes; pressure chambers; compression resistance; organ dimensions; stomatal opening; canopy temperature; xylem cavitation; chlorophyll activity.

Because most vegetables have the bulk of their roots in the top 30 cm of soil (Wright and Stark 1990, Stanley and Maynard 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 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. More recent technologies such as Time Domain Reflectometry and Capacitance Probes can function more precisely at shallow soil depths, however their use in vegetables is still very much in its infancy (Henderson 1993). Infrared thermometry is probably not appropriate for most vegetables, 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. A recent irrigation scheduling project in WA established the use of tensiometers in potatoes for areas of that state (HRDC 1992).

In practical irrigation management, the 2 most successful and widely used systems to date have involved using neutron probe techniques to monitor soil water content profiles through time; or tensiometers to assess soil water potentials at one or more locations within and below the root zone. In vegetable crops, neutron probe measurements are generally conducted 1-3 times per week, while tensiometer readings are usually recorded each morning.

In terms of water requirements for optimum production of vegetable crops, there is surprisingly little information, much of which is conflicting. In their review of irrigation scheduling, Stanley and Maynard (1990) state 'The goal of irrigation management is to maintain soil water potentials in the -10 to -30 kPa range for vegetables grown under irrigated conditions, in order to minimise water stress and maximise production for these high value crops.' Earlier reviews, e.g. by Taylor (1972), suggest allowing soils to dry to water potentials of less than -200 kPa between irrigation in vegetables.

In reality, the critical soil water status at which vegetables will require irrigation for optimum production are location dependent, and must rely on local research and experience. For example, within the USA, the critical soil water potential values for maximum production of green beans varied from -25 kPa to -200 kPa, depending on production technology and climate (Stanley and Maynard 1990). Thus literature from other regions of the world can only act as a guide for Australian producers.

Lettuce and brassicas are most sensitive to water stress during head development; for green beans the sensitive stages are during flowering and pod enlargement; for sweet corn during silking, tasselling and ear development; for potatoes at tuber initiation and bulking up. In overseas literature, critical soil water suctions at which these crops should be irrigated have varied from: 20-60 kPa for lettuce; 60-160 kPa for brassicas; 25-200 kPa for green beans; 50-100 kPa for sweet corn and 30-50 kPa for potatoes (Stanley and Maynard 1990, Howell 1990, Wright and Stark 1990, Doorenbos and Kassam 1979, Taylor 1972). The tremendous variability in these values emphasises the need for regional determination and verification of the operating parameters for irrigation scheduling systems.

Drip irrigation systems can improve irrigation efficiency by more even water distribution, reduced evaporative losses (particularly during early crop growth stages), fewer disease outbreaks, more precise application control and lower operating pressures. Drip systems can be used for chemigation and fertigation, metering low doses of pesticides and nutrients appropriate for the crop growth stage. Drip systems are virtually unaffected by adverse weather conditions, enabling irrigation to be carried out any time of the day or night, as dictated by crop or manager requirements. Disadvantages include higher capital outlays, maintenance, installation and retrieval costs.

Within the family of drip irrigation systems, there has been some interest and research into sub-surface application. The main advantages compared to surface systems are reduced evaporation from wet soil surfaces, less photo-degradation due to UV sunlight and less exposure to surface damage from animals or machinery. The main disadvantages include blockages, location and repair of small leaks and high installation and retrieval costs.

Following severe droughts in the southern Queensland during 1987 and 88, which severely depleted groundwater supplies, there was a strong push by producers to increase irrigation efficiencies in vegetable industries. In response to this perceived need, a project to develop practical irrigation scheduling systems for shallow-rooted vegetables was submitted to and jointly funded by QLD Fruit and Vegetable Growers (QFVG) and the Horticultural Research and Development Corporation (HRDC). The main objectives were to compare methods for estimating crop water needs and to determine irrigation requirements for vegetable production; with a sub-objective of comparing irrigation efficiency and crop performance under sprinkler and drip systems. This report details the research and results from that project.

Materials and methods.

Techniques for scheduling irrigation, various application systems and the water requirements of several vegetable types were evaluated in a total of 14 experiments at Gatton Research Station (Table 1). In addition, irrigation was monitored in other experiments both at GRS and on-farm. Grower irrigation practices were also monitored on several occasions. Full methodologies, data, results and conclusions for each of these experiments are included in the experimental reports accompanying this final report.

Table 1. Crop types and growing periods for irrigation experiments at Gatton Research Station.

Experiment code	Crop	Cultivar	Planting date	Harvest date
BROC90	Broccoli	Pacific	30.08.90	12.11.90
BENA91	Green beans	Labrador	07.03.91	13.05.91
LETA91	Lettuce	Yatesdale	17.04.91	11.06.91
BROC91	Broccoli	Pacific	20.06.91	10.09.91
LETW91	Lettuce	Oxley	20.06.91	09.09.91
BEAN91	Green beans	Superstar	10.10.91	abandoned
CORN91	Sweet corn	Kulara II	28.10.91	14.01.92
BEAN92	Green beans	Labrador	11.03.92	15.05.92
LETT92	Lettuce	Yatesdale	10.04.92	04.06.92
BROC92	Broccoli	Greenbelt	02.06.92	20.08.92
CABB92	Cabbage	Galaxy	09.07.92	19.10.92
CORN92	Sweet corn	H9	09.11.92	02.02.93
POTA93	Potato	Sebago	23.02.93	16.06.93
POTW93	Potato	Sebago	24.06.93	22.10.93

The experiments were conducted on a black earth soil (*Ug5.15*) at Gatton Research Station (lat 27°33'S, long 152°20'E). In each case the experimental designs were randomised complete blocks, with 5 irrigation treatments replicated 3 times. For the bean, lettuce, broccoli, cabbage and potato experiments, each plot was 6 rows wide (4.5-5 m) and 10 m long, with the middle 2 rows as treatment rows and the outer 4 rows as buffer areas. In the sweet corn experiments, plots were 3 rows wide (3 m) and 10 m long, with a treatment row and 2 outer buffer rows.

Initial irrigations for the first 7-10 days after planting or transplanting utilised standard solid-set pipes and overhead sprinklers. For all other irrigations, systems of mini-sprinklers, drip tape or sub-surface drip tubing were used to individually water each plot. Schematics of plot layouts are shown in Figs. 1, 2 and 3.

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

The plots watered with surface drip tape had tapes positioned immediately adjacent to the treatment rows and the 2 nearest buffer rows. The tape used was 'T-Tape Row Crop' with drip emitters every 20 cm, and an output of about 7.3 $Lm^{-1}hr^{-1}$ at an operating pressure of 70 kPa. This corresponded to an application rate of approximately 9 mm/hr on a total area basis.

The beds watered with the sub-surface system had the 'AGRI-GRO' continuous drip tubing positioned directly under the treatment rows and the 2 nearest buffer rows. In most instances the tube was installed using a small trench digger, at a depth of about 20 cm. The tube was generally installed 4-7 days before planting, with the whole experimental area cultivated and harrowed after installation. The tubing had an initial output of around 5.4 $Lm^{-1}hr^{-1}$ at an operating pressure of 90 kPa. This corresponded to an application rate of approximately 7 mm/hr on a total area basis.

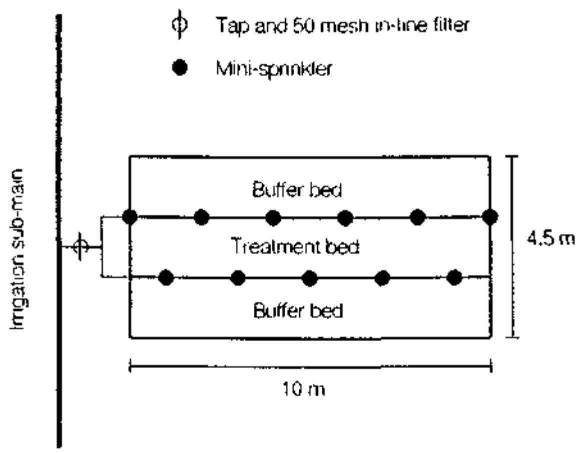


Figure 1. **Mini-sprinkler system designs for individual plots in experiments investigating irrigation scheduling in green beans, lettuce, broccoli, cabbage and potato.**

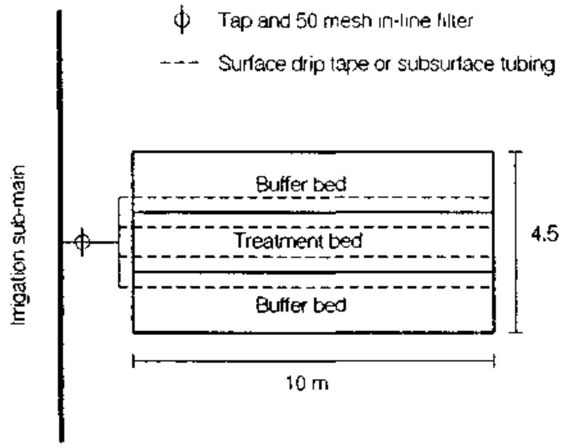


Figure 2. **Surface and sub-surface drip system designs for individual plots in experiments investigating irrigation scheduling in green beans, lettuce, broccoli and cabbage.**

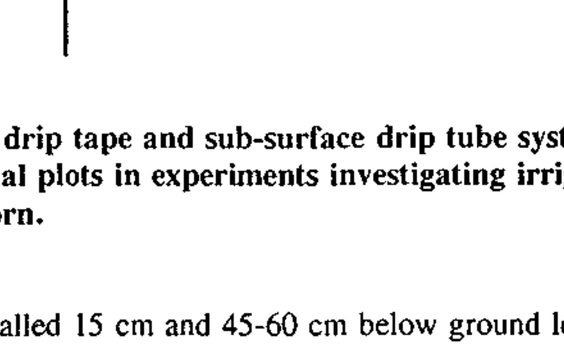


Figure 3. **Surface drip tape and sub-surface drip tube system designs for individual plots in experiments investigating irrigation scheduling in sweet corn.**

Tensiometers were installed 15 cm and 45-60 cm below ground level in each treatment bed. *Loctronic* tensiometers were used, consisting of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum, while an electronic vacuum gauge attached to the syringe records the vacuum in the tensiometer air gap. Tensiometer readings were recorded daily, usually around 9 am.

Critical Tensiometer Values (T) were used to trigger irrigations in these experiments. Irrigation was applied when readings for the tensiometers installed 15 cm below the ground surface were greater than the **T** individually set for each treatment. These 'trigger' tensiometers were set 20 cm below the tops of the hills in the potato experiments. The five irrigation treatments for each of the experiments are detailed in Table 2.

Table 2. Irrigation regimes for 14 irrigation scheduling experiments.

Experiment code	Crop	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5
BROC90	Broccoli	SPR20	SPR40	SPR60	SPR80	SPR4DAY
BENA91	Green beans	SPR3DAY	SPR20	SPR7DAY	SPR50	SPR80
LETA91	Lettuce	SPR3DAY	SPR20	SPR7DAY	SPR50	SPR80
BROC91	Broccoli	SPR20	SPR30	SPR50	SPR80	SPR90
LETW91	Lettuce	SPR20	SPR30	SPR50	SPR65	SPR80
BEAN91	Green beans	SPR20	SPR35	SPR50	SPR70	SPR90
CORN91	Sweet corn	SUR20	SUR35	SUR50	SUR70	SUR90
BEAN92	Green beans	SPR70/80	SPR70/40	SPR40/40	SUR40/40	SUB40/40
LETT92	Lettuce	SPR40	SPR20	SPR15	SUR20	SUB20
BROC92	Broccoli	SPR35/35	SPR60/35	SPR60/60	SUR35/35	SUB35/35
CABB92	Cabbage	SPR35/35	SPR60/35	SPR60/60	SUR35/35	SUB35/35
CORN92	Sweet corn	SUR20	SUR35	SUR50	SUR80	SUB35
POTA93	Potato	SPR30	SPR45	SPR60	SPR80	SPR10DAY
POTW93	Potato	SPR30	SPR45	SPR60	SPR80	SPR10DAY

The letter codes in Table 2 refer to:

SPR - irrigated with overhead mini-sprinklers
SUR - irrigated with surface drip tape
SUB - irrigated with AGRI-GRO sub-surface drip tubing

The numbers following the letter codes refer to the **T** values at which irrigation was to be initiated. In beans, broccoli and cabbage, the 2 numbers in the treatment codes refer to **T** values before and after flower budding, buttoning and the beginning of head formation respectively. The xDAY codes refer to a calendar schedule, with plots watered every x days irrespective of tensiometer readings.

Each plot was irrigated according to its allocated treatment. Plots with the same irrigation treatment were occasionally watered on different days, due to differences in the time for the tensiometers to reach values necessary to trigger irrigation.

Aluminium neutron probe access tubes were installed to depths of 80-110 cm in each treatment bed, 5 cm inside treatment rows and equidistant between 2 neighbouring plants. Neutron moisture meter readings were taken twice a week using a Campbell Pacific Nuclear Hydroprobe. A single reading was taken at 5-8 depth intervals, commencing 5 cm below the ground surface, incrementing by 10 cm. On each day that the neutron probe measurements were made, 5 standard counts was also conducted in a 200 L drum of water. Calibration equations for the neutron probe data were developed during the first 7 experiments and assumed to be the same for the remainder.

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

Using simple spreadsheets, we calculated daily water balances for each experimental plot. Rainfall, irrigation, stored soil water, pan evaporation, evapotranspiration and drainage of soil water below the crops' effective root zones were determined from planting through to harvest. Details of the calculations are available from the authors.

Apart from the soil water measurements, crop growth was also measured during the growing period, using non-destructive parameters such as crop height or width. At the conclusion of the experiments, the crops were harvested to determine various yield parameters, as detailed in the individual reports.

In the on-farm crop monitoring exercises, tensiometers were installed after the crops emerged. We recorded readings on a regular basis, generally up to twice a week during key growth periods. We monitored overhead-irrigated potatoes, sprinkler-irrigated broccoli, cauliflower and lettuce, and drip-irrigated lettuce.

Results and discussion.

Detailed results for each experiment are found in the individual reports. The results and comments in this section are general overviews from the whole evaluation period.

Scheduling methodology

During this project we evaluated a range of techniques that could be used for scheduling irrigation in vegetables. For most of the project we concentrated on methods using tensiometers or neutron probes, however we also conducted field tests of 2 electronic soil water monitoring systems in several experiments. A detailed discussion of electronic systems is included in the HRDC final report on Project VG134 'Comparisons of irrigation scheduling and drip application technologies for vegetable production'.

The key issue when scheduling vegetable irrigation on the basis of soil water status is the need to intensively monitor the upper 20 cm of the soil profile. For the majority of vegetable crops, the vast bulk of root activity is in this soil zone, although some roots obviously penetrate substantially deeper into the soil profile. By studying water uptake patterns in each of the experiments, we have estimated the average effective rooting depths of each of the vegetables investigated in the project.

Figures 4-8 show changes in soil water profiles after irrigation or rain had effectively wet the soil to 50-80 cm. The 'field capacity' values are those measured 2 days after watering. The refill values are soil water profiles immediately prior to the next irrigation. The wetter refill curves show the extent to which the soil was allowed to dry before irrigating for maximum production. The driest curves show soil water profiles in treatments with no irrigation over an extended period of time. The soil suction pressures (x kPa) refer to the **T** values for the irrigation treatments that gave rise to these wetter and drier 'refill' profiles. All the soil water profiles shown in the Figures were from measurements conducted late in the growing period, when crop rooting depths and water uptake were at a maximum.

In the black earth soils of the Lockyer Valley, lettuce are very shallow rooted. Even when rooting depth has reached a maximum, 85% of water uptake is from the upper 20 cm of the soil profile, in a crop irrigated for maximum production. Infrequently irrigated lettuce still extract very little water from deeper than 30 cm (Fig. 4).

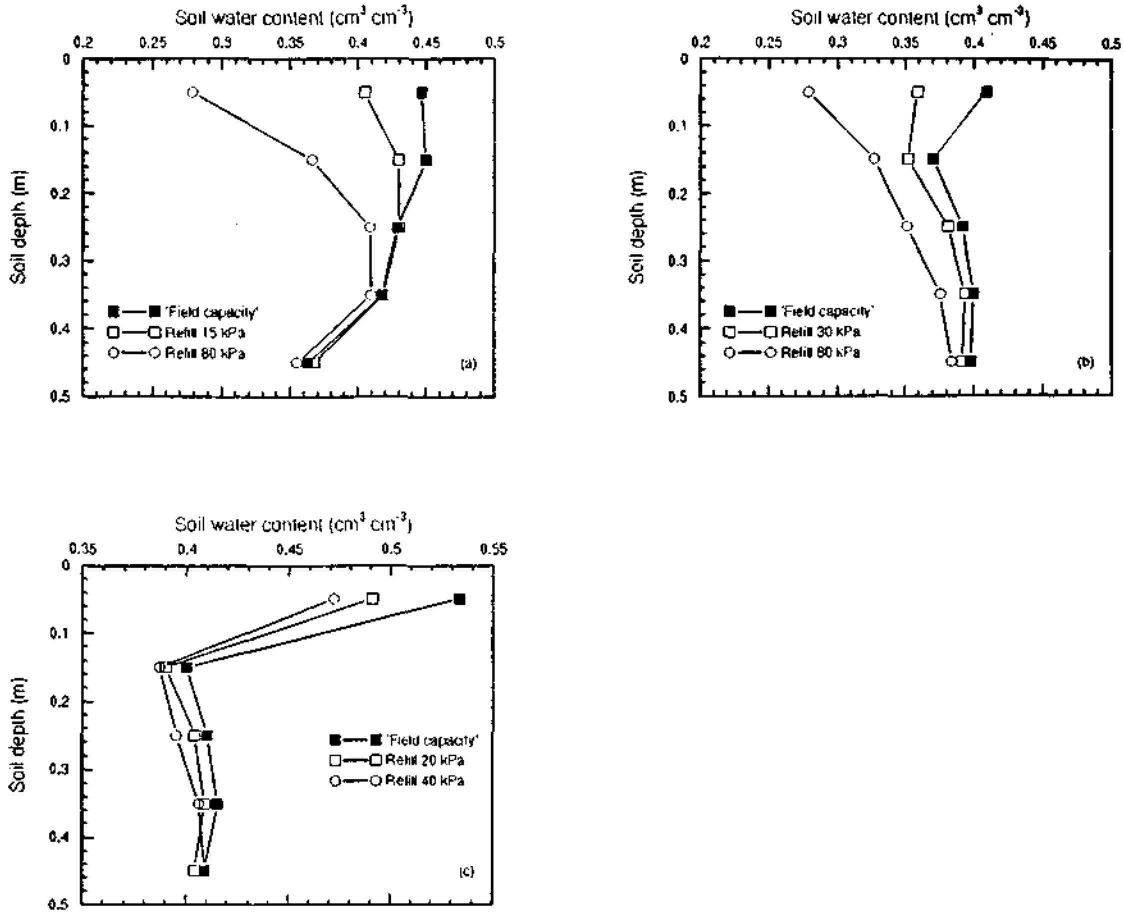


Figure 4. **Soil water profiles show water extraction and drainage for mature lettuce crops grown in (a) autumn 1991; (b) winter 1991; and (c) autumn 1992. Profiles were 2 days after irrigation (■——■); immediately prior to irrigation in the maximum production treatments (□——□); immediately prior to irrigation in the infrequently irrigated treatments (○——○).**

Similar to lettuce, potatoes also have very shallow root systems in these fine-textured clay soils. When irrigated for maximum production of high quality tubers, 85% of water uptake is from the upper 25 cm of the soil profile, with 70% from the upper 20 cm. Even in virtually non-irrigated potato crops, we found very little uptake of soil water from more than 50 cm below the top of the hill (Fig. 5).

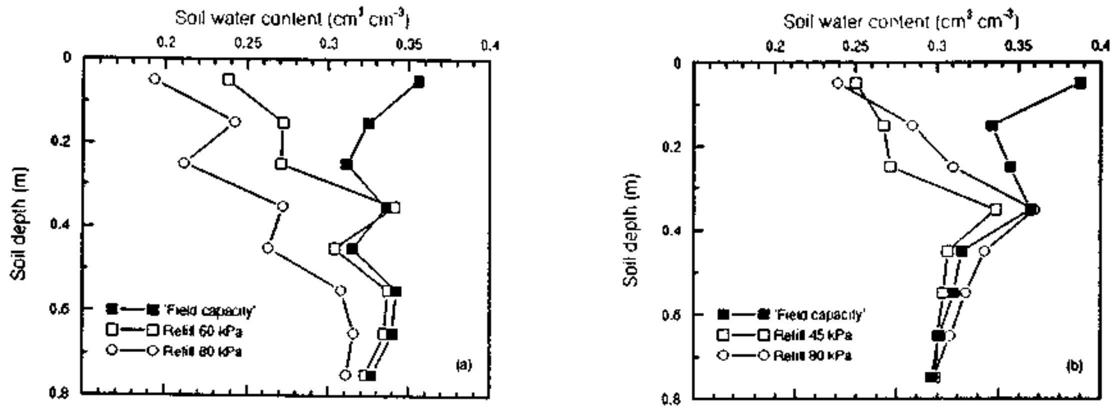


Figure 5. **Soil water profiles show water extraction and drainage for potato crops in the late bulking stage during (a) winter 1993; and (b) spring 1993. Profiles were 2 days after irrigation (■———■); immediately prior to irrigation in the maximum production treatments (□———□); immediately prior to irrigation in the infrequently irrigated treatments (○———○).**

We found green beans, brassicas and sweet corn all had deeper effective root systems than lettuce and potatoes. In crops irrigated for maximum production, 80-85% of water uptake was from the upper 30 cm of the soil profile for green beans, 35 cm for brassicas and 40 cm for sweet corn. In all 3 vegetables, around 60% of water uptake was from the top 20 cm of the soil profile (Figs. 6-8). In the least frequently irrigated crops in these experiments, there was only limited water uptake from deeper than 60 cm in the soil profile. Most of the changes in water contents below 60 cm were associated with slow deep drainage, rather than uptake by plants.

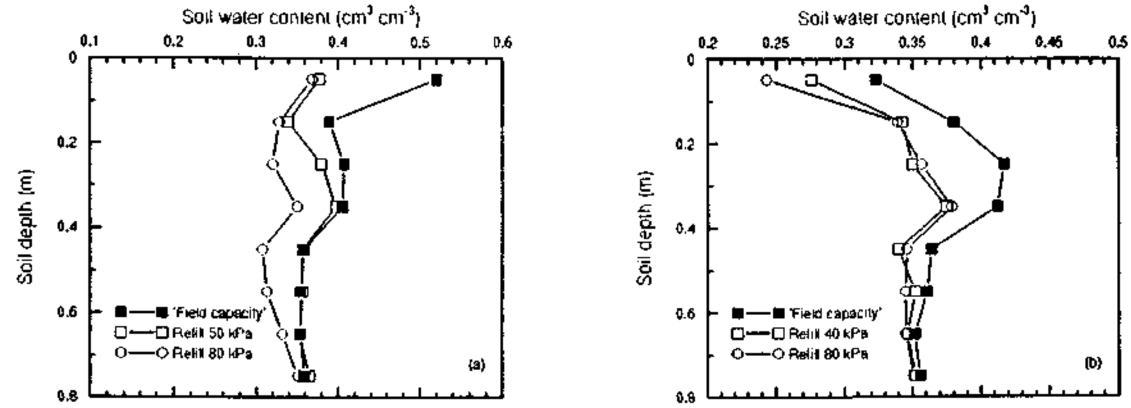


Figure 6. **Soil water profiles show water extraction and drainage for maturing green bean crops grown in (a) autumn 1991; and (b) autumn 1992. Profiles were 2 days after irrigation (■——■); immediately prior to irrigation in the maximum production treatments (□——□); immediately prior to irrigation in the infrequently irrigated treatments (○——○).**

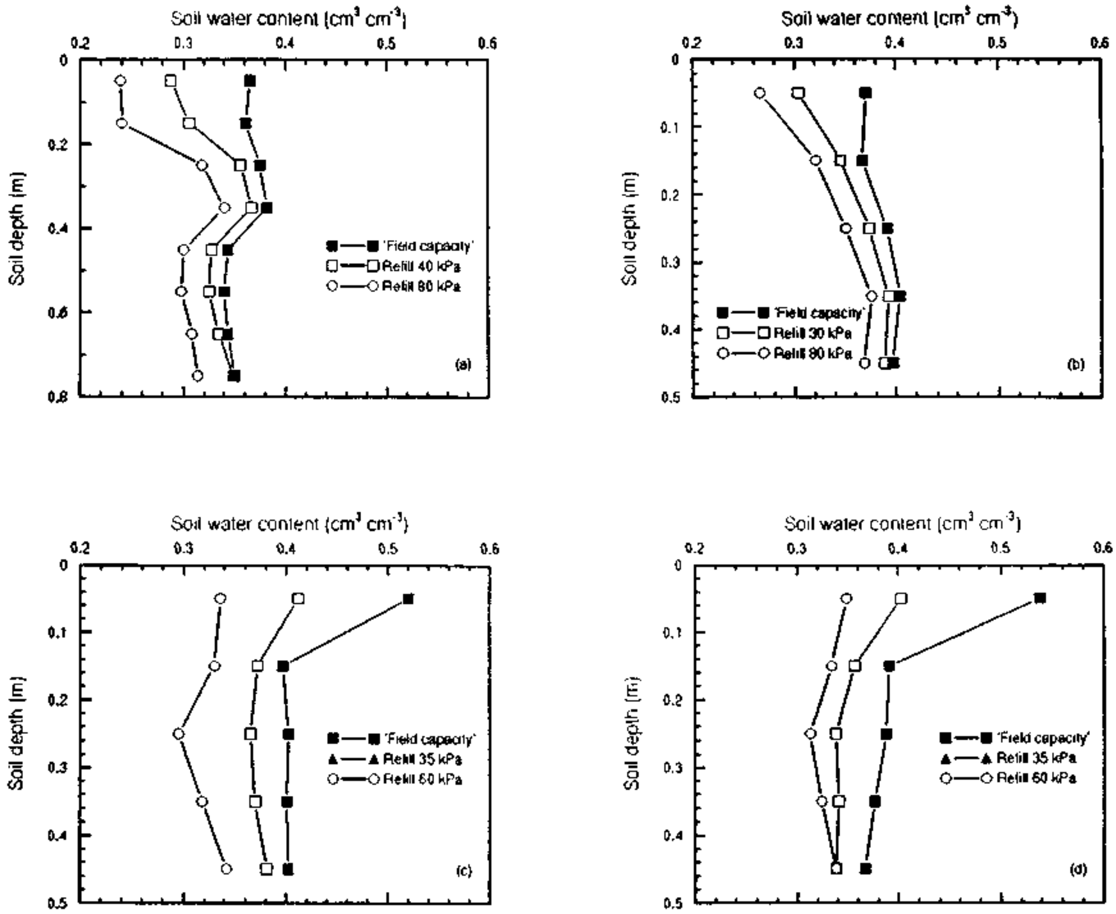


Figure 7. **Soil water profiles show water extraction and drainage for maturing broccoli crops grown in (a) spring 1990; (b) winter 1991; (c) winter 1992; and (d) a cabbage crop grown in winter 1992. Profiles were 2 days after irrigation (■——■); immediately prior to irrigation in the maximum production treatments (□——□); immediately prior to irrigation in the infrequently irrigated treatments (○——○).**

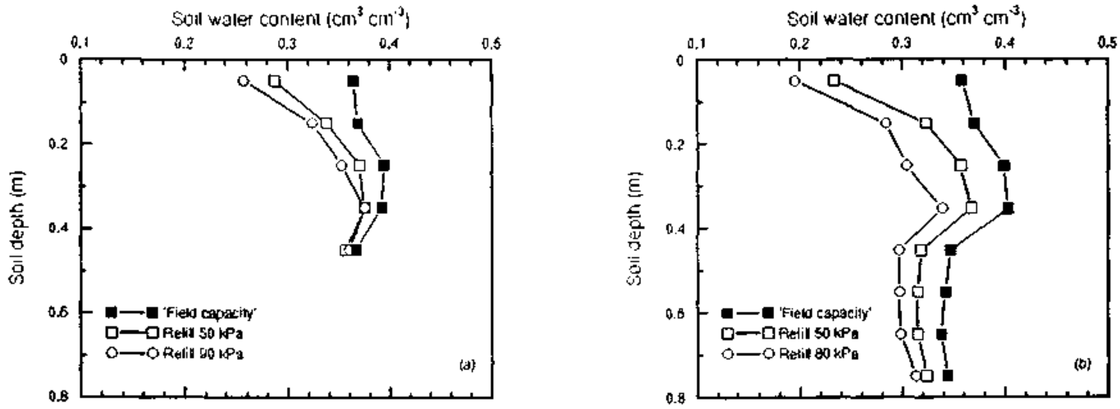


Figure 8. **Soil water profiles show water extraction and drainage for maturing sweet corn crops grown in (a) summer 1991/92; and (b) summer 19993. Profiles were 2 days after irrigation (■——■); immediately prior to irrigation in the maximum production treatments (□——□); immediately prior to irrigation in the infrequently irrigated treatments (○——○).**

The patterns of root activity we noted in our experimental work emphasise the need to monitor the top 20 cm of the soil profile, in irrigation scheduling systems where soil water status is the factor for determining when and how much to irrigate. The shallowest reading in most commercial neutron probe services has usually been taken at 20 cm below the ground surface. In many vegetable crops, this is too deep to accurately determine soil water changes in the critical shallower root zones. By taking neutron moisture meter readings at 5 cm and 15 cm below ground level, we were able to measure water changes in these surface layers more accurately. However, this required intensive, site-specific calibration of the NMM, because relationships between NMM readings and soil water contents in these surface soil layers were very different to those from deeper in the soil profile. This was partially because of texture differences, but mainly because of changing proportions of fast neutrons escaping into the atmosphere. Most commercial neutron probe operators, either growers or consultants, would generally be unable to commit the time or resources to intensively calibrate each site prior to irrigation scheduling.

With most of our vegetable crops, the intervals between irrigation are generally less than 10 days, frequently less than 7 days, and in the case of crops such as lettuce on coarse textured soils, can even be less than 1 day. A neutron probe service that monitored soil water profiles every 2-3 days would be relatively costly; probably too expensive for routine irrigation scheduling in a standard crop.

The great benefit of the NMM is the ability to monitor water content in the entire soil profile. In conjunction with accurate rainfall and irrigation data, this information is very helpful in developing crop water balances, where the efficiency of irrigation, as well as the amounts of water used by the crops and draining beyond the root zone can be quantified. In this project, we used NMM information extensively to develop water use patterns for the various vegetable crops. This intensive soil water monitoring is invaluable in research, and may be useful for producers using new irrigation equipment; growing new crops; or trying new watering patterns, to gain a better understanding of the impacts of these changes on soil water balances.

As a general overview, NMM techniques are probably inappropriate for routine irrigation scheduling in shallow-rooted vegetable crops. The intensity of monitoring and calibration required to accurately determine when and how much water vegetables need is probably too expensive for most vegetable producers. The NMM may have a role in specific situations, where a producer is developing new irrigation methods that are very different from their current operation, and they feel the need to accurately monitor soil water movement, particularly deep drainage. It may be that as newer electronic soil water monitoring systems (e.g. those based on capacitance or heat dissipation cells) become more commercially available, that the NMM will become displaced technology.

Although relatively old technology, in our project we found tensiometers to be the most cost-effective method for monitoring soil water status 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 problem with the tensiometer system was 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 give immediate estimates of soil water deficits within the root zone. The amount of irrigation applied at a given tensiometer reading relies to some extent on previous experience with the particular soil type / crop combination. We aim to lose no more than 10% of the applied irrigation as drainage.

A copy of an article I wrote on using tensiometers in vegetables is included as Appendix 1 in this report. Tensiometers are easiest to use in overhead-irrigated vegetables; flood, furrow and drip irrigation systems are more complex, because tensiometer positioning is more critical. A specific instance of using tensiometers in a commercial drip-irrigated lettuce crop is included in Appendix 2.

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

Standard tensiometers consist of a ceramic tip, plastic housing, vacuum gauge and water reservoir. In modern designs, each component is individually replaceable, minimising repair costs. In addition, the best of these models have a water reservoir with a rubber membrane and valve design capable of removing air bubbles from the tensiometer without the need for a vacuum pump. This enhancement improves field operations and reliability of tensiometers in the field. A standard tensiometer with the above features costs about

$ 110. In situations where more than 10 tensiometers are required by a single operator, it becomes more economical to use the *Loctronic* tensiometer system.

In the conduct of this project, we had limited experience with 'portable' tensiometers, where the tensiometer is inserted into the soil and a value read after a few minutes. We found that because of extended equilibration times, the soil suctions determined using these 'portable' tensiometers generally significantly under-estimated the values obtained using standard tensiometers. I would be very wary of using such equipment in an irrigation scheduling system in vegetables.

An example of using tensiometers to schedule vegetable irrigation is provided with results from one of the potato experiments conducted in the last few months of the project. By that time I had a fair idea of the amounts of water required to refill the root zone for any given set of tensiometer readings. This meant that soil water in the root zone was replenished with irrigation, without excess deep drainage.

In Fig. 9, the effects of changing tensiometer values for triggering irrigation (**T**) have on the frequency and amounts of irrigation, and consequences for soil water status in the root zone and deep drainage are shown. Where **T** was set at 30 kPa (Fig. 9a), the potatoes received an average of 23 mm irrigation every 5.2 days during the tuber initiation and yield formation period. Note the rapid rises in soil suction values in the 15 cm and 20 cm deep tensiometers between 30-60 days after planting (DAP), indicating a period of high water use. Note also that the deep tensiometer values fell sharply at 42 DAP and 80 DAP. The first decline was due to an accidental over-irrigation of 194 mm (due to timer breakdown). The second deep drainage event followed 27 mm of rain on an already moist soil profile. By allowing surface soil suctions to increase to 60 kPa between irrigations, watering frequencies were slightly reduced (average 28 mm every 5.5 days) although the total quantities applied were relatively similar. The advantage of increasing the **T** value is that the potential for storing rainfall for use by the crop is increased, due to slightly drier average soil conditions over time. This is shown by the deep tensiometer values in Fig. 9b, which although falling after the rain at 80 DAP, do not indicate saturated soil conditions. This suggests less deep drainage under the latter irrigation regime.

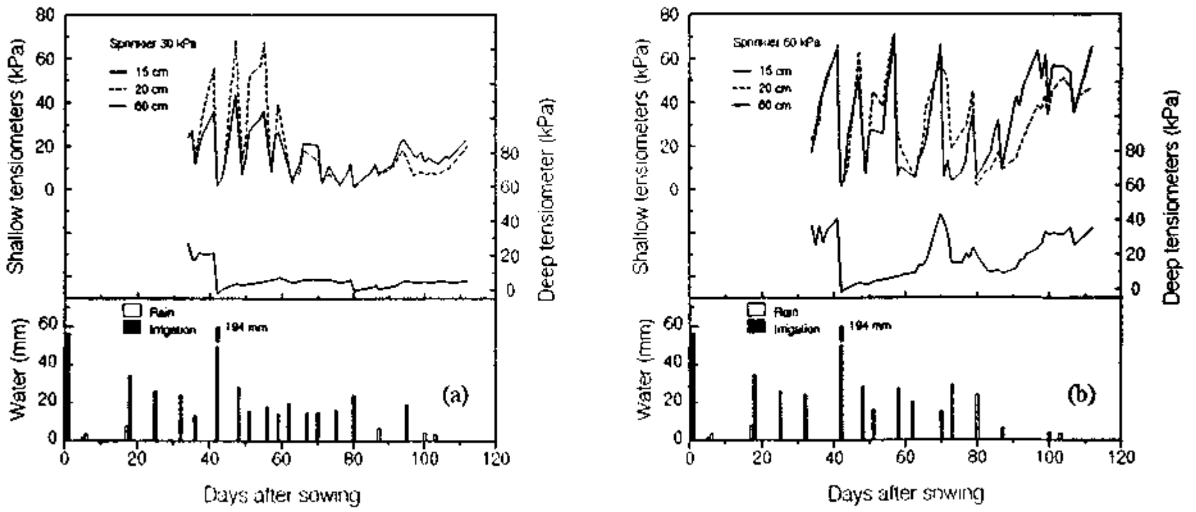


Figure 9. Fluctuations in soil matric suction at 15, 20 and 60 cm below the top of the hill, where potatoes were irrigated when soil matric suction at 20 cm exceeded (a) 30 kPa; or (b) 60 kPa during the growing period.

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

Crop irrigation regimes.

The following Critical Tensiometer Values (T) and irrigation regimes were generally developed from experiments using overhead sprinkler irrigation. An exception was with sweet corn, where only drip systems were used, due to the difficulty of installing a mini-sprinkler system capable of watering a 2 m high crop. Some adjustment in the irrigation regimes would be required for application methods other than overhead sprinklers, in particular where drip irrigation is used. Obviously these irrigation requirements depend on cultivar and growing conditions (both weather and agronomic). It should be noted that there can frequently be other reasons affecting irrigation timing, e.g. the need to incorporate herbicides or fertilisers, or to dry out the surface to increase trafficability or reduce disease. The tensiometer readings are only another input into the scheduling decision. Irrigation timing during the first few weeks of vegetable growth should not rely solely on the tensiometer readings, as the root system of plants have not developed sufficiently to affect even the shallow tensiometers.

Lettuce.

Unfortunately the 3 completed lettuce experiments were beset by a number of difficulties, including a significant outbreak of Lettuce Necrotic Yellows, and a less severe incidence of Downy Mildew. There was substantial rainfall during some of the experiments, masking irrigation effects.

As previously shown (Fig. 4), lettuce have very shallow root systems (and hence low capacity to exploit soil water reserves). Development of lettuce heads also involves rapid reproduction and expansion of turgid, water-filled cells, with a low tolerance for water stress. In addition, physiological disorders such as tip-burn, caused by poor calcium movement through the plant, are exacerbated by even low levels of water stress, particularly during hot, dry conditions. The consequence of these factors is that high-quality lettuce can only be produced where frequent irrigation (sometimes as often as twice-daily) is possible. Because they are frequently irrigated, the soil profiles under a lettuce crop are generally always moist. There is little opportunity for the development of dry soil layers capable of storing rain. This maintenance of wet soil conditions is obvious in the tensiometer values (at both 15 cm and 45 cm below the ground surface) from the autumn 1991 lettuce experiment (Fig. 10). The results shown are for the treatment irrigated at a T of 20 kPa; optimum for lettuce grown in warm conditions. Because of the moist surface soils, it is easy to apply too much water at any given irrigation. In the LETW91 experiment, scheduling with tensiometers (compared to set irrigations twice-weekly) reduced drainage losses by 30%.

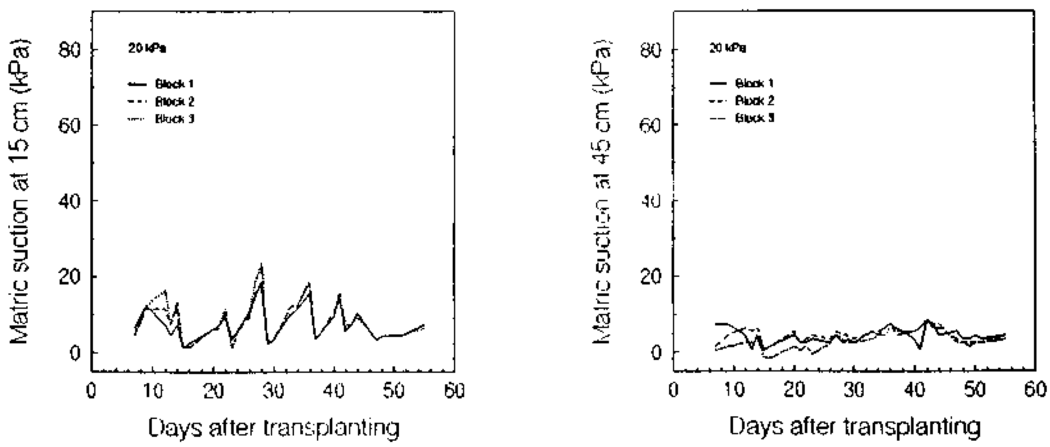


Figure 10. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where autumn lettuce were irrigated when soil matric suction at 15 cm exceeded 20 kPa.

It should also be noted that what is an appropriate T value for lettuce in one environment may not be suitable in another. For example, in the lettuce experiment conducted during the winter of 1991 (LETT91W), T values could be increased from 15-20 kPa in autumn to 25-30 kPa in winter, with no loss in yield or quality. This was because the plant root systems could extract water at a lower rate from the drier soil, yet still meet a lower evaporative demand. The net result of increasing the **T** value from 20 kPa to 30 kPa was a requirement for 4 fewer irrigations, 60 mm less overall irrigation, and a reduction of deep drainage losses by 20 mm (Fig. 11)

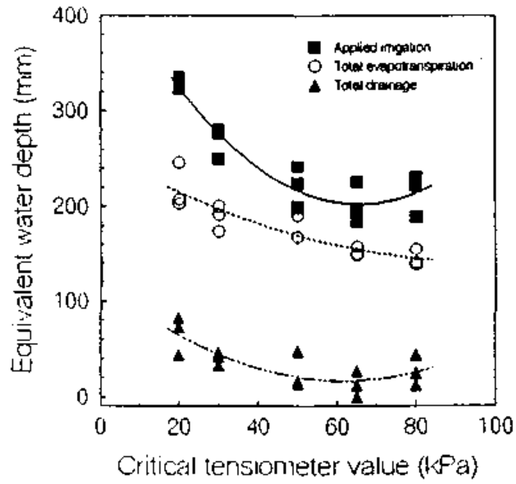


Figure 11. **Changes in quantities of irrigation, total evapotranspiration and drainage losses in winter lettuce as the Critical Tensiometer Value increased.**

One of the consequences of high-frequency irrigation in lettuce is increased difficulty in managing diseases and crop nutrition. In the LETT91A experiment, there was a significant outbreak of Downy Mildew, which was worst in the most frequently irrigated treatments (as would be expected). As a result there was a non-significant trend for fewer marketable lettuce in these wetter plots. However, there was a significant trend for larger and heavier heads in the well-watered treatments (Fig. 12).

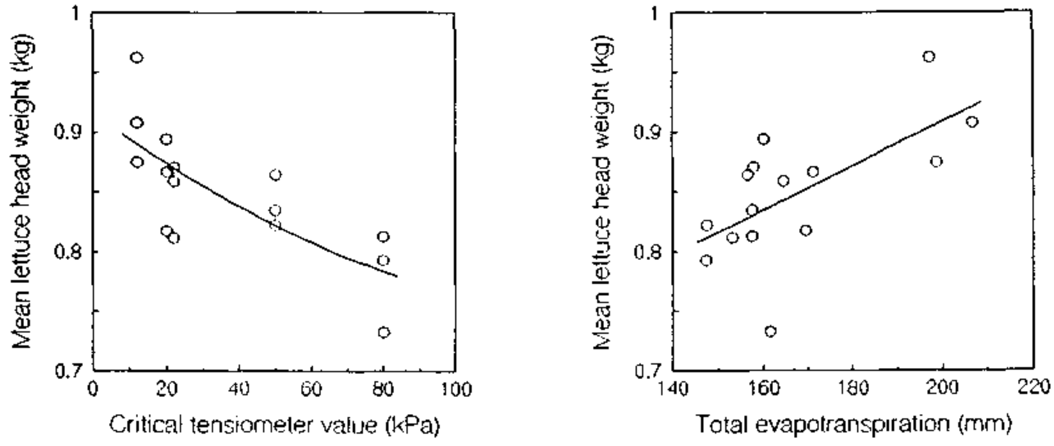


Figure 12. **The mean weight of marketable lettuce heads was increased by reducing the Critical Tensiometer Value, or increasing the total evapotranspiration of autumn grown lettuce.**

The winter lettuce experiment in the same year was adversely affected by Lettuce Necrotic Yellows virus, which caused tremendous variability within and between plots. There was some indication of poorer nitrogen nutrition in the most frequently watered plots. In a soil environment with such high leaching potential, due to the continuously-wet soil conditions, it is probable that a system of several split-applications of mobile nutrients such as nitrogen would be beneficial. Differences between irrigation treatments in the lettuce experiment carried out in autumn 1992 (LETT92) were masked by episodic rainfall. The frequency of the rain was such that the lettuce only required 5 irrigation during the growing period. Unfortunately this meant there were no significant differences between the treatments irrigated at **T** values varying from 15 kPa to 40 kPa (Fig. 13)

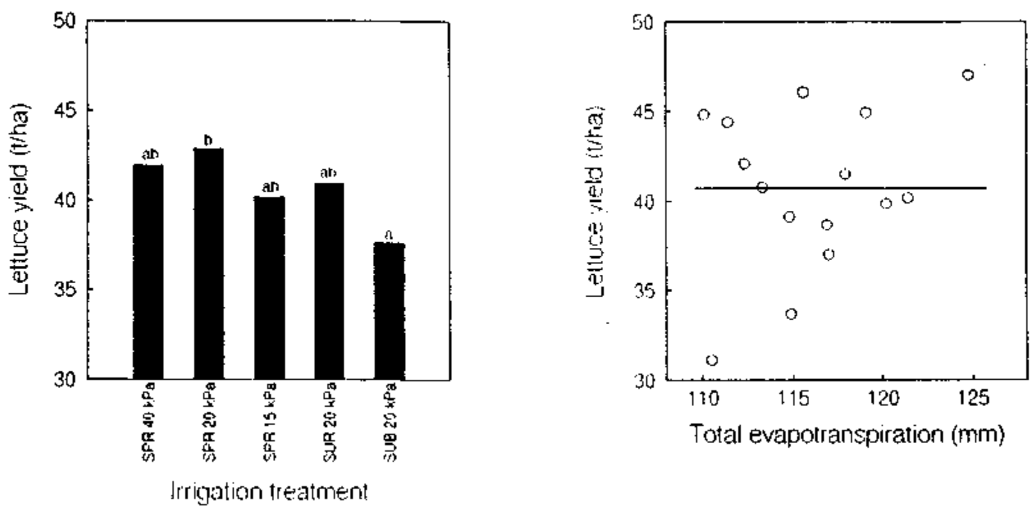


Figure 13. The total yield of marketable lettuce heads was slightly reduced by subsurface drip irrigation, however it was unaffected by altering either the Critical Tensiometer Value or the total evapotranspiration of autumn grown lettuce.

Apart from attention to disease and nutrition management in lettuce crops grown under high irrigation frequencies, lettuce arrangement and planting densities also affect irrigation use efficiency. Where the soil surface is continually being wet with light, frequent water applications, it is important to maximise rate and extent of crop canopy development. By rapidly expanding crop leaf area, the proportion of applied water lost to soil evaporation (as opposed to plant transpiration) can be reduced. This can be achieved in a number of ways;, the most obvious is to increase planting density to the maximum that does not reduce yield or quality. Most lettuce producers are currently using such a system, with no bare ground evident during the latter stages of the growing period. The rapid development of closed crop canopies can however have adverse effects on the incidence of diseases that prefer humid, shaded conditions. A compromise between the ultimate in irrigation use efficiency and disease management will probably be required in such instances.

Results for the individual lettuce experiments are available in the individual reports. Overall, maximum yields and quality were generally achieved with **T** set at 15-20 kPa for autumn and spring crops and 20-25 kPa for winter production. Mean head sizes in the 3 experiments were 0.82, 1.20 and 1.10 kg respectively, with little size difference between treatments with irrigations triggered at tensiometer values between 15 and 40 kPa. However, treatments with higher **T** values were more liable to suffer from tip-burn, particularly in sudden weather changes to warmer or less humid conditions.

Results for *transplanted* lettuce suggest that optimum lettuce yields and quality are obtained when irrigation commences at values of 15-25 kPa for tensiometers installed at 15 cm below ground level. The lower value is appropriate for autumn lettuce, with the higher value for winter production. On black earth soil types, this involves the following irrigation regimes. For autumn crops, 13-15 mm of water every 2.5-3 days for the first 20 days, followed by 15-17 mm every 4-5 days as the lettuce root systems develop and evaporative demand declines. In winter production, 15 mm of water every 4-5 days for the first 30 days, followed by 20 mm every 5-6 days until harvest, seemed sufficient to optimise lettuce yields and quality. In both production periods, the total irrigation requirement is 230-250 mm, meeting a target evapotranspiration of about 210-220 mm.

Broccoli.

With deeper root systems, greater tolerance to water stress, and because the harvested part is a reproductive rather than vegetative organ, broccoli can cope with higher levels of soil water deficit than can lettuce. As a consequence, in the 3 experiments we conducted during the project, optimum broccoli yields with greatest irrigation efficiency occurred when **T** was set at 35-40 kPa. Compared to treatments with lower **T** values, this reduced irrigation requirements and total deep drainage. An example of the irrigation requirements and water balances with **T** at 40 kPa is shown in Figs. 14 and 15, for the BROC90 experiment. Interestingly, in this experiment (which was a relatively late spring planting), hot weather conditions around 4-6 weeks after transplanting seemed to adversely affect surface root systems, increasing the proportion of water uptake from deeper soil zones. Because of hot conditions during budding and head formation, overall head quality in this experiment was poor, with marketable broccoli numbers highly variable across the experiment.

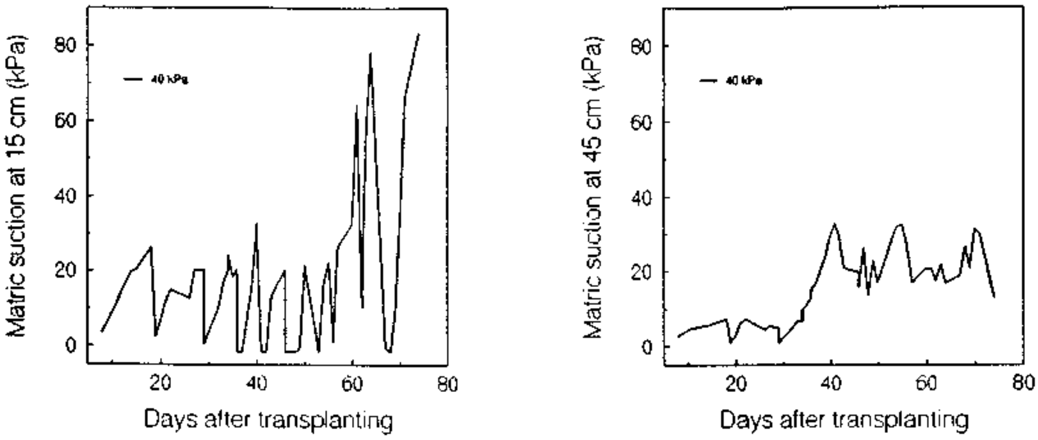


Figure 14. **Fluctuations in soil matric suction at 15 and 45 cm below ground level, where spring broccoli was irrigated when soil matric suction at 15 cm exceeded 40 kPa.**

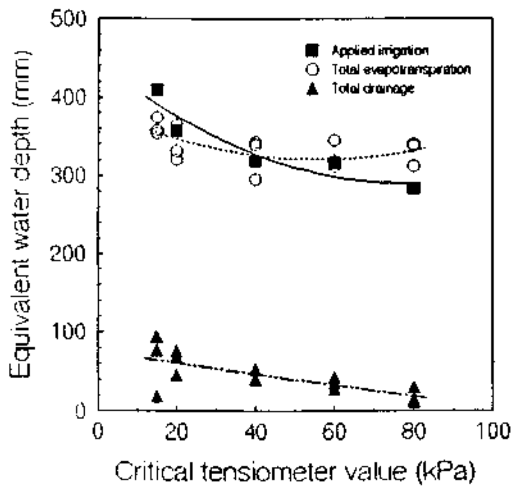


Figure 15. **Reductions in quantities of irrigation, total evapotranspiration and drainage losses in spring broccoli as the Critical Tensiometer Value was increased.**

In the BROC91 experiment, the optimum irrigation regime appeared to be somewhere between the treatments with **T** values of 30 kPa and 50 kPa. Tensiometer patterns for these 2 treatments are shown in Figs. 16 and 17 respectively. Note that at 30 kPa the subsoil stayed relatively wet for most of the growing period; for the 50 kPa treatment there was some subsoil drying during the latter growth stages. The differences between these treatments is reflected in the total growing period water balances (Fig. 18), with the wetter 30 kPa treatment having much greater quantities of irrigation and deep drainage. This example underlines the irrigation efficiency benefits of using as high a **T** value as possible while still maintaining crop yields and product quality. In this experiment, increasing **T** from 30 kPa to 50 kPa slightly reduced the number of marketable heads, with a greater impact on mean head weight and total yield (Figs. 19-21).

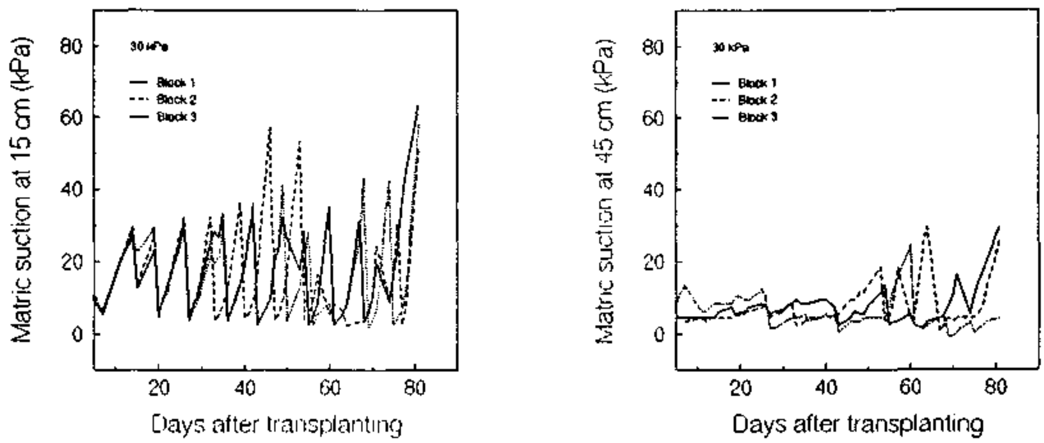


Figure 16. **Fluctuations in soil matric suction at 15 and 45 cm below ground level, where winter broccoli was irrigated when soil matric suction at 15 cm exceeded 30 kPa.**

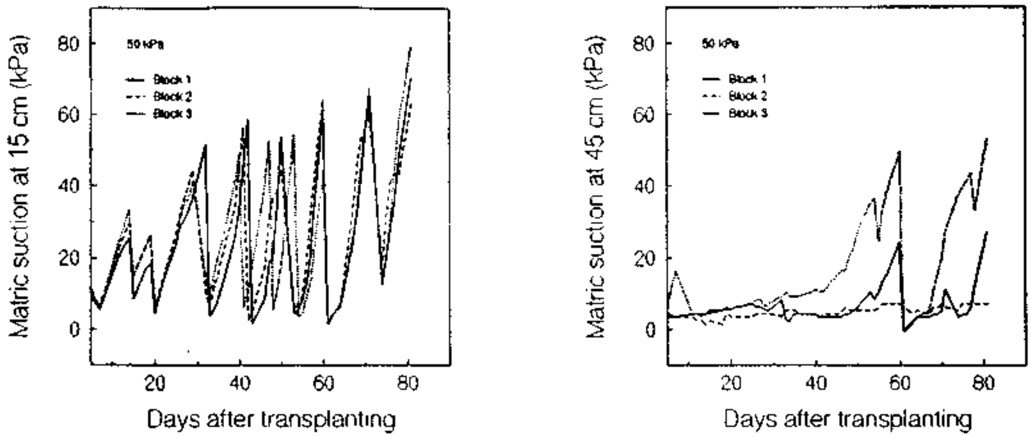


Figure 17. **Fluctuations in soil matric suction at 15 and 45 cm below ground level, where winter broccoli was irrigated when soil matric suction at 15 cm exceeded 50 kPa.**

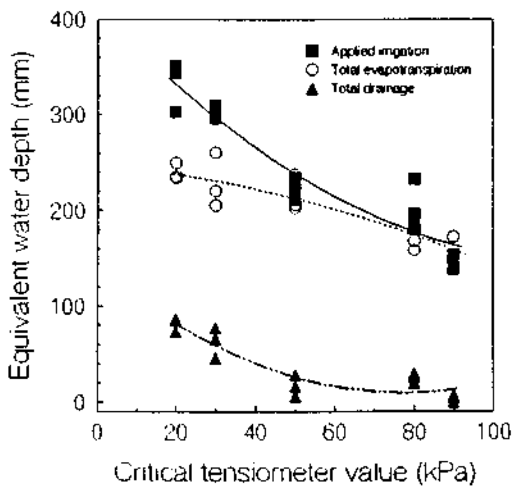


Figure 18. **Reductions in quantities of irrigation, total evapotranspiration and drainage losses in winter broccoli as the Critical Tensiometer Value was increased.**

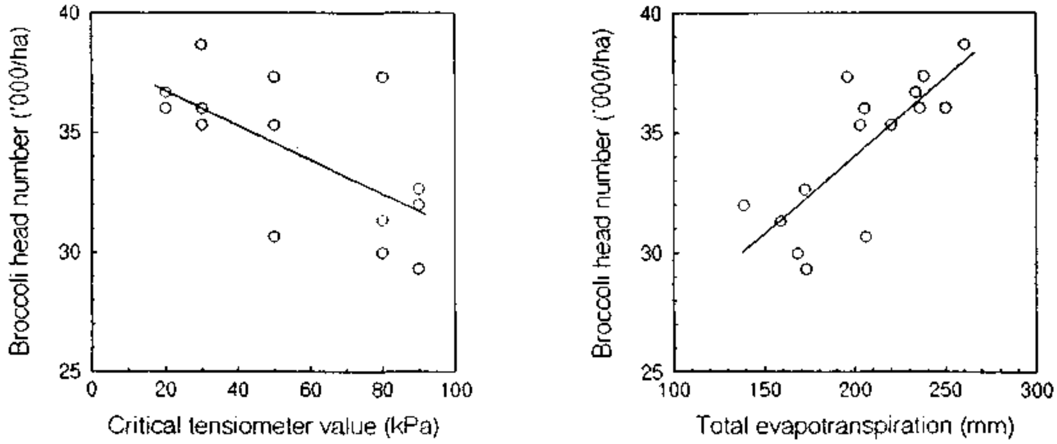


Figure 19. **The number of marketable broccoli heads was increased by reducing the Critical Tensiometer Value, or increasing the total evapotranspiration of winter broccoli.**

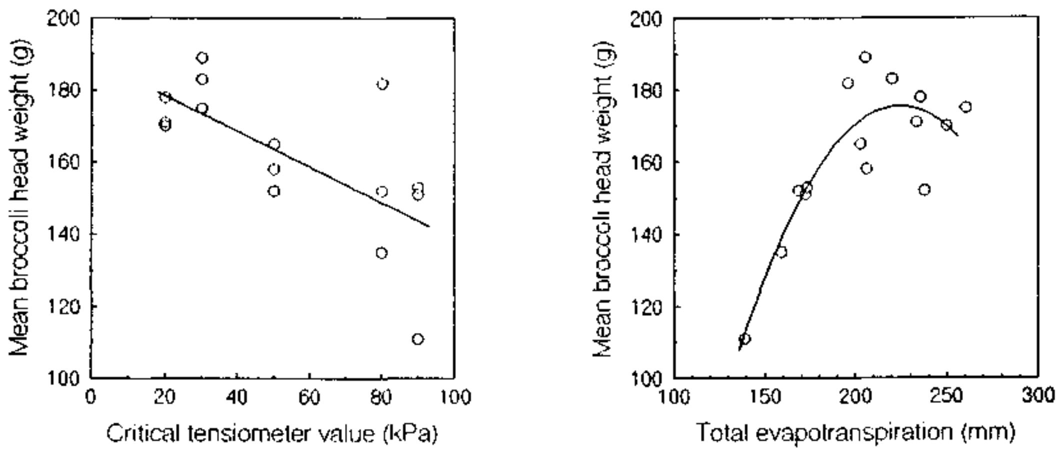


Figure 20. **The mean weight of marketable broccoli heads was increased by reducing the Critical Tensiometer Value, or increasing the total evapotranspiration of winter broccoli.**

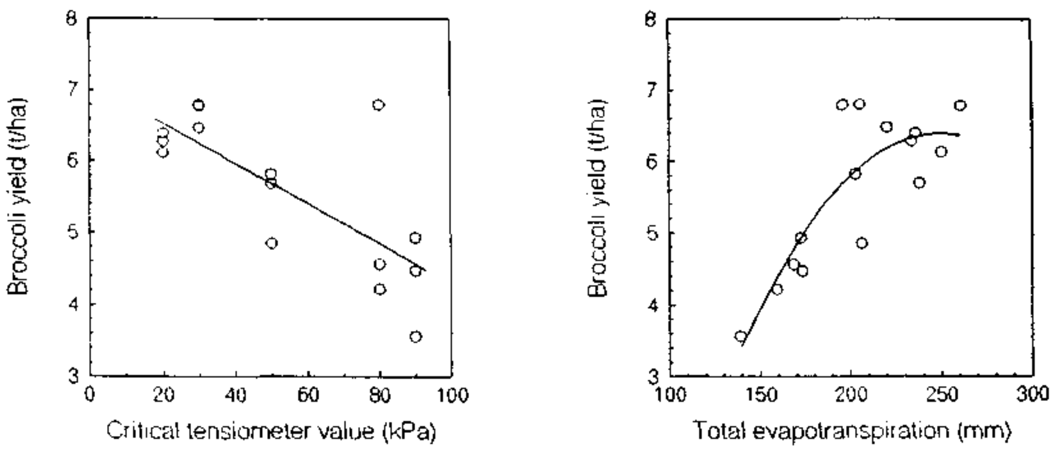


Figure 21. The total yield of marketable broccoli heads was increased by reducing the Critical Tensiometer Value, or increasing the total evapotranspiration of winter broccoli.

Because of rainfall during the pre-buttoning period, there was little differentiation between the irrigation treatments in the BROC92 experiment (Fig. 22). Due to the experience with tensiometers in these soils gained during this project, we were able to refine the amounts of irrigation applied at any given tensiometer reading in a particular crop at a specified growth stage. As a result, in this experiment there was no excessive irrigation; any deep drainage was associated with rainfall in excess of the soil water storage capacity. Because of the lack of treatment differentiation, there were no significant effects of irrigation method or frequency on the number of broccoli heads harvested (around 39 000/ha = 95% cut out), mean weight and diameter of the harvested heads (187 g, 11 cm), overall yield (7.3 t/ha) or time to maturity. There were no significant relationships between any of the broccoli yield parameters and total evapotranspiration (Fig. 23).

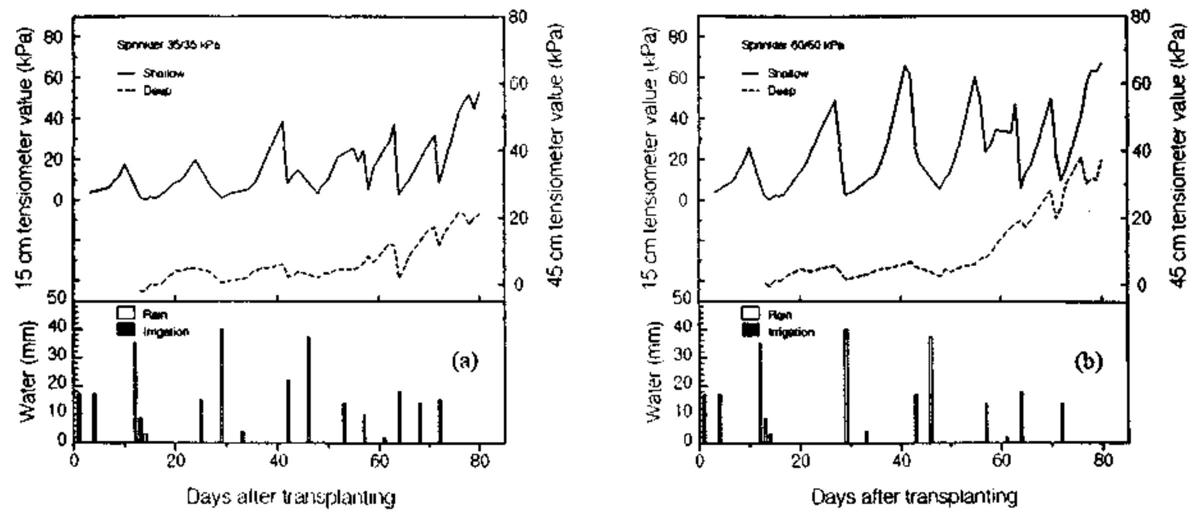


Figure 23. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where winter broccoli were irrigated using mini-sprinklers, when soil matric suction at 15 cm exceeded (a) 35 kPa or (b) 60 kPa during the growing period.

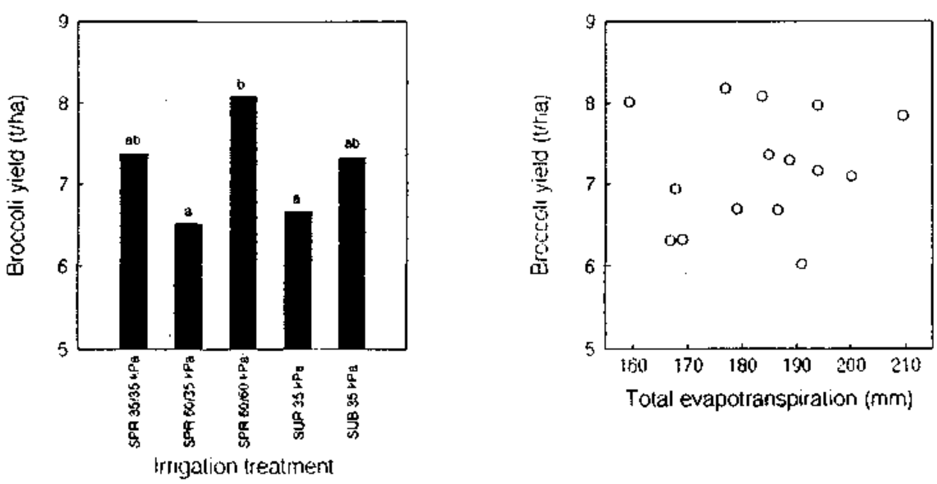


Figure 23. The total yield of marketable broccoli heads was slightly affected by irrigation regime, however it was not related to the total evapotranspiration of winter grown broccoli.

Experimental results suggest that a Critical Tensiometer Value for maximum production of broccoli is probably 35-50 kPa, with the lower value in conditions of high evaporative demand. On black earth soil types, this involves the following approximate irrigation sequences (given that no rainfall occurs). About 15-17 mm every 5-7 days for the first 7 weeks, increasing to 20 mm every 5 days as the broccoli

root systems develop. Normally the target evapotranspiration for broccoli is probably about 230-280 mm for autumn and spring crops, and 180-220 mm for winter crops. In average seasons, the total irrigation requirement would be about 2.2-3 ML/ha, allowing for inefficiencies and drainage losses. This regime applies to sprinkler irrigation. Similar overall quantities would probably be required for drip irrigation systems, supplied in smaller amounts on a more frequent basis. Obviously any rainfall during the intervening period would reduce these requirements, although there may still be a need to irrigate for other purposes, such as fertiliser or pesticide incorporation. The regime would also be affected by cultivar and agronomic practices.

Cabbage.

We only conducted one experiment on cabbage during this project. Results indicated that optimum irrigation frequencies and quantities were similar to those for broccoli. Cabbage is probably less sensitive to water stress during the vegetative phase compared to the head development phase. Deficit irrigation during the vegetative phase may encourage activity of deeper roots, as well as provide a more effective reserve for capturing rainfall and reducing deep drainage. Cabbage water use appears to increase markedly once head development commences. Irrigation and tensiometer sequences for 2 sprinkler irrigated treatments in the CABB92 experiment are shown in Fig. 24. Increasing **T** from 35 kPa to 60 kPa markedly reduced the amount of irrigation applied, however there was very little deep drainage from either treatment (Fig. 25). In this experiment, increasing **T** from 35 kPa to 60 kPa only slightly reduced cabbage yields (Fig. 26).

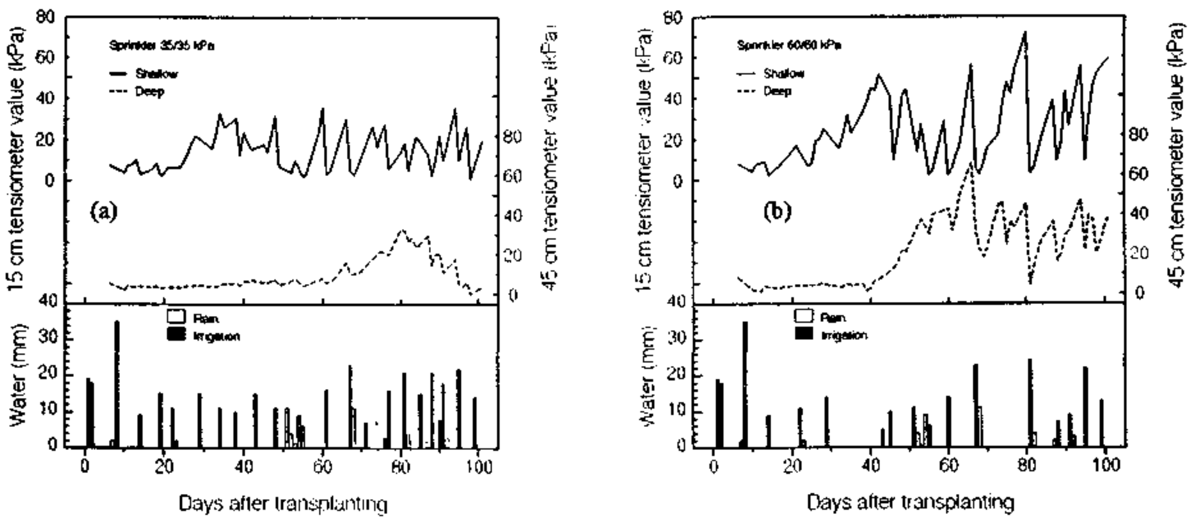


Figure 24. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where winter cabbage were irrigated using mini-sprinklers, when soil matric suction at 15 cm exceeded (a) 35 kPa or (b) 60 kPa during the growing period.

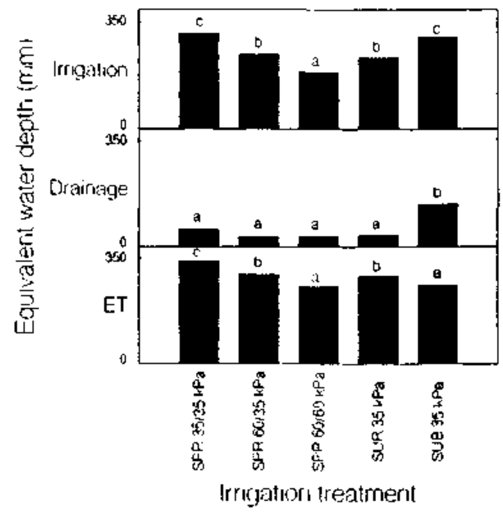


Figure 25. **Changes in quantities of irrigation, total evapotranspiration and drainage losses under 5 irrigation regimes in winter cabbage. Bars labelled with the same letter were not significantly different ($P<0.05$).**

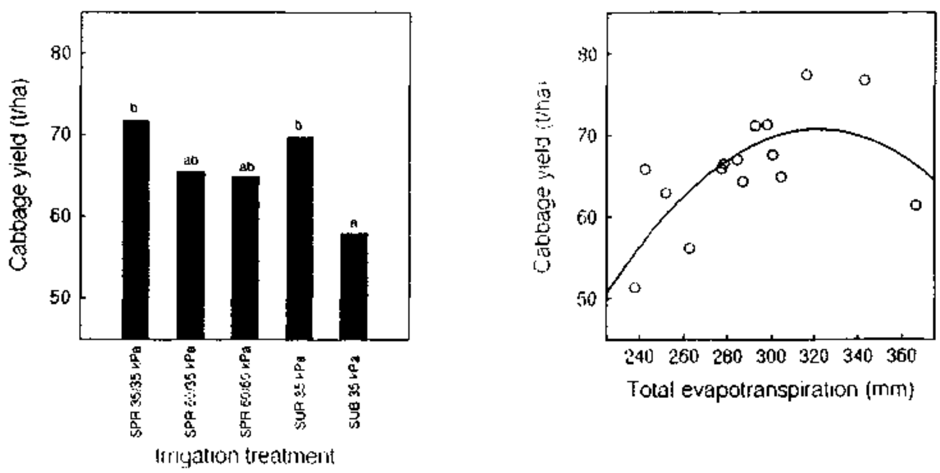


Figure 26. **The total yield of marketable cabbage heads was reduced by utilising sub-surface irrigation or reducing total ET below 300 mm.**

Results from this single experiment suggest that a Critical Tensiometer Value for maximum production of winter-spring cabbage is probably 50-60 kPa during the vegetative phase, dropping to 40-50 kPa during the head development phase (the lower values would apply in conditions of high evaporative demand). On black earth soil types, this involves the following approximate irrigation sequences (given that no rainfall occurs). About 12-15 mm every 7-10 days for the first 8 weeks, increasing to 17-19 mm every 4-5 days for the 6 weeks until harvest. The target

evapotranspiration for cabbage would probably be around 300-320 mm, with a total irrigation requirement of about 3-3.3 ML/ha, allowing for inefficiencies and drainage losses. This regime applies to sprinkler irrigation. Slightly lower overall quantities would probably be required for drip irrigation systems, supplied in smaller amounts on a more frequent basis. Obviously any rainfall during the intervening period would reduce these requirements, although there may still be a need to irrigate for other purposes, such as fertiliser or pesticide incorporation. The regime would also be affected by cultivar and agronomic practices.

Green beans.

During the initial green bean experiment early in the project (BENA91), we tended to over-irrigate each of the treatments, due to over-estimation of the soil water storage available for re-filling. This can be seen in the chart of deep tensiometer values for the 50 kPa treatment, where several dips to 0 kPa indicate deep drainage events (Fig. 27). This demonstrates the problem that many people using tensiometers initially have with judging the correct amount of water to apply at a given tensiometer reading. Given experience with different soils and crops however, this inaccuracy is soon overcome.

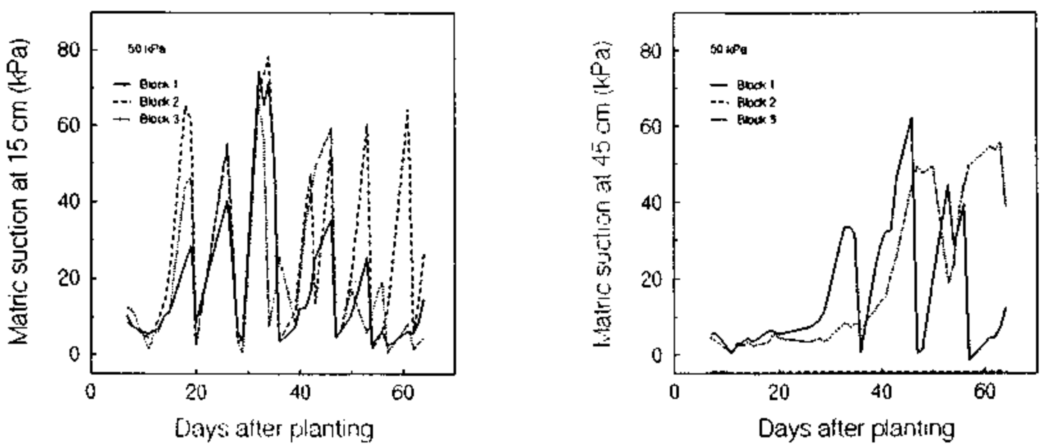


Figure 27. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where autumn green beans were irrigated when soil matric suction at 15 cm exceeded 50 kPa.

In this early experiment, even the least frequently irrigated treatment, with **T** set at 80 kPa, was watered more often (i.e. every 7-10 days) than common commercial grower practice (every 11-14 days). Fresh pod yields from this experiment were high (11-12 t/ha), twice average commercial production. Although there were no significant effects of irrigation regime on bean yields, there was certainly no advantage of a **T** value less than 50 kPa (Fig. 28).

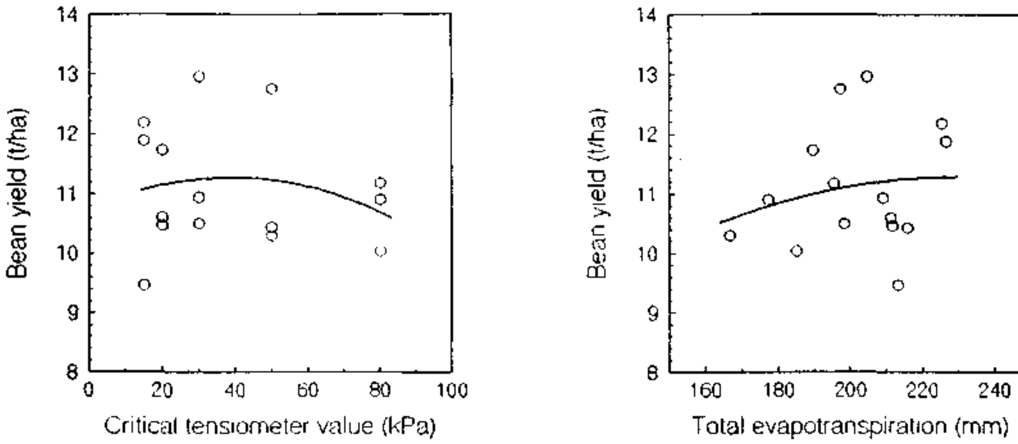


Figure 28. **The total yield of green beans was not significantly affected by altering either the Critical Tensiometer Value or the total evapotranspiration of autumn grown green beans.**

In the 1992 autumn bean experiment (BEAN92), rainfall during the growing period interfered with differentiation between irrigation treatments, however there was a significant trend for plots with a T value of 40 kPa during the pre-budding period to slightly out-yield those with a T of 70 kPa. There was also a significant trend for higher yields in plots with higher total ET (Fig. 29).

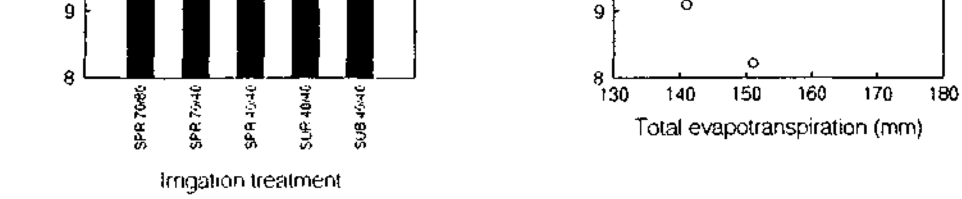


Figure 29. **The yield of autumn grown green beans was slightly affected by the Critical Tensiometer Value used pre-budding, with a significant trend for increased yields as total evapotranspiration during the growing season rose.**

In the green bean experiments successfully completed, setting T at 40-50 kPa resulted in yields of around 11.3 t/ha in both instances. Allowing the shallow tensiometer values to reach 70-80 kPa between irrigations reduced bean yields by 5-10%, while using T of 20-30 kPa increased drainage losses and had no significant impact on production. There was some concern expressed about increased risk of lodging in the more frequently irrigated treatments, however we had no difficulty machine harvesting all the plots in these experiments.

Results suggest that the Critical Tensiometer Value for green beans is probably around 40-50 kPa pre-budding, declining to 40 kPa after flowering. Under this criteria, irrigation would be required every 6-7 days for the growing period, with 17-20 mm for the first 7 weeks after planting, increasing to 20-23 mm per irrigation for the final 3 weeks until harvesting. Given this sequence, a total of about 11 irrigations (220 mm) would be needed to obtain optimum green beans yields and quality while minimising irrigation costs and drainage losses. This regime applies to overhead application systems. Similar overall quantities would probably be required for drip irrigation systems, supplied in smaller amounts on a more frequent basis. Obviously any rainfall during the intervening period would reduce these requirements, although there may still be a need to irrigate for other purposes, such as fertiliser or pesticide incorporation. The target evapotranspiration for the growing season is probably around 170 mm in cool, moist conditions, increasing to 210 mm in warm, dry growing periods. These values would also be affected by cultivar and agronomic practices.

Although increased irrigation frequency may enhance risks of fertiliser (and pesticide) leaching, disease outbreaks and crop lodging, we have not encountered these problems to date. Careful attention to crop nutrition and pest management, as well as precise monitoring of the amounts of water applied at each irrigation, is required. There may be a case for selecting cultivars with a stronger bush habit, to reduce lodging losses.

Sweet corn.

Because of the need to irrigate with a drip tape system, the sweet corn in our experiments were irrigated more frequently than in a commercial operation with overhead application. It rained often during the first sweet corn experiment, resulting in little differentiation between irrigation treatments, shown by the tensiometer and water application charts for plots watered at 50 kPa or 90 kPa respectively (Fig. 30).

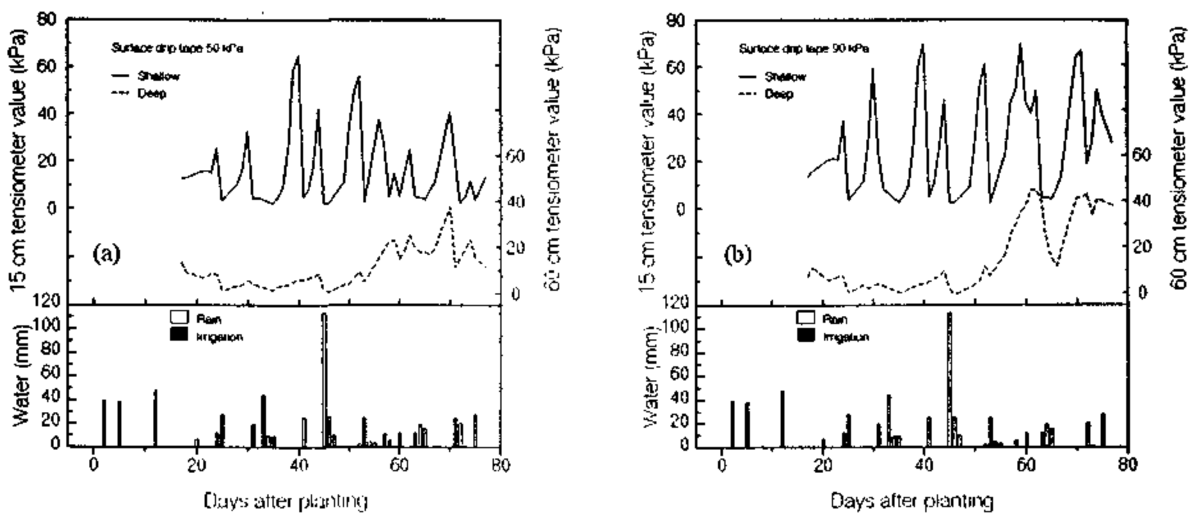


Figure 30. Fluctuations in soil matric suction at 15 and 60 cm below ground level, where sweet corn were irrigated using surface drip tape, when soil matric suction at 15 cm exceeded (a) 50 kPa or (b) 90 kPa during the growing period.

The calculated water balances indicate substantial through-drainage during the life of this sweet corn crop (Fig. 31). There were 2 components to this drainage, associated with (i) excess irrigation and (ii) excess rainfall. All drainage due to excess irrigation (about 65 mm) occurred at the first 3 irrigations, using standard irrigation pipes and commercial practices. This was prior to commencing the scheduling program and different irrigation treatments.

Over 70% of drainage was due to rainfall in excess of the soil water holding reserve at the time. There was significantly less total drainage in the 70 and 90 kPa treatments, when compared with the more frequently irrigated sweet corn. In these former plots, drier soil conditions between irrigations created a greater capacity to absorb rainfall before runoff or drainage occurred.

The water balances also indicated that the 70 and 90 kPa treatments had significantly lower total evapotranspiration (ET) than the more frequently irrigated sweet corn (Fig. 31). These differences came about during the final 3 weeks prior to cob harvesting.

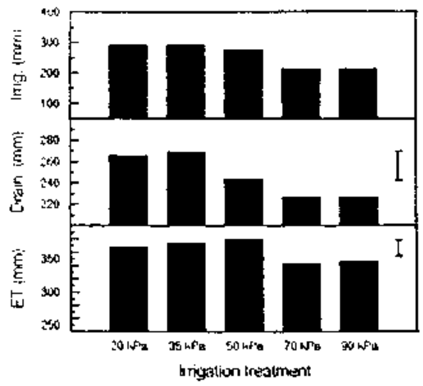


Figure 31. Changes in quantities of irrigation, total evapotranspiration and drainage losses under 5 irrigation regimes in sweet corn. Bars indicate the 5% L.S.D.

Yield differences between irrigation treatments were small (< 2 t/ha) and generally not significant. Any differences were associated with variation in cob numbers, not individual cob weights (Fig. 32). Interestingly, data from individual plots showed a significant ($P<0.01$) linear relationship between estimated total ET and cob yield. Maximum yield was attained at an ET value of about 370 mm.

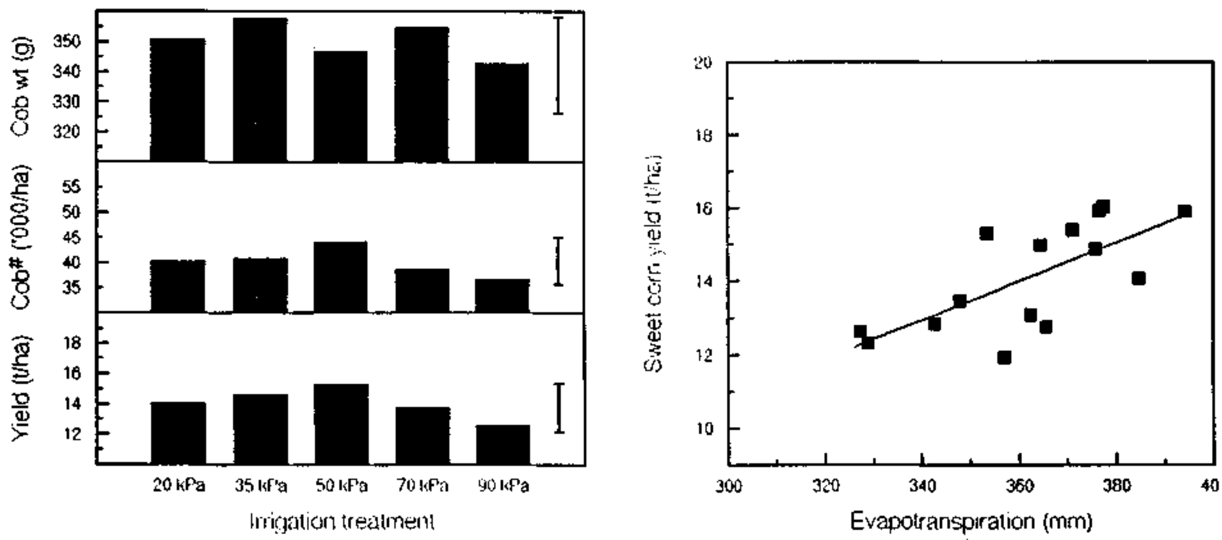


Figure 32. Sweet corn yield parameters were not significantly affected by altering Critical Tensiometer Values, however yield was significantly increased at higher ET totals.

A relatively dry summer meant we were able to differentiate irrigation treatments in the 1992/93 experiment (CORN92). This is shown by the contrast in irrigation regimes and tensiometer fluctuations between the plots with T values set at 50 kPa and 80 kPa (Fig. 33).

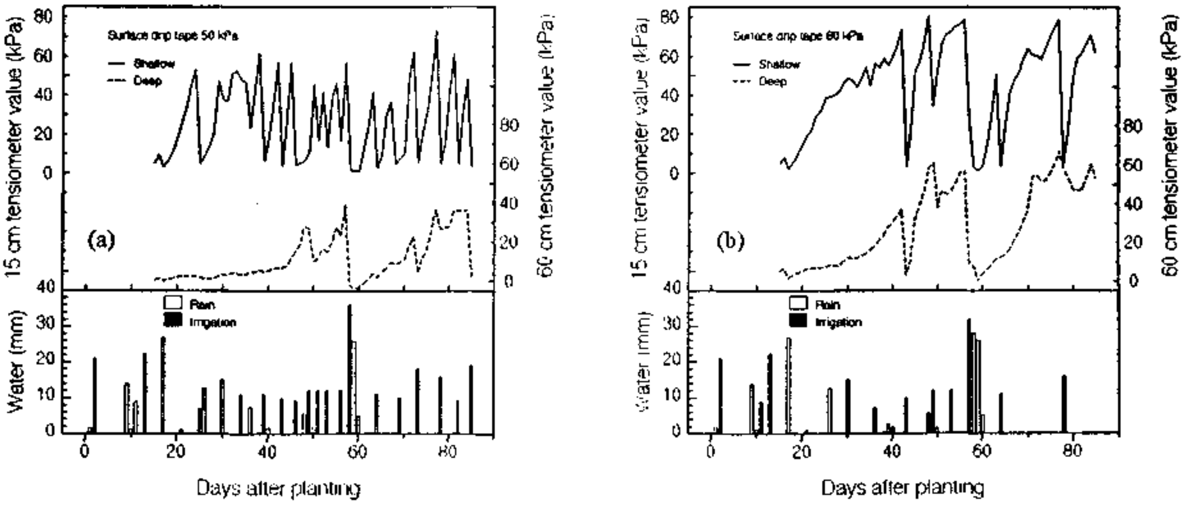


Figure 33. Fluctuations in soil matric suction at 15 and 60 cm below ground level, where sweet corn were irrigated using surface drip tape, when soil matric suction at 15 cm exceeded (a) 50 kPa or (b) 80 kPa during the growing period.

Setting T at 50 kPa minimised deep drainage compared to treatments with lower **T** values (Fig. 34), while maintaining maximum yields (Fig. 35).

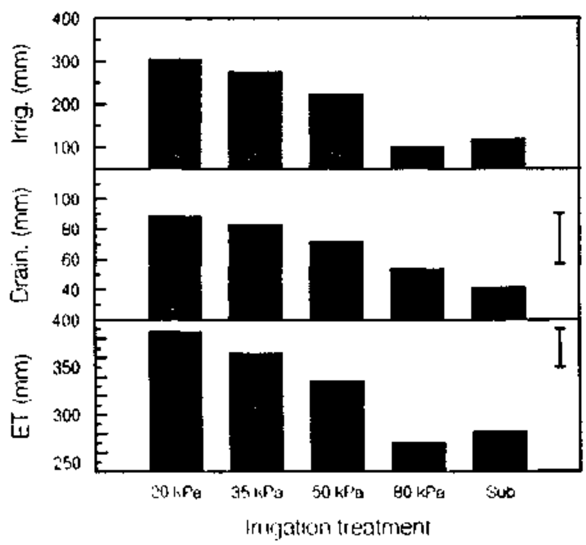


Figure 34. Changes in quantities of irrigation, total evapotranspiration and drainage losses under 5 irrigation regimes in sweet corn. Bars indicate the 5% L.S.D.

There were no significant differences in yield between treatments watered at **T** values between 20 and 50 kPa (inclusive). The 80 kPa and sub-surface treatments yielded significantly less than the other 3 treatments ($P < 0.01$). Yield reductions were due to fewer cobs, although there was a trend for slightly smaller cobs in the 80 kPa treatment (Fig. 35). There appeared to be a curvi-linear relationship between ET and cob yield (Y) in 1992/93 (Fig. 35). Yield increased with total ET to a maximum of 17 t/ha at a total ET of about 340 mm. Increasing ET beyond this value did not improve sweet corn yield

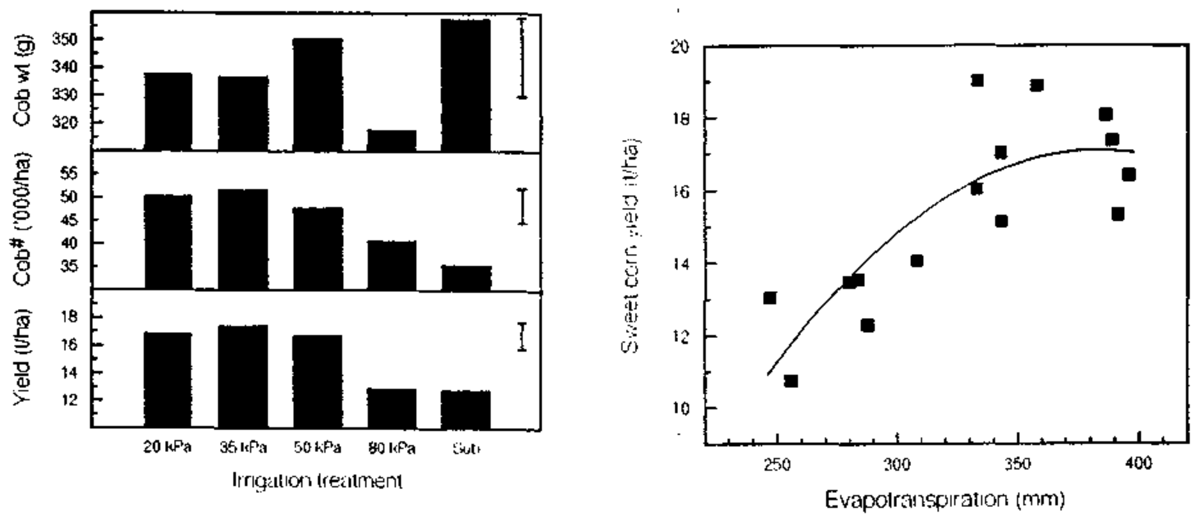


Figure 35. **Sweet corn yield was reduced at Critical Tensiometer Values > 50 kPa, with yield significantly increased at higher ET totals.**

In the latter sweet corn experiment, once we commenced managing irrigation with our scheduling systems (utilising watering regimes suggested by our previous research), virtually no drainage could be attributed directly to over-irrigation, except for a couple of occasions in the 20 kPa treatment. The bulk of deep drainage was due to rainfall in excess of the storage capacity of the soil profile. Because of the wetter soil surface, these rainfall excesses are more likely to occur in more frequently irrigated treatments. It is likely that deficit irrigation during the vegetative phase may encourage activity of deeper roots, as well as provide a more effective reserve for capturing rainfall and reducing deep drainage.

Initial indications are that a Critical Tensiometer Value for maximum production of summer sweet corn is probably 50-60 kPa pre-silking, dropping to 50 kPa during the pollination and cob development phases. On black earth soil types under trickle, this involves irrigation about every 4 days, applying 10 mm per irrigation for the first 7 weeks after planting, increasing to 15 mm per irrigation until harvest. Under overhead irrigation, the frequency would be reduced and the total depths increased. The target evapotranspiration for sweet corn would probably be around 340-370 mm, with a total irrigation requirement of about 3.5-4 ML/ha, allowing for inefficiencies and drainage losses. Obviously any rainfall during the intervening period would reduce these requirements, although there may still be a need to irrigate for other

purposes, such as fertiliser or pesticide incorporation. The regime would also be affected by cultivar and agronomic practices.

Potatoes.

Prior to conducting the 2 intensive experiments at Gatton R.S., we monitored 4 growers' crops. Sites 1 and 2 were irrigated least frequently (every 8 days on average), with their shallow tensiometers (15 cm deep) recording the highest peak readings (circa 80 kPa). These sites had the lowest ET rates (3.0 mm/day) during the main growth period, 4-10 weeks after emergence. The potato crop at Site 1 used very little water from 9 weeks after emergence until harvest, 3 weeks later. On average, Site 3 was watered every 6 days. Its shallow tensiometer peak readings were generally lower than the first 2 sites, although they occasionally reached 70 kPa. Average ET rates at Site 3 were around 3.4 mm/day during the peak growth period, although they declined substantially in the final 4 weeks prior to harvest. The potatoes at Site 4 were the most frequently irrigated (every 5 days), leading to ET rates of 5 mm/day during the peak growth period - around 50% higher than the other sites. Relatively high ET rates continued until 10 days prior to harvesting. The shallow tensiometers at this site peaked at 40 kPa from 3 weeks after emergence until harvesting. Drainage from excess irrigation was about 10% at all sites; slightly more at Site 2. Harvested yields at Site 1 were about 18 t/ha and at Sites 2 and 3 around 23 t/ha. Maximum production was at Site 4, which yielded 38-40 t/ha.

The growth stages of a potato crop can be divided into 4 phases; (i) establishment and early vegetative growth = 0-45 days after planting (DAP); (ii) tuber initiation = 41-65 DAP; (iii) yield formation = 56-110 DAP; (iv) ripening = 103-120 DAP. In the first potato experiment in autumn 1993, during the tuber initiation phase in the 45 kPa treatment, values for tensiometers at 20 cm rose rapidly to 60 kPa within 3-4 days of irrigation (Fig. 36). This indicated very high rates of water use during this period. Note also that water uptake is greater at 20 cm than at 15 cm, indicating more root activity deeper in the hill. Irrigation frequency was increased during the yield formation phase, to try and maintain the shallow tensiometer values within the appropriate treatment levels. During tuber initiation and yield formation, this treatment received an average 24 mm of irrigation every 4.8 days, with higher frequencies at the start of the yield formation period. The deep tensiometers indicated drainage occurred following an accidental over-irrigation at 42 DAP and rainfall at 80 DAP (Fig. 36).

Interestingly, the shallow tensiometers in the 80 kPa treatment (Fig. 36) fluctuated less than the corresponding tensiometers in the more frequently irrigated treatments. It is possible that early water stress at the time of tuber initiation killed most of the feeder roots responsible for water uptake in the hill. During tuber initiation and yield formation this treatment was irrigated with 24 mm every 10.4 days, with no irrigation during the 23 days prior to harvesting. Deep tensiometer values suggest there was no deep drainage in this treatment.

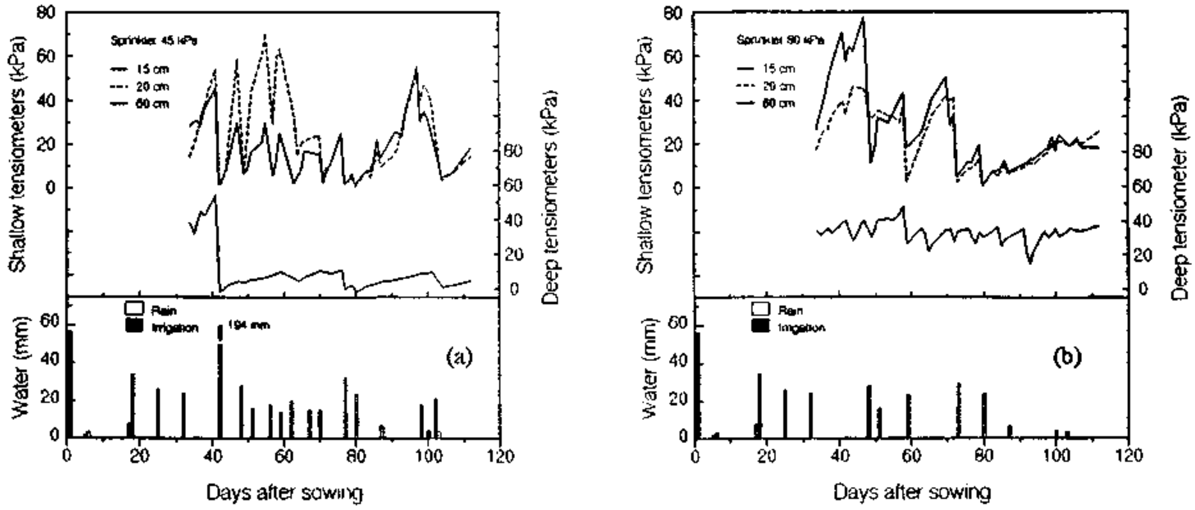


Figure 36. **Fluctuations in soil matric suction at 15, 20 and 60 cm below the top of the hill, where autumn potatoes were irrigated when soil matric suction at 20 cm exceeded (a) 45 kPa; or (b) 80 kPa during the growing period.**

The 3 most frequently irrigated treatments all produced a similar total number of tubers across the grade ranges (Fig. 37). There was a trend for the 45 kPa treatment to have slightly fewer smalls and slightly more #1 grade and over-size than the other 2 treatments. The 80 kPa and 10 day irrigation treatments produced fewer tubers than the other 3 treatments across the whole range of sizes. They had a much higher proportion of small potatoes compared to the more frequently irrigated potatoes. There were very strong relationships between the numbers of tubers harvested ('000/ha), both #1 grade and total, and total evapotranspiration of the potato crop.

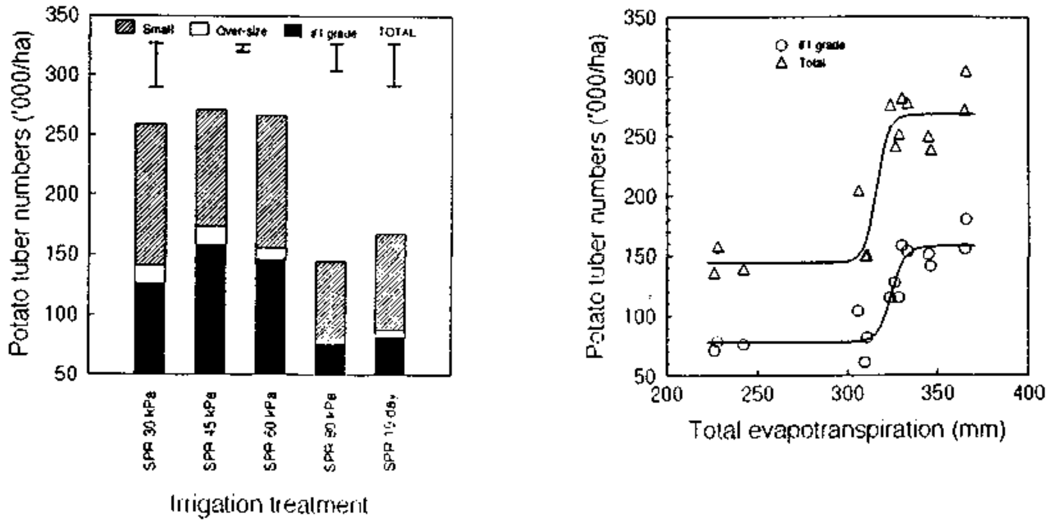
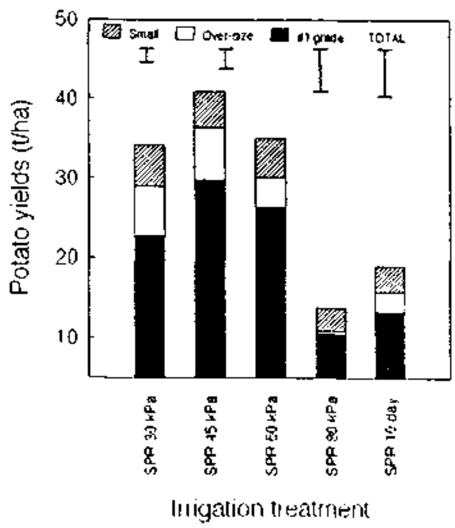


Figure 37. **The numbers of potato tubers in an autumn grown crop were significantly affected by altering Critical Tensiometer Value, or the total evapotranspiration of autumn grown potatoes.**

Potato yields (Fig. 38) reflected differences in tuber numbers. Because the 45 kPa treatment had converted significantly more small tubers into #1 grade, it had the highest yields of the frequently irrigated treatments. Yields of the 30 kPa and 60 kPa treatments were 3-5 t/ha lower, due to slightly smaller potatoes in each of the size classes. The lower yields of the 2 least frequently irrigated treatments were due to fewer and smaller tubers. As expected, there were good relationships between yields of #1 grade potatoes, all potatoes and ET.



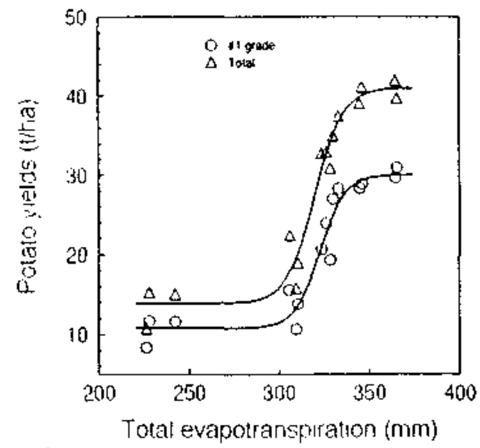


Figure 38. **The yields of potato tubers in an autumn grown crop were significantly affected by altering Critical Tensiometer Value, or the total evapotranspiration of autumn grown potatoes.**

Periods of water stress in the hill that lasted for more than 3-4 days seemed to adversely affect root performance in that zone; i.e. once dry for that length of time, future water uptake by potato plants from that surface zone seemed inhibited. Water uptake by potato roots appeared to substantially decline once tensiometer values increased above 60 kPa.

Water stress during the tuber initiation and early yield formation phases was the critical factor that reduced the numbers of tubers produced in the 80 kPa and 10 day irrigation treatments. Improved water relations (shown by higher ET rates) late in the growing period did not markedly increase the yields of the 10 day irrigation treatment. In the more frequently irrigated potatoes, it seemed that the slightly higher yields of the 45 kPa treatment compared to the 30 kPa and 60 kPa treatments was due to improved water status late in the growing period, just prior to maturity. It would have been interesting to look at the effects of this additional late irrigation on the specific gravity of potatoes produced.

It should be noted there was a moderate to severe outbreak of purple-top wilt in this experiment, that became apparent late in the growing period. Although no objective measurements were made, it seemed that the disease was worse in the 2 driest treatments; perhaps made more visible by an inability to maintain a high vegetative growth rate.

In the winter grown potato experiment, differentiation between irrigation treatments did not occur until well into the tuber bulking up period (refer to the individual experiment report for details). There was no significant effect of irrigation treatment on the total number of potatoes produced (Fig. 39). There was a trend for more over-size potatoes in the 30 kPa treatment compared to the 45 kPa, 60 kPa and 10 day treatments, with virtually no over-size tubers in the 80 kPa plots. In contrast to the autumn potato experiment, in this investigation there were no significant relationships between the numbers of tubers harvested and total evapotranspiration.

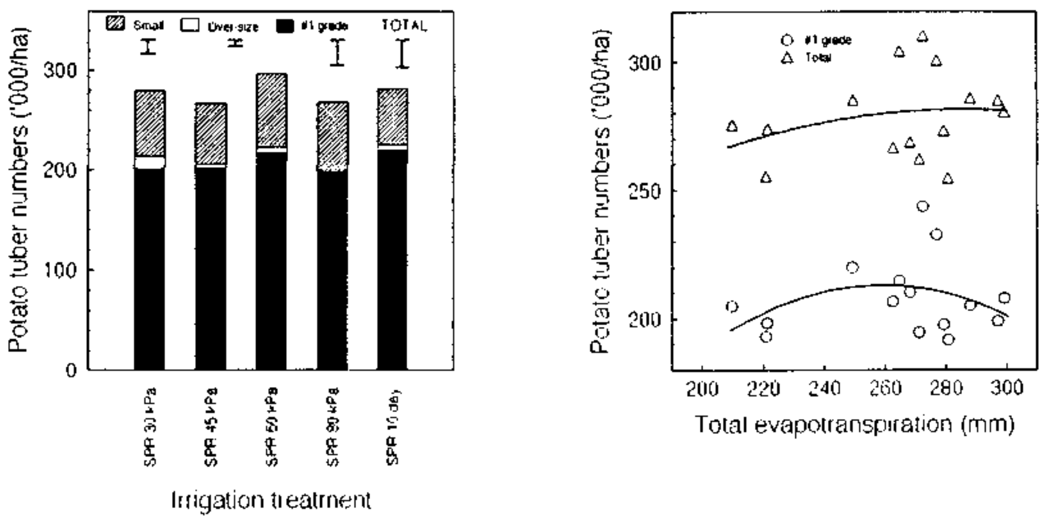


Figure 39. The numbers of potato tubers were unaffected by altering Critical Tensiometer Value, or the total evapotranspiration of winter grown potatoes.

There were no differences in the yield of small potatoes across the experiment, with all treatments producing 3.8-4.9 t/ha (Fig. 40). The 80 kPa treatment produced around 10 t/ha less #1 grade potatoes than the other 4 treatments. This was because the average tuber weight for the 80 kPa plots was 146 g, compared to 172 g for the 45 kPa, 60 kPa and 10 day treatments. Average individual tuber weights for the 30 kPa plots were about 12 g heavier still. The 80 kPa plots had virtually no over-size potatoes. The 60 kPa and 10 day treatments had nearly identical yields of over-size potatoes, with the 30 kPa plots having significantly higher yields of this grade and the 45 kPa plots trending slightly lower. Mean over-size tuber weights for the 30 kPa, 60 kPa and 10 day treatments were 430 g, while the 45 kPa over-size tubers averaged 395 g.

Total yields obviously reflected the sums of the 3 size grades. There was a quadratic relationship between yields of #1 grade potatoes and ET; with a linear relationship between total potato yields and ET.

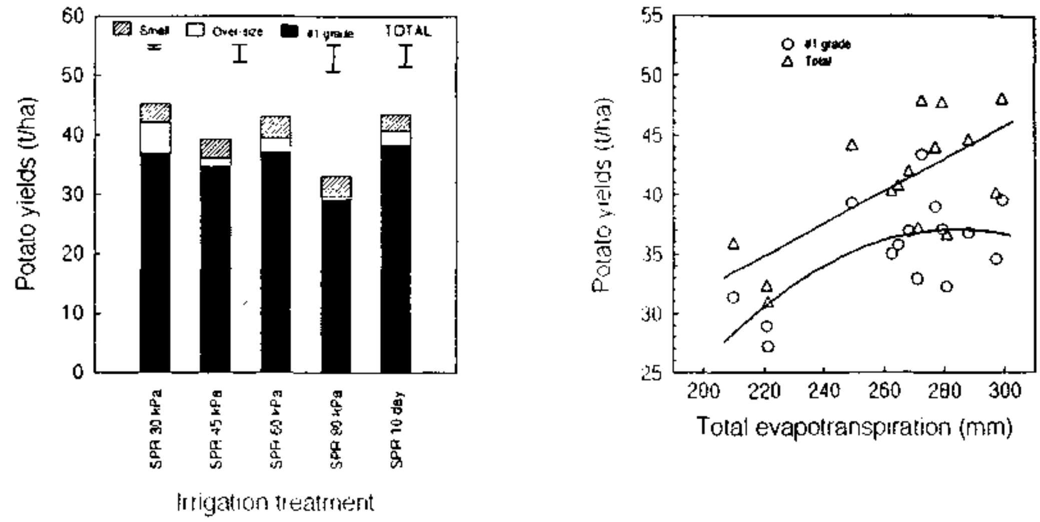


Figure 40. The yields of potato tubers were significantly affected by altering Critical Tensiometer Value, or the total evapotranspiration of winter grown potatoes.

As would be expected, the tubers from the least-irrigated treatment had the highest dry matter contents (Fig. 41). There was less difference between the other 4 treatments, although the 30 kPa treatment had significantly lower tuber dry matters than the 45 kPa or 60 kPa potatoes. There was a significant negative linear relationship between tuber dry matter and total evapotranspiration.

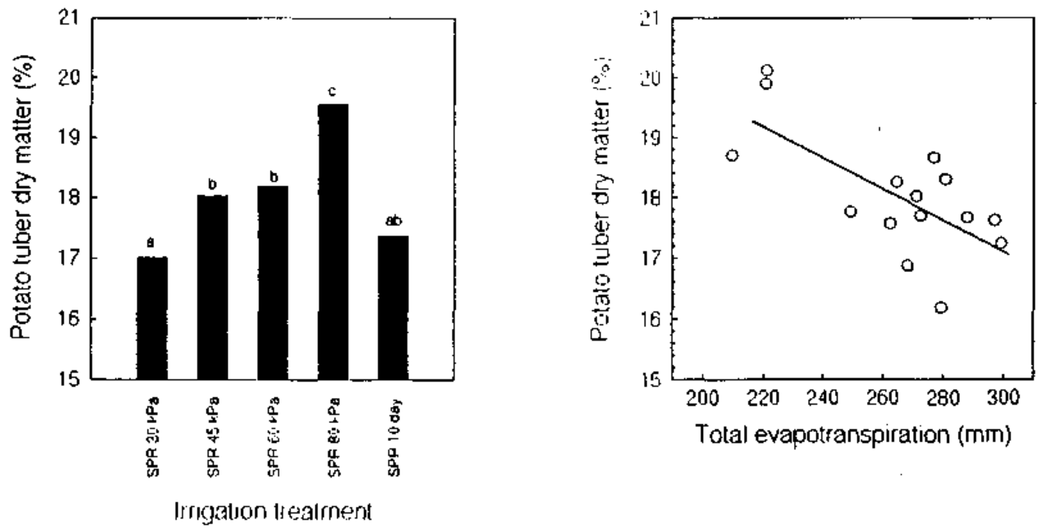


Figure 41. The dry matter content of potato tubers were significantly affected by altering Critical Tensiometer Value, or the total evapotranspiration of winter grown potatoes.

The lower yields of the 80 kPa plots are obviously due to lower ET rates (and hence photosynthate accumulation) during the yield formation period (70-110 DAP). With slightly more frequent irrigation during the latter stages of yield formation, the 30 kPa treatment maintained higher ET rates than the other 3 high yielding treatments. It appears this higher transpiration resulted in greater accumulation of both starch and water in the potato tubers, bringing about a greater weight and lower dry matter content in both the #1 grade and over-size tubers. This is clearly evident in Fig. 11, where the yield of #1 grade potatoes reached a plateau at an ET of 270 mm, while overall tuber yield continued to increase with higher ET values.

Note that due to the weather and water use patterns, the 10 day treatment was nearly an identical irrigation regime to 60 kPa treatment. Thus it is not surprising that the potato performance in these 2 treatments was also very similar.

Results from experiments and observations to date suggest that a Critical Tensiometer Value for maximum production of autumn grown potatoes is probably 40-50 kPa, with the lower value in conditions of high evaporative demand. On black earth soil types, this involves the following approximate irrigation sequences (given that no rainfall occurs). Growers should be looking to apply about 28 mm every 7-8 days (9-10 days in winter) during the establishment and early vegetative phases (i.e. from potato emergence to 5-6 weeks after sowing). During the more stress-sensitive tuber initiation and yield formation phases, irrigation frequency would probably need to be increased to 25 mm every 5 days (7-9 days in winter/early spring), paying particular attention to water use during the early part of this stage. It may be possible to further increase yields by maintaining moist soil conditions later into the season than traditionally thought desirable. This should be balanced against other considerations such as ease of harvest, dirt contamination of the potatoes, tuber quality and disease management. 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.

From these results the target evapotranspiration for winter/spring potatoes is probably 280-300 mm, with a total irrigation requirement of about 3.5 ML/ha, allowing for inefficiencies and drainage losses. Obviously any rainfall during the intervening period would reduce these requirements, although there may still be a need to irrigate for other purposes, such as fertiliser or pesticide incorporation. The regime would also be affected by cultivar and agronomic practices.

Irrigation application systems.

In several of the later experiments in the project (CORN91, BEAN92, LETT92, BROC92, CABB92 and CORN92), we compared overhead sprinkler irrigation with surface and sub-surface drip application systems, both in terms of irrigation efficiency and crop performance. There was virtually no difference in the irrigation applied, total deep drainage or crop evapotranspiration between plots irrigated with overhead sprinklers or surface drip tape. There were also no differences in crop growth or yield between these 2 methods of irrigation.

In this project, we used a drip tape with emitters every 20 cm, and tape place only 0.7 m apart. We also conducted our experiments on a soil with strong lateral movement of water away from the drip lines. As a consequence, virtually the whole width of the soil profile was moistened after irrigation, giving a similar wetting pattern to that obtained with sprinkler irrigation. Because of the small areas to be irrigated, and with the ability to water at night (during still conditions), we also got very high proportions of the sprinkler applied water actually entering the soil profile, rather than evaporating during application or from the crop canopy. Given these conditions, it was not surprising that we got similar water use patterns and crop performance from both the sprinkler and surface drip tape irrigated treatments. In a commercial situation, where sprinkler systems are usually less efficient, and drip emitters are more widely spaced (both laterally and within the row), there may be more significant water savings from using a drip system compared to sprinkler application. Nevertheless, there are liable to be much greater water-savings from implementing an effective irrigation schedule, than from changing from an efficient sprinkler irrigation system to a drip system in vegetables (unless other changes such as mulching with plastic etc. are also employed).

The performance of the particular sub-surface drip tubing we evaluated are discussed in detail in the HRDC report 'Comparisons of irrigation scheduling and drip application technologies for vegetable production (VG134)'. There are also specific comments in the pertinent individual experiment reports included in this current document. In summary, the AGRI-GRO drip tube that we evaluated initially appeared well constructed, durable and leaked relatively uniformly. Over 10 months it became brittle and liable to cracks in the walls. Installation was time and labour intensive; combined with capital outlay this made the product relatively expensive. Retrieval of tube from > 10 cm underground was seldom successful. In many experiments leak rate declined after about 50 days installation; with deleterious effects on crop performance. Where the AGRI-GRO tube was buried >12 cm below ground level, surface soil (containing the bulk of roots for vegetables such as lettuce, broccoli, cabbage) could not be moistened, despite numerous and frequent irrigation. Under high evaporative demand, this reduced yields of both lettuce and cabbage, compared to other irrigation systems. In cooler or wetter weather, the AGRI-GRO system provided yields similar to other application methods. Irrigation requirements under the sub-surface drip tube treatment were >= both overhead sprinklers or surface drip tape. Any reductions in evaporation were offset by increases in deep drainage under the sub-surface tube.

AGRI-GRO sub-surface drip tube is probably not suited to current vegetable production systems; least to short-term, shallow rooted vegetables e.g. lettuce; particularly in sandier soils. It may have most potential in permanent installations; e.g. perennials or amenity horticulture. Permanent installations in vegetables are unlikely to happen within the next 5-10 years. A drip tube of higher quality and durability, with a lower initial purchase price, buried only a few cm below the ground surface, may be more suited to current vegetable production systems.

General conclusions.

When monitoring soil water status for irrigation scheduling in vegetables, it is critical to obtain measurements from the upper 20 cm of the soil profile. In vegetable crops such as lettuce, potatoes, green beans, brassicas and sweet corn, that are irrigated for optimum production, 60-85% of water use is from the upper 20 cm (even with fully developed crop root systems). Prior to complete extension of their root systems, the proportion of water uptake from surface soil zones is even greater.

From a practical standpoint, we found irrigation scheduling using tensiometers to be effective under a various soil and environmental conditions for the range of vegetable types previously mentioned. Newer tensiometer models are easy to install and use, give accurate, reliable readings, require little maintenance and are relatively cheap.

Because of the need to monitor water status in the surface soil zones, we found that the neutron moisture meter required precise calibration to provide useful scheduling information. This was tedious and time consuming and unlikely to be acceptable to most producers. For research purposes, the NMM was very useful in developing our understanding of crop water use patterns and general water balances in our experiments. Newer electronic soil water monitoring systems (e.g. those based on capacitance or heat dissipation cells) are becoming more commercially available; it is possible that the NMM will become displaced technology.

Based on experimental results, we developed a range of irrigation regimes for optimum production in lettuce, broccoli, cabbage, green beans, sweet corn and potatoes. We determined values for tensiometers installed at 15-20 cm below the soil surface that indicate when irrigation is required. These values are only guidelines; to be modified by producers to take into account differences in soil types, climatic conditions, cultivar and agronomic variations. The critical tensiometer values we propose are initial estimates which the irrigation manager can alter on the basis of experience in with their individual conditions.

Our experience suggests that many lettuce and brassica growers probably apply sufficient water for maximum production; the more likely problem is over-watering. In contrast, green bean, sweet corn and potato producers are probably not irrigating frequently enough, but applying too much water at each irrigation.

Irrigation scheduling based on crop water requirements is obviously only one factor (albeit an important one) influencing decisions on when and how much to water. Irrigation also interacts with other production issues such as disease, insect and weed control, plant nutrition, crop access, and produce quality (including post-harvest performance). The aim of irrigation scheduling is to provide an <u>objective</u> measure of crop water needs, as the basis for informed irrigation decisions.

When considering scheduling systems, producers must bear in mind how they apply their water. With flood, furrow, hand-shift sprinklers or large travelling irrigators, it is unlikely they will want (or be able to) water more than once per week. In such circumstances there is probably little point in monitoring soil water content hourly! Similarly, high precision irrigation scheduling is wasted effort, if irrigation across the paddock is uneven. Priorities in irrigation management are: (a) select the most appropriate application methods for the crop to be grown; (b) ensure even coverage across the paddock - no locations vary by more than 15% from the average. Only then should expensive irrigation scheduling technology be considered.

In our project, there was virtually no difference in irrigation efficiency or crop performance between well-designed sprinkler systems and drip-tape systems. In a commercial situation, where sprinkler systems are usually less efficient, and drip emitters are more widely spaced (both laterally and within the row), there may be more significant water savings from using a drip system compared to sprinkler application. Nevertheless, there are liable to be much greater water-savings from implementing an effective irrigation schedule, than from changing from an efficient sprinkler irrigation system to a drip system in vegetables.

Acknowledgments.

I wish to gratefully acknowledge the generous financial support from the Vegetable and Heavy Vegetable Sectional Groups of the Queensland Fruit and Vegetable Growers, and the Horticultural Research and Development Corporation. The Queensland Department of Primary Industries provided my salary and 50% of my experimentalist's salary for the duration of the project. Special thanks to those producers who participated in various parts of the project; Geoff Storey, Craig Wilson, Gary Jamieson, Shane Litzow, Russel Greinke, David Hood, Howard Poole, Chris Sweet, John Baronio and Percy Bichel. I would particularly like to express my appreciation to my co-worker Mick Webber, for his valuable contributions in the field and on the computer, in often arduous and uncomfortable conditions.

References.

Campbell G.S. and Mulla D.J. (1990). Measurement of soil water content and potential. *In* 'Irrigation of Agricultural Crops.' (Eds. B.A. Stewart and D.R. Nielsen.) pp. 127-42. (American Society of Agronomy Inc., Crop Science Society of America Inc., Soil Science Society of America Inc: Madison, Wisconsin USA).

Doorenbos J. and Kassam A.H. (1979). Yield response to water. FAO Irrigation and Drainage Paper 33. (FAO: Rome, Italy).

Henderson C.W.L. (1993). Comparisons of irrigation scheduling and drip application technologies for vegetable production. Final Report HRDC Project VG314.

Howell T.A. (1990). Relationships between crop production and transpiration, evapotranspiration, and irrigation. *In* 'Irrigation of Agricultural Crops.' (Eds. B.A. Stewart and D.R. Nielsen.) pp 391-429. (American Society of Agronomy Inc., Crop Science Society of America Inc., Soil Science Society of America Inc.: Madison, Wisconsin USA).

HRDC (1992). Horticultural Research and Development Corporation Research Report 1991/92.

Hsiao T.C. (1990). Measurement of plant water status. *In* 'Irrigation of Agricultural Crops.' (Eds. B.A. Stewart and D.R. Nielsen.) pp. 224-80. (American Society of Agronomy Inc., Crop Science Society of America Inc., Soil Science Society of America Inc: Madison, Wisconsin USA).

Jolly P. and Chung B. (1991). Crop water stress assessment using an infrared thermometer. Tasmanian Dept of Primary Industries Technical Bulletin.

Stanley C.D. and Maynard D.N. (1990). Irrigation of selected crops - vegetables. *In* 'Irrigation of Agricultural Crops.' (Eds B.A. Stewart and D.R. Nielsen.) pp 921-950. (American Society of Agronomy Inc., Crop Science Society of America Inc., Soil Science Society of America Inc.: Madison, Wisconsin USA).

Taylor S.A. (1972). 'Physical Edaphology - The Physics of Irrigated and Non-Irrigated Soils.' (revised by G.L. Ashcroft). pp 414-450. (W.H. Freeman and Co: San Francisco, California USA).

Wright J.L. and Stark J.C. (1990). Irrigation of selected crops - potato. *In* 'Irrigation of Agricultural Crops.' (Eds B.A. Stewart and D.R. Nielsen.) pp 860-888. (American Society Of Agronomy Inc., Crop Science Society of America Inc., Soil Science Society of America Inc.: Madison, Wisconsin USA).

Appendix 1

Tensiometers in vegetables made easy.

Craig Henderson, DPI, 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 applied 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. Future papers will deal with management in specific crops.

Tensiometers in theory.

Tensiometers measure availability of soil water to plants. Common designs consist of 4 basic parts (Fig 1). In wet soil, the vacuum gauge displays 0-5 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.

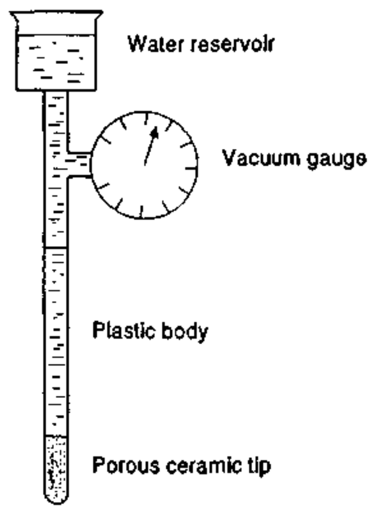


Figure 1. Design of a standard tensiometer.

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 (Fig 2). A crop planting should have at least 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 (20 cm below the top of the hill for potatoes). The deep tensiometer is located 45 cm below ground level for shallow rooted vegetables (e.g. 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.

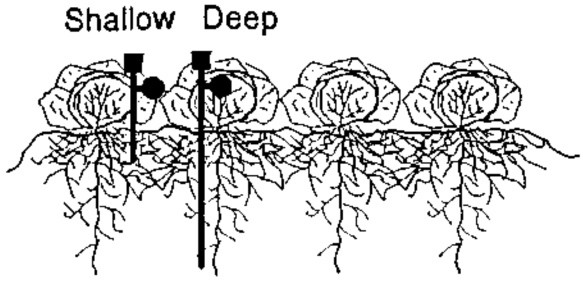


Figure 2. Profile of a typical tensiometer monitoring site in vegetables.

The shallow tensiometer indicates when to water, e.g. for winter lettuce at Gatton R.S. 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 applied 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 using tensiometers. Since 1989, we have installed more than 600 tensiometer 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.

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

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 simply 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 10-15 mm diameter dowel is useful for packing. Don't over-compact the soil into plasticine, but remove any large air gaps. Continue replacing soil until the hole is filled. It doesn't 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 don't 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 algicide-treated water. Within a week of installation, readings should rise and fall with irrigation/rainfall. Check tensiometers early in the morning, at least twice a week (preferably every 1-2 days). Lightly tap the gauge before reading. **Clearly mark tensiometer locations, 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 >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 (i) applying suction to the tensiometer with a vacuum pump, or (ii) remove the gauge, rinse with clean water and suck it. If the needle does not move the gauge has a problem.

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, algicide and a 1 m long 50 mm diameter auger (total cost < $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 detailed information on tensiometers, or irrigation scheduling in general, can contact **Craig Henderson at Gatton Research Station (074) 621122.**

Appendix 2

The practicality of using tensiometers in drip-irrigated lettuce.

by Craig Henderson, DPI, Gatton Research Station.

Summary. **Tensiometers were used to monitor water management in drip-irrigated lettuce, grown in a krasnozem soil at Toowoomba during the summer of 1992-93. Tensiometers installed 15 and 45 cm below the soil surface operated effectively for the duration of the growing period. Location of tensiometers in relation to dripper outlets had dramatic effects on the readings obtained. In this production system, optimum placement for shallow tensiometers appears to be within the lettuce row, midway between dripper outlets, using critical matric suction values of 15-20 kPa to trigger irrigation. Observations in this lettuce crop suggest that current irrigation management is efficient. There may be some scope for reduced quantities of water during the initial 3 weeks after transplanting.**

Introduction.

During the past 3 years we have used tensiometers to manage irrigation in vegetables, including lettuce. Our system has maximised lettuce production and efficiency of irrigation with overhead sprinklers on black earth soils. Some growers have expressed concerns about the practicality of tensiometers in cracking, freely-draining krasnozem soils, particularly when used in conjunction with drip irrigation.

Experimental method.

Tensiometers were operated in a lettuce crop on a krasnozem soil at Storey Farms in Toowoomba, during the summer of 1992-93. Two stations of tensiometers (4 per station) were installed on 22 January, 2 days after the lettuce were transplanted. Lettuce were grown in 4 rows per 1.75 m wide bed, with an intra-row plant spacing of 30 cm. Netafim tubing, with drippers every 40 cm, was laid between alternate lettuce rows, as shown in Fig. 1.

At each station, tensiometers were installed with the sensing tips 15 cm below the ground surface, at distances of 7, 15 and 24 cm from the drip-line. The 4th tensiometer was located 45 cm deep, within the lettuce row (Fig. 1). Tensiometers were generally read daily, with occasional 2 or 3 day intervals between readings.

Overhead sprinklers were used to irrigate the lettuce until 15 days after transplanting (DAT). From then, until harvesting on the 4 March (43 DAT), irrigation was via the drip system. All other agronomic practices were standard for commercial lettuce production.

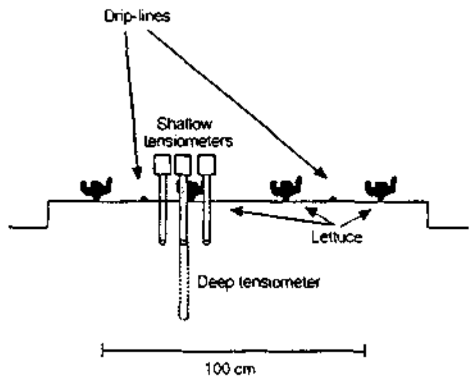


Figure 1. Layout of lettuce, drip-lines and tensiometers in the monitoring experiment.

Observations.

During the entire period of sprinkler irrigation, all the shallow tensiometers registered low matric suctions (high soil water contents), consistently around 6-8 kPa (Fig. 2). Deep tensiometer values were stable at 5-8 kPa. There may have been slight drainage losses via unsaturated flow during this period, however the amounts would not have been substantial.

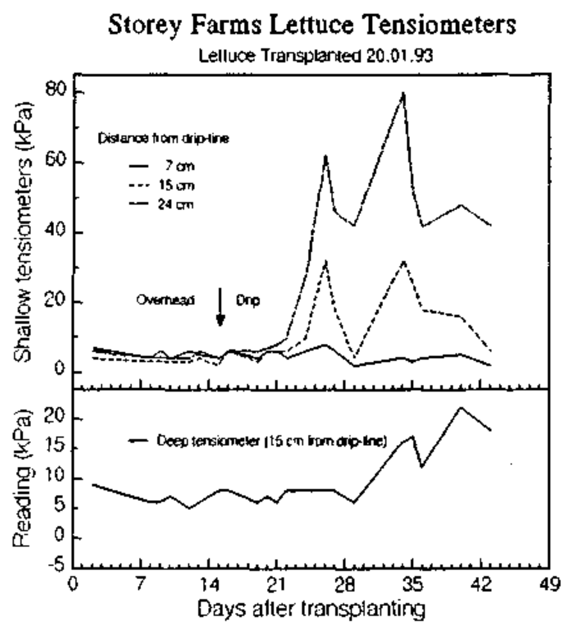


Figure 2. Dynamics of tensiometer readings during the growth of a lettuce crop.

After the switch to drip irrigation, the tensiometers indicated soil water content remained around field capacity across the whole width of the bed for the next 7 days. The shallow tensiometers nearest the drip-line continued to display low values through to harvest (Fig. 2). From 21-35 DAT, the shallow tensiometers within the lettuce row showed the soil drying out to 30 kPa between major irrigations or rainfall. From 35 DAT until harvest, values remained below 20 kPa. In contrast, matric suction values for the shallow tensiometers on the opposite side of the lettuce row to the drip-line rose rapidly from 21 DAT (Fig. 2). Even though matric suction declined after major irrigation or rain, these tensiometers never registered values below 40 kPa for the 3 weeks prior to harvesting.

Although there may have been slight drainage losses around 28 DAT (Fig. 2), from then until harvest the deep tensiometers indicated slowly drying soil conditions, suggesting that over-irrigation was not a problem.

Comments.

All the tensiometers functioned well after installation, giving continuous, reasonable values for the growing period. One of the shallow tensiometers located 24 cm from the drip-line lost vacuum on 2 occasions during the 3 weeks prior to harvest. This was due to dry soil conditions at that location in the bed. This dry soil in the inter-row space without a drip-line (see Fig. 1) was an interesting observation. From about 10 days after the drip-line commences functioning until harvest, it is unlikely that significant root growth or nutrient uptake occurs in this zone, unless substantial rainfall re-wets the whole bed width.

Location of tensiometers with respect to drippers and plants is obviously more critical in drip-irrigated crops compared to overhead systems, particularly with relatively widely spaced drippers, as in this instance. For this production system, the optimum placement for the shallow tensiometer is probably within the lettuce row, as close to midway between drippers as possible. As an initial best-guess at a critical tensiometer value for triggering irrigation (once the crop is established), I would estimate around 15-20 kPa. Tensiometer values will probably not reset to 0-4 kPa after irrigation, but continually fluctuate between 10 and 20 kPa. An alternative strategy may be to locate the shallow tensiometer directly opposite a dripper and use lower critical tensiometer values, e.g. 8-10 kPa.

The tensiometer installed at 45 cm should ideally remain relatively stable at around 10 kPa, although increases to 20-30 kPa are not a problem, provided the shallow tensiometers are still below the critical values.

In this production system, the irrigation management currently employed is already efficient. After many years of producing lettuce in this location, this is not surprising. Possibly the quantities of water applied during the first 3 weeks after transplanting could be slightly reduced (e.g. 10-15%), without impacting on the lettuce crop.

Using tensiometers may help fine-tune some aspects, particularly when minor, intermittent rainfall, or abnormal weather conditions occur. The next advance in irrigation management would probably involve the use of a real-time monitoring system, able to give instantaneous measurement and display of soil water status at short time intervals, e.g. every few minutes. Such systems, using TDR, heat dissipation or capacitance probes are being developed and marketed. Their use in commercial applications is still probably some way off. In my view, aspects such as the correct placement for probes in relation to crop and irrigation source, operating hardware and software still need a deal of work.

Acknowledgment.

I gratefully thank Geoff Storey and his staff for their assistance and forbearance in allowing us to conduct these observations on their farm.

INDIVIDUAL EXPERIMENT REPORTS

BROC90	S8902.01	Broccoli
BENA91	S8902.02	Green beans
LETA91	S8902.03	Lettuce
BROC91	S8902.04	Broccoli
LETW91	S8902.05	Lettuce
BEAN91	S8902.06	Green beans
CORN91	S8902.07	Sweet corn
BEAN92	S8902.08	Green beans
LETT92	S8902.09	Lettuce
BROC92	S8902.10	Broccoli
CABB92	S8902.11	Cabbage
CORN92	S8902.12	Sweet corn
POTA93	P378.13	Potatoes
POTW93	P378.15	Potatoes

Queensland Fruit and Vegetable Growers

DPI QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES SOUTH EAST REGION

HRDC

EXPERIMENT REPORT

1. **Report** **Final** **Date of Report:** 3-3-92

Initiation Date: 4-7-90 **Completion Date:** 12-11-90

Project Number: S8902

Project Title: Irrigation scheduling in vegetables

Experiment Number: S8902.01 **Officer Responsible:** Craig Henderson

Experiment Title: Irrigation scheduling for spring grown broccoli.

2. Experiment Objectives

This experiment investigated the critical tensiometer values for maximum broccoli production, and evaluated crop water use. The efficiency of irrigation was examined by determining the quantities of applied water that drained beyond the root zones during the growing period.

3. Summary of Results

The experiment was conducted at Gatton Research Station, from August-November 1990. Broccoli (cv. *Pacific*) were grown using standard agronomy, with 5 irrigation treatments replicated 3 times in a RCB design. Plots were 4.5 m wide and 10 m long, with a total experimental area of 0.07 ha. The five irrigation treatments involved commencing irrigation at different Critical Tensiometer Values (**T** kPa) for a tensiometer installed 15 cm below ground level in each plot. The **T** values were 20, 40, 60 and 80 kPa, as well as a control treatment that was watered every 4-5 days. Each plot was independently watered using a mini-sprinkler system that gave uniform application across the treatment beds, with no incursion into adjacent plots. Irrigation regime had no significant effect on the number of broccoli heads harvested. There were significant reductions in irrigation frequency, total evapotranspiration, drainage losses and mean head size as **T** increased to 80 kPa. Because of adverse weather conditions, particularly affecting timing of irrigation, the results from this experiment were inconclusive. They do suggest that for spring sown broccoli, optimum yields would probably be achieved with **T** set between 30 and 40 kPa. Under this watering regime, broccoli would be irrigated every 6 days for the first 40 days after transplanting, increasing in frequency to every 4-5 days until harvest. Initial irrigations of 20 mm, increasing to 20-25 mm after about 30 days, would be an approximate schedule. Broccoli may use around 300 mm of water for maximum production, with a further 20 mm lost to through drainage.

EXPERIMENT REPORT

Irrigation scheduling for spring grown broccoli

by C. Henderson and M. Webber
Department of Primary Industries
Gatton Research Station

Experiment No. S8902.01 30.8.90-12.11.90

1. Relevance to Industry

In many regions, including the Lockyer Valley, irrigation demands regularly exceed the reliable capacity of the water supply, resulting in scarcity or reliance on poorer quality water. In many vegetable enterprises irrigation is a significant proportion of overall production costs. Shallow rooted vegetables are substantial users of water; for example brassicas and lettuce require 2-4 ML per hectare per crop. Until recently, the frequency and amount of irrigation was relatively ad hoc, based on tradition and grower experience, combined with superficial observations of plant or soil conditions.

Some vegetable growers use tensiometers or neutron probes to monitor soil water status and schedule irrigations. Both methods have advantages and disadvantages, however tensiometers appear to have the best immediate potential for use in shallow rooted vegetables.

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 overwatering, problems with leaching of nutrients and pesticides into groundwater (and beyond the zone of usefulness) are reduced, as well as a decrease in disease levels.

2. Objectives

This experiment investigated the critical tensiometer values for maximum broccoli production, and evaluated crop water use. The efficiency of irrigation was examined by determining the quantities of applied water that drained beyond the root zones during the growing period.

3. Materials and methods

The experiment was conducted on a black earth soil (*Ug5.15*) at Gatton Research Station (lat 27°33'S, long 152°20'E). The experimental design was a randomised complete block, with 5 irrigation treatments replicated 3 times. Each plot was 3 beds (2 rows of broccoli per 1.5 m bed) wide and 10 m long.

The soil was prepared as per standard practice for broccoli. Broccoli seedlings (cv. *Pacific*) were transplanted on the 30th August 1990, with 0.7 m between the rows and 0.33 m intra-row spacing. A total of 450 kg/ha of compound fertiliser (59 kg N, 10 kg P, 60 kg K, 85 kg S) was applied immediately before planting. Two sidedressings of 60 kg/ha N (as urea) were broadcast on 6th September and 18th October 1990. Molybdenum (0.042 kg/ha as sodium molybdate) and boron (0.031 kg/ha as hydrated sodium octoborate) were sprayed on the 17th September 1990, and again on the 11th October 1991. Fluazifop-butyl herbicide at 0.106 kg of active constituent per hectare was sprayed over the area 4 weeks after transplanting. Insects were controlled with regular applications of insecticides, including chlorpyrifos, prothiofos, methomyl, mevinphos and fenvalerate.

During the first 4 weeks after transplanting the whole area was irrigated with standard solid set pipes and overhead sprinklers. After this first week, a system of mini-sprinklers was installed to individually water each plot. A schematic of the individual plot layout is given in Fig. 1. Each plot consisted of 3 beds of broccoli side by side. The central bed was the treatment area, while the two outside beds were buffer zones. Lines of mini-sprinklers was installed down the 2 outer edges of the treatment beds, with 2 m between each sprinkler within a line. The sprinklers in the 2 lines were offset by 1 m, to give a staggered pattern down the bed (Fig. 1). Each sprinkler was mounted on a 1 m high stake, and had an output radius of about 2 m and volume of 70 L/hr at 130 kPa operating pressure. Using this system, the irrigation was relatively uniform across the treatment bed, with no drift into neighbouring treatment beds. The application rate was around 20 mm/hr over the treatment beds. An electronic timing system was used to commence irrigation at 2 am on the appropriate days, to avoid windy conditions often prevalent during daylight hours.

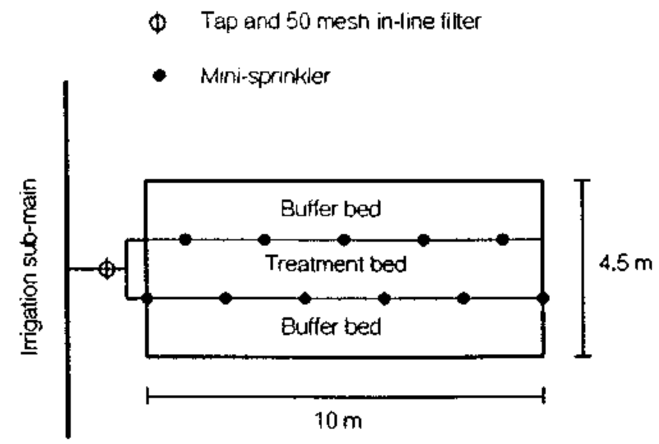


Fig. 1. Mini-sprinkler system design for an individual plot in an experiment investigating irrigation scheduling in spring grown broccoli.

Tensiometers were installed 15 cm and 45 cm below ground level in each treatment bed of Block 2 only. *Loctronic* tensiometers were used, consisting of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum, while an electronic vacuum gauge attached to the syringe records the vacuum in the tensiometer air gap. Tensiometer readings were recorded daily, usually around 8 am. On the basis of the tensiometer readings, 5 separate irrigation treatments were scheduled:

1. Irrigation when the 15 cm tensiometer had 20 kPa soil water suction.
2. Irrigation when the 15 cm tensiometer had 40 kPa soil water suction.
3. Irrigation when the 15 cm tensiometer had 60 kPa soil water suction.
4. Irrigation when the 15 cm tensiometer had 80 kPa soil water suction.
5. Irrigation at regular intervals to maintain the soil in a wet condition (control).

The 3 replicates of each treatment were always watered on the same day.

Aluminium neutron probe access tubes were installed to a depth of 120 cm in each treatment bed, 5 cm inside a broccoli row and equidistant between 2 neighbouring plants. Neutron moisture meter readings were taken twice a week using a Campbell Pacific Nuclear Hydroprobe. A single reading was taken at 10 depth intervals, commencing 5 cm below the ground surface, incrementing by 10 cm. On each day that the neutron probe measurements were made, 5 standard counts was also conducted in a 200 L drum of water. Calibrations for the neutron probe were assumed to be tha same as for other experiments conducted on the site.

Weather data, including rainfall, Class A Pan evaporation, maximum and minimum temperatures were recorded daily. The equivalent depths of water applied at each irrigation were measured using rain gauges in each of the experimental plots. The water meter at the irrigation pump was calibrated with the rain gauges, so that when the broccoli plants overgrew the rain gauges, the depths of water applied to each plot could still be determined.

The height and widths of the broccoli plants were measured on the 9th and 23 October. Four plants were randomly selected and assessed in each plot. Broccoli were harvested from the treatment beds as the heads became mature. Harvesting took place on the 1st, 8th and 12th November 1991. On each occasion the number of heads were counted, and the total weight of heads for the plot determined.

4. Results

Rainfall during the growing period was 76.7 mm, however much of the total water requirement of the crop was met by irrigation and stored soil water at transplanting.

The data indicated there was virtually no uptake of soil water by the broccoli below 50 cm; only the upper 50 cm of the soil profile was used in determining water use and drainage. The calibration equations for the neutron probe took the following form;

$$V = a + b * FC \qquad \text{Equation (1)}$$

where V = volumetric water content ($cm^3 cm^{-3}$)
FC = fractional neutron count (reading in soil divided by standard count in water)
a and b are equation parameters

The parameter values and r^2 for the calibration equations for each of the blocks and depth intervals are given in Table 1.

Table 1

Parameters and goodness of fit for calibration equations relating volumetric soil water content to neutron probe readings.

Depth interval cm	Block 1			Block 2			Block 3		
	a	b	r^2	a	b	r^2	a	b	r^2
0-10	0.062	1.199	0.94	0.024	1.147	0.91	0.078	0.964	0.93
10-20	0.087	0.520	0.82	0.076	0.504	0.90	0.086	0.503	0.88
20-30	-0.125	0.829	0.73	-0.196	0.925	0.92	-0.122	0.831	0.96
30-40	-0.060	0.677	0.64	-0.062	0.705	0.73	-0.057	0.726	0.67
40-50	-0.032	0.600	0.46	-0.191	0.878	0.78	0.057	0.516	0.44

All r^2 values were highly significant ($P<0.01$), except for those less than 0.50, which were significant ($P<0.05$).

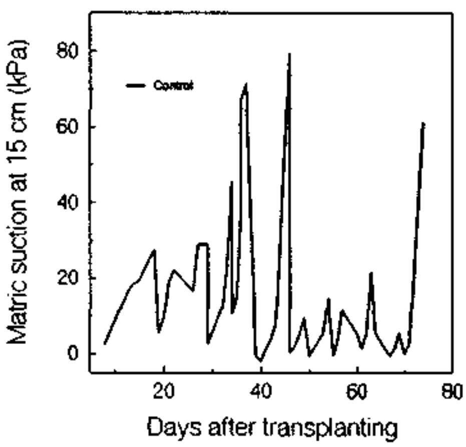
Using a simple spreadsheet, a daily water balance was calculated for each plot. Rainfall, irrigation, stored soil water, pan evaporation, evapotranspiration and drainage of soil water below 50 cm were determined from transplanting through to harvest. Details of the calculations are available from the authors.

The tensiometer data for the 5 irrigation treatments (Fig.s 2-6) do not follow the expected patterns, i.e. rising to a Critical Tensiometer Value (T kPa) between irrigation cycles, and falling when water was applied. Due to windy weather during the middle of the growing period, we did not water on several days when the tensiometers indicated irrigation was required. As a result, tensiometers in some plots rose well above the specified **T** values, particularly in the wetter treatments.

Deep and shallow tensiometers in all treatments followed similar patterns for the first 4 weeks after transplanting, when broccoli was watered with standard solid-set pipes. Surface tensiometers fluctuated between 0 and 30 kPa, while deeper units were consistent at 10-15 kPa matric suction (Figs. 2-6). For treatments where irrigations were triggered at 20 kPa (Fig. 3), or were conducted on a regular basis (Fig. 2), the matric suctions in both the surface and deeper soil layers rose to 70 or 80 kPa on at least 2 occasions between 4 and 7 weeks after transplanting (during the dry, windy period). For the remainder of the growing period, surface tensiometer values in both treatments were around 20 kPa, although the soil dried slightly during the final week of harvesting. Tensiometers at 45 cm were used for scheduling, tending to cycle between 0 and 30 kPa.

In plots where T was set at 40 kPa (Fig. 4), the shallow tensiometer fluctuated from 0-30 kPa for the first 7 weeks after transplanting, then cycled between 0 and 80 kPa for the rest of the growing period. The tensiometer at 45 cm rose to peaks of 20-35 kPa between irrigations from about 40 days after transplanting.

Both drier treatments, where T was 60 or 80 kPa, fluctuated between 0 and 60-70 kPa matric suction in the surface soil from about 4 weeks after transplanting until the final harvest. The deeper tensiometers cycled in a similar manner, commencing about 6 weeks after transplanting. The 80 kPa treatment (Fig. 6) tended to show a slower increase in matric suction after watering than the treatment irrigated at 60 kPa (Fig. 5).



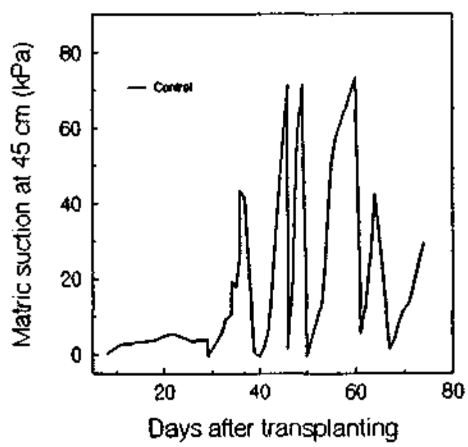


Fig. 2. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where broccoli was regularly irrigated (control).

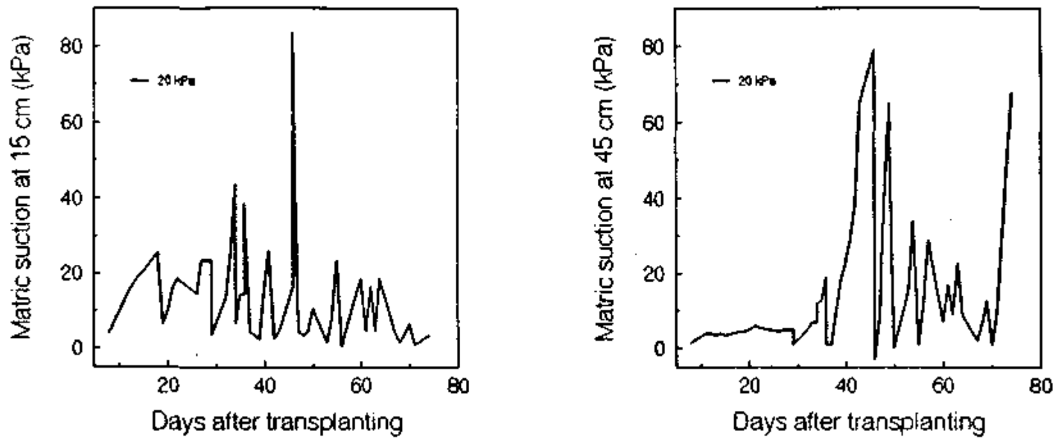


Fig. 3. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where broccoli was irrigated when soil matric suction at 15 cm exceeded 20 kPa.

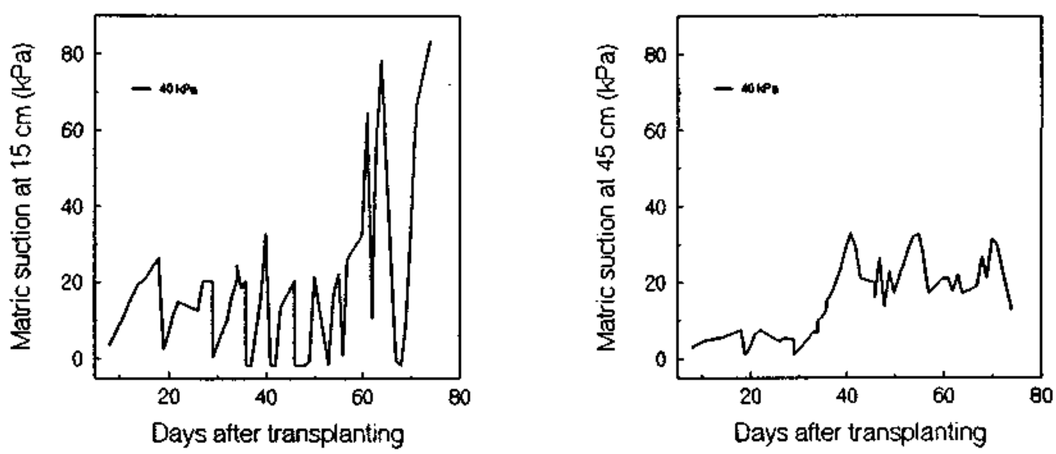


Fig. 4. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where broccoli was irrigated when soil matric suction at 15 cm exceeded 40 kPa.

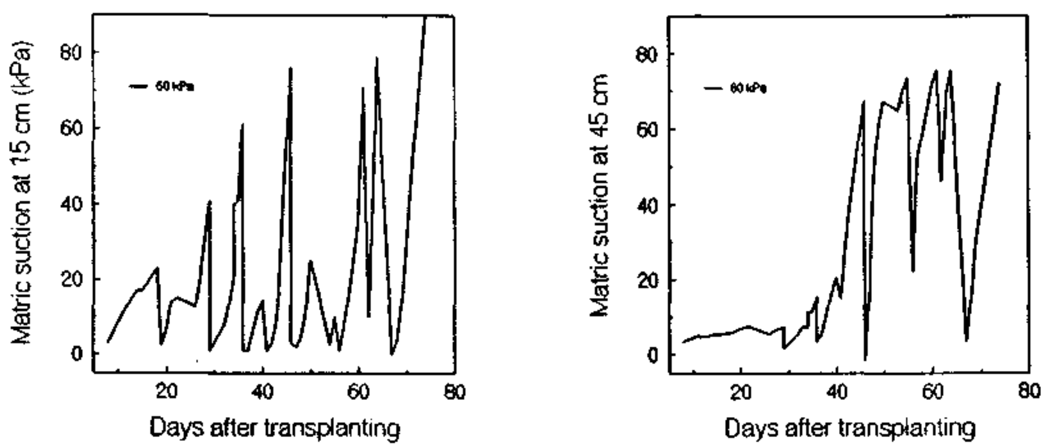


Fig. 5. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where broccoli was irrigated when soil matric suction at 15 cm exceeded 60 kPa.

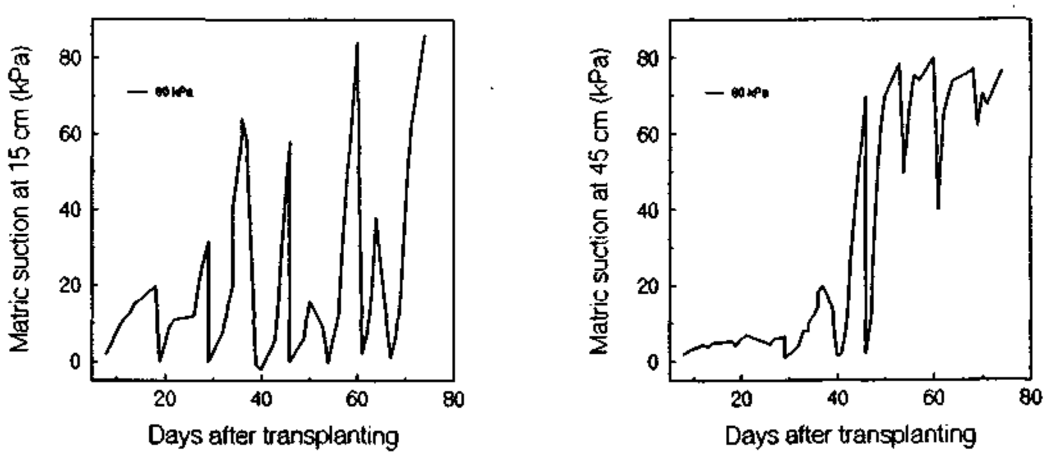


Fig. 6. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where broccoli was irrigated when soil matric suction at 15 cm exceeded 80 kPa.

There were fewer irrigations as T was increased (Table 2). The wettest (control) treatment received 18 irrigations during the growing period, while the driest (80 kPa) was irrigated only 10 times. There were only small differences in quantities of water applied at each irrigation for the first 55 days after transplanting (Table 3). During the first 30 days after transplanting, irrigations of 30 mm every 6 days resulted in drainage losses of about 15%. The control treatment was the most frequently irrigated over the next 25 days, and the 40 and 80 kPa treatments the least frequently watered (Table 2). All plots received about 23 mm per irrigation during this period, with most drainage (approximately 20%) in the control treatments and least in the broccoli watered at 40-80 kPa. Irrigation frequencies varied substantially in the final 19 days of the broccoli growing period (Table 2), although the amounts applied at each irrigation (circa 17 mm) were fairly consistent for 4 of the treatments (Table 3). The treatment with T set at 80 kPa only received 1 irrigation of 29 mm during the final 19 days. Drainage losses during this period were around 17% for the 20, 40 and 60 kPa treatments and about 35% for the wettest plots. There was no drainage below 50 cm for the 80 kPa treatment.

Table 2

Mean intervals (days) between irrigations for 5 watering regimes in spring grown broccoli.

Irrigation treatment	Growth period (days after transplanting)			Total number of irrigations
	0-30	31-55	56-74	
Control	6.0 a	4.2 a	2.7 a	18 d
20 kPa	6.0 a	5.0 b	3.2 b	16 c
40 kPa	6.0 a	6.2 c	4.8 c	13 b
60 kPa	6.0 a	5.0 b	6.3 d	13 b
80 kPa	6.0 a	6.2 c	19.0 e	10 a

Table 3

Mean irrigation quantities and drainage losses for 5 watering regimes in spring grown broccoli.

Irrigation treatment	Growth period (Days after transplanting)					
	0-30		31-55		56-74	
	Irrig. (mm)	Drain. (mm)	Irrig. (mm)	Drain. (mm)	Irrig. (mm)	Drain. (mm)
Control	30.4 a	3.6 a	23.3 b	4.5 c	16.9 b	6.0 a
20 kPa	30.4 a	3.9 a	23.4 c	3.4 bc	14.7 a	4.2 a
40 kPa	30.4 a	5.8 a	24.5 d	1.9 ab	17.2 c	2.1 a
60 kPa	30.4 a	4.4 a	21.6 a	0.8 a	18.7 d	3.0 a
80 kPa	30.4 a	3.6 a	25.8 e	0.3 a	29.0 e	0.0 a

A summary of the total growing period water balance for each of the irrigation treatments (Fig. 7) shows curvilinear relationships between the Critical Tensiometer Value (T kPa), Irrigation (I mm), Total Evapotranspiration (ET mm) and Total Drainage (D mm), where;

$\mathbf{I} = 444 - 3.89\ \mathbf{T} + 0.0246\ \mathbf{T}^2$ $\qquad r^2 = 0.88^{***}$ $\qquad$ Equation (2)

$\mathbf{ET} = 384 - 2.21\ \mathbf{T} + 0.0195\ \mathbf{T}^2$ $\qquad r^2 = 0.37^{ns}$ $\qquad$ Equation (3)

$\mathbf{D} = 75 - 0.700\ \mathbf{T} - 0.00000747\ \mathbf{T}^2$ $\qquad r^2 = 0.52^{*}$ $\qquad$ Equation (4)

Most of the extra water applied to the control and 20 kPa treatments was lost through increased drainage (Fig. 7), with only a slight, non-significant trend for greater evapotranspiration in these well-watered areas. Note that differences in the cumulative evapotranspiration between the irrigation treatments did not become noticeable until about 40 days after transplanting, when full canopy cover had occurred (Fig. 8). This suggests that any differences in total evapotranspiration were mainly due to increased transpiration by broccoli on the well watered plots, rather than differences in soil evaporation.

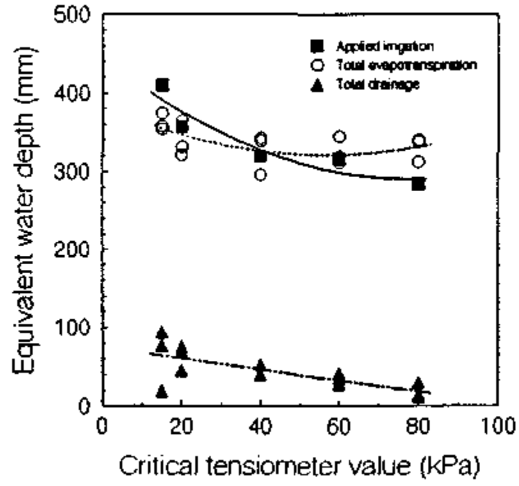


Fig. 7. Reductions in quantities of irrigation, total evapotranspiration and drainage losses as the Critical Tensiometer Value was increased.

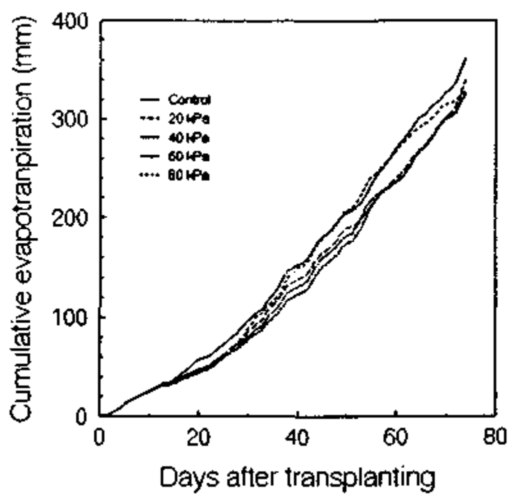


Fig. 8. Reductions in cumulative evapotranspiration as the Critical Tensiometer Value was increased.

The control treatments had the tallest broccoli plants at both times of assessment, while the plots watered at a **T** value of 40 kPa were the shortest. Other treatments were intermediate in stature between these 2 extremes. There was less difference in plant width, although a consistent trend for the 40 kPa treatments to have plants with the smallest diameters was apparent (Fig. 9).

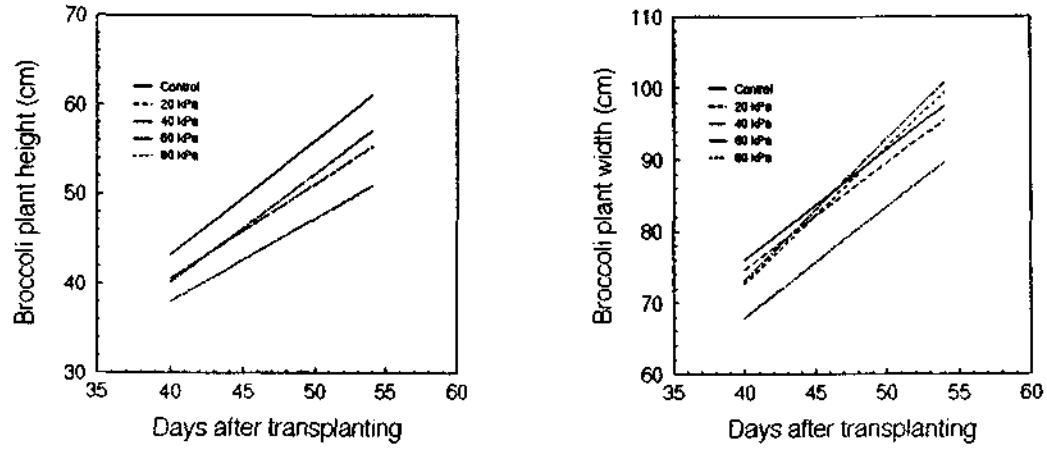


Fig. 9. Changing the Critical Tensiometer Value affected the height and diameter of spring grown broccoli plants.

The number of broccoli heads harvested (**B** '000/ha), although relatively variable across the experiment, was related to neither **T** nor **ET**, averaging around 33 000/ha (Fig. 10). Although there were no significant relationships between overall broccoli yields (**Y** t/ha) and **T** or **ET** (Fig. 11), there was a trend for highest yields at the highest **ET** values. This was associated with increases in head size (**W** g) as **ET** rose (Fig. 12). In general, head quality was relatively poor, due to hot weather during the budding and head formation stages of the broccoli. Irrigation treatment had no significant effect on the timing of the broccoli harvest, as shown by the proportion of the yields obtained in the first 2 of 3 cuttings (Fig. 13).

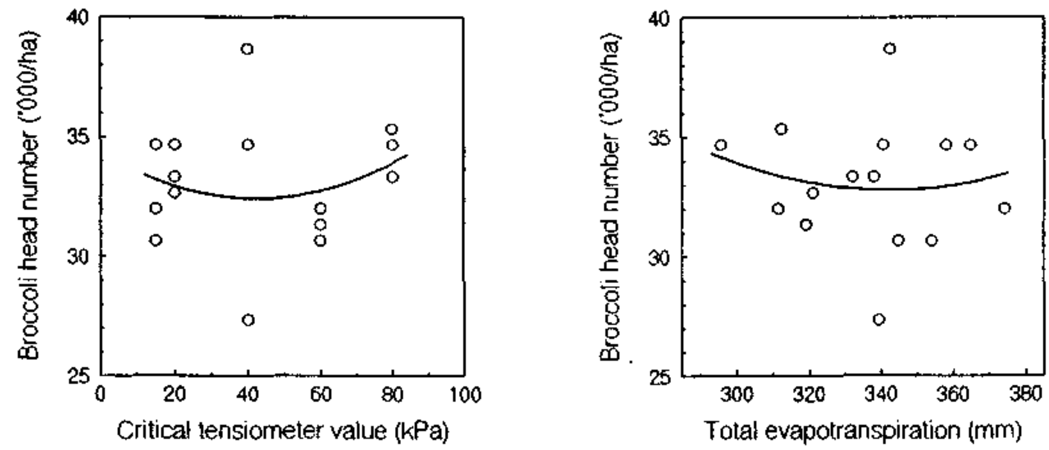


Fig. 10. The number of marketable broccoli heads was unaffected by changes in the Critical Tensiometer Value or total evapotranspiration of spring grown broccoli.

$\mathbf{B} = 34.3 - 0.0894\ \mathbf{T} + 0.00105\ \mathbf{T}^2 \qquad r^2 = 0.04^{ns}$ Equation (5)

$\mathbf{B} = 106.7 - 0.0432\ \mathbf{ET} + 0.000631\ \mathbf{ET}^2 \quad r^2 = 0.02^{ns}$ Equation (6)

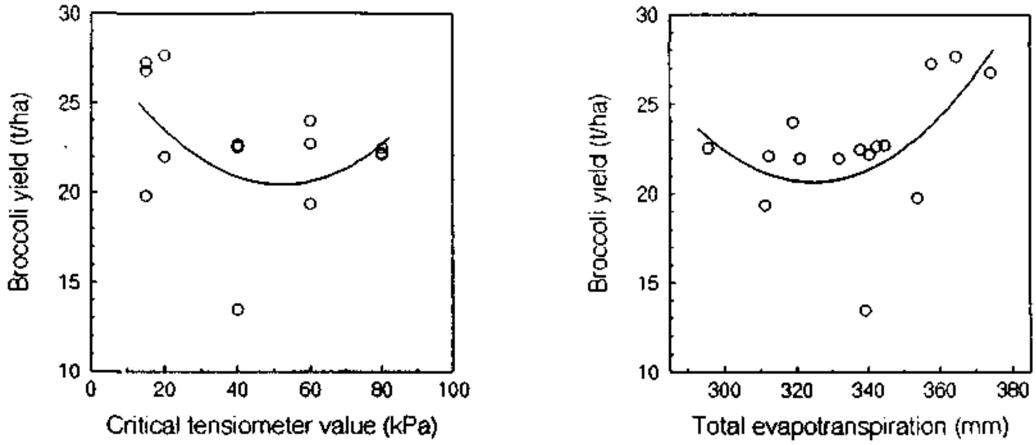


Fig. 11. The total yield of marketable broccoli heads was not significantly affected by changing the Critical Tensiometer Value nor the total evapotranspiration of spring grown broccoli.

$\mathbf{Y = 28.5 - 0.306\ T + 0.00293\ T^2}$ $r^2 = 0.20^{ns}$ Equation (7)

$\mathbf{Y = 328 - 1.89\ ET + 0.00291\ ET^2}$ $r^2 = 0.34^{ns}$ Equation (8)

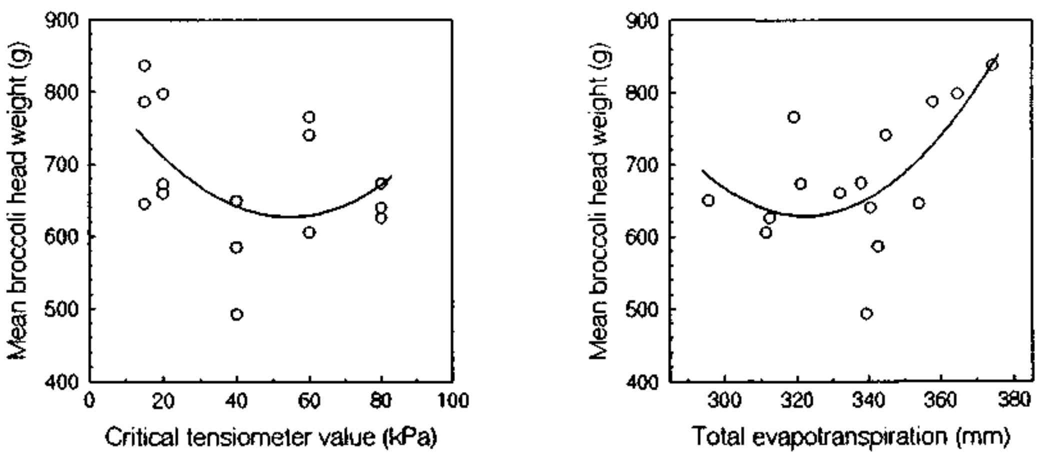


Fig. 12. The mean weight of marketable broccoli heads was not significantly affected by changing the Critical Tensiometer Value, but was related to the total evapotranspiration of spring grown broccoli.

$\mathbf{W = 836 - 7.618\ T + 0.0696\ ET^2}$ $r^2 = 0.21^{ns}$ Equation (9)

$\mathbf{W = 8705 - 50.1\ ET + 0.0777\ ET^2}$ $r^2 = 0.42^{*}$ Equation (10)

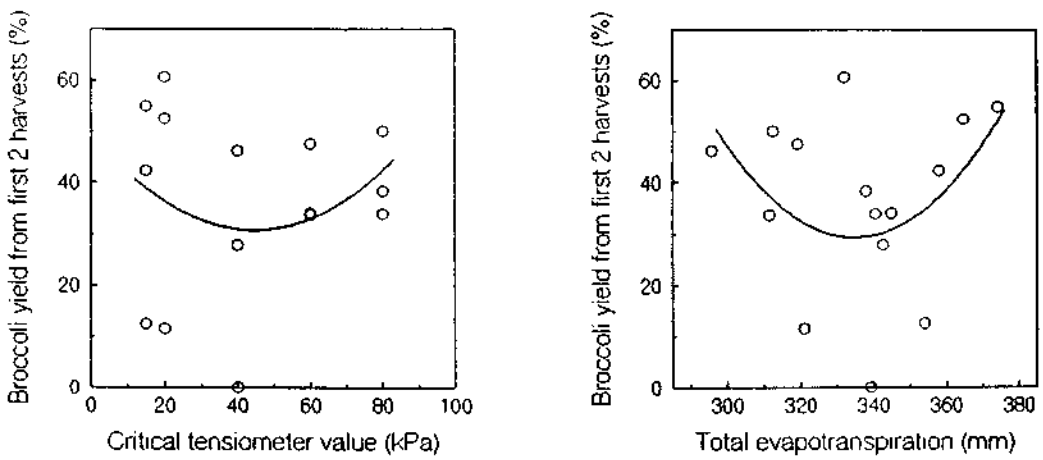


Fig. 13. Neither Critical Tensiometer Value nor total evapotranspiration affect the percentage of marketable broccoli heads harvested in the first cut of a 3 cut harvesting period in winter grown broccoli.

5. Discussion and conclusions

The tensiometer system used in this experiment proved useful for scheduling irrigation. It was easy to install and use, gave accurate, reliable readings, required little maintenance and was relatively cheap. The neutron probe needed intensive calibration to give accurate readings in the surface soil, where most evaporation and plant water use occurred. The neutron probe provided useful information for deriving daily water balances, however the intense nature of our monitoring would be neither appropriate nor possible for most farmers or consultants.

One problem with the tensiometer system was determining the correct quantities (as opposed to frequencies) of irrigation to apply to avoid excessive losses through drainage beyond the root zone. Unlike the neutron probe, tensiometers do not give immediate estimates of soil water deficits within the root zone, so the amount of irrigation applied relies to some extent on previous experience with the particular soil type/crop combination. In most instances we would be hoping to lose about 10% of the applied irrigation as drainage, rather than the 20% that occurred in the 20 kPa irrigation treatment.

Due to problems with application timing, the irrigation regimes actually imposed differed from those indicated by the tensiometer system. The period of hot weather around 4-6 weeks after transplanting appeared to damage the surface root system of the broccoli. Water uptake from this surface zone appeared to be affected, with a greater proportion of water extracted from the deeper soil layers.

The results from this experiment were not particularly conclusive, however we suggest that the following irrigation regime would be most appropriate for broccoli growing under conditions of gradually increasing evaporative demand toward harvest. Using a Critical Tensiometer Value (for the shallow tensiometer) of around 30-40 kPa, irrigation would be applied every 6 days for the first 40 days after transplanting, increasing in frequency to every 4-5 days until harvest, watering more frequently under hot, dry conditions. On the black earth soil types, it is probable that around 20 mm would be applied at each irrigation for the first 30 days, increasing to 20-25 mm per irrigation until harvest. Obviously any rainfall during the intervening period would reduce these requirements. Given this sequence, a total of 14 irrigations (around 320 mm) would be needed to obtain optimum broccoli yields and quality while minimising irrigation costs and drainage losses. The target evapotranspiration for the growing season appeared to be around 300 mm, although this would obviously depend on cultivar and growing conditions (both weather and agronomic). This Critical Tensiometer Value of around 35 kPa is somewhat lower than overseas values for broccoli (45-60 kPa), emphasising the need for local research.

We intend to conduct further experiments investigating irrigation scheduling techniques and application methods for brassica production.

EXPERIMENT REPORT

1. **Report** **Final** **Date of Report:** 7-2-92

Initiation Date: 25-1-91 **Completion Date:** 13-5-91

Project Number: S8902

Project Title: Irrigation scheduling in vegetables

Experiment Number: S8902.02 **Officer Responsible:** Craig Henderson

Experiment Title: Irrigation scheduling for autumn grown green beans.

2. Experiment Objectives

This experiment investigated the critical tensiometer values for maximum green bean production and evaluated crop water use. The efficiency of irrigation was examined by determining the quantities of applied water that drained beyond the root zones during the growing period.

3. Summary of Results

The experiment was conducted at Gatton Research Station, from March-May 1991. Green beans (cv. *Labrador*) were grown using standard agronomy, with 5 irrigation treatments replicated 3 times in a RCB design. Plots were 5.1 m wide and 10 m long, with a total experimental area of 0.08 ha. The five irrigation treatments involved irrigating twice or once a week, or commencing irrigation at 3 different Critical Tensiometer Values (**T** kPa), using tensiometers installed 15 cm below ground level in each plot. The **T** values were 20, 50, and 80 kPa. Each plot was independently watered using a mini-sprinkler system that gave uniform application across the treatment beds, with no incursion into adjacent plots. The total amounts of irrigation and drainage losses were greatest in the treatments watered on a weekly basis, or at a **T** value of 50 kPa. There were significant trends for total evapotranspiration and bean plant growth to decline as **T** increased. While there were no significant differences in bean yields, there was a slight trend for the plots watered at **T** of 80 kPa to produce slightly lower yields. From the results, we believe that optimum yields will be achieved where **T** is set between 40-50 kPa for the autumn grown green beans. Under this watering regime, the crop would initially be irrigated every 5 days for the first 7 weeks after planting, reducing in frequency to every 6-7 days until harvest, with 17-23 mm applied at each irrigation. The beans would use around 210 mm of water for maximum production, with a further 40 mm drainage.

EXPERIMENT REPORT

Irrigation scheduling for autumn grown green beans

by C. Henderson and M. Webber
Department of Primary Industries
Gatton Research Station

Experiment No. S8902.02 7.3.91-13.5.91

1. Relevance to Industry

In many regions, including the Lockyer Valley, irrigation demands regularly exceed the reliable capacity of the water supply, resulting in scarcity or reliance on poorer quality water. In many vegetable enterprises irrigation is a significant proportion of overall production costs. Green beans generally require around 3 ML of irrigation per crop. Until recently, the frequency and amount of irrigation was relatively ad hoc, based on tradition and grower experience, combined with superficial observations of plant or soil conditions.

Some vegetable growers use tensiometers or neutron probes to monitor soil water status and schedule irrigations. Both methods have advantages and disadvantages, however tensiometers appear to have the best immediate potential for use in shallow rooted vegetables. Beans have deeper root systems than many other vegetables, however most water uptake still occurs in the upper 0.5 m of the soil profile.

Matching irrigation to crop requirements maximises production by minimising plant water stress, nutrient deficiencies and some diseases, as well as preventing build up of salinity problems. By preventing overwatering, problems with leaching of nutrients and pesticides into groundwater (and beyond the zone of usefulness) are reduced, as well as a decrease in disease levels.

2. Objectives

This experiment investigated the critical tensiometer values for maximum green bean production, and evaluated crop water use. The efficiency of irrigation was examined by determining the quantities of applied water that drained beyond the root zones during the growing period.

3. Materials and methods

The experiment was conducted on a black earth soil (*Ug5.15*) at Gatton Research Station (lat 27°33'S, long 152°20'E). The experimental design was a randomised complete block, with 5 irrigation treatments replicated 3 times. Each plot was 3 beds (2 rows of green beans per 1.7 m bed) wide and 10 m long.

The soil was prepared as per standard practice for green beans. Beans (cv. *Labrador*) were sown on the 7th March 1991, with 0.85 m between the rows and 0.048 m intra-row spacing. A total of 60 kg/ha of N as urea was broadcast 1 day after planting, with a sidedressing of the same quantity on 19th April 1991. Initial weed control was achieved by spraying pendimethalin at 1 kg/ha of active constituent over the experimental area immediately after sowing. The herbicide was incorporated with irrigation the following day. Insects were controlled with regular applications of insecticides, including dimethoate, methomyl and endosulfan.

For the first week after planting the whole area was irrigated with standard solid-set pipes and overhead sprinklers. After this first week, systems of mini-sprinklers were installed to individually water each plot. A schematic of the individual plot layout is given in Figure 1. Each plot consisted of 3 beds of green beans side by side. The central bed was the treatment area, while the two outside beds were buffer zones. Lines of mini-sprinklers was installed down the 2 outer edges of the treatment beds, with 2 m between each sprinkler within a line. The sprinklers in the 2 lines were offset by 1 m, to give a staggered pattern down the bed (Figure 1). Each sprinkler was mounted on a 1 m high stake, and had an output radius of about 2 m and volume of 70 L/hr at 130 kPa operating pressure. Using this system, the irrigation was relatively uniform across the treatment bed, with no drift into neighbouring treatment beds. The application rate was around 20 mm/hr over the treatment beds. An electronic timing system was used to commence irrigation at 2 am on the appropriate days, to avoid windy conditions often prevalent during daylight hours.

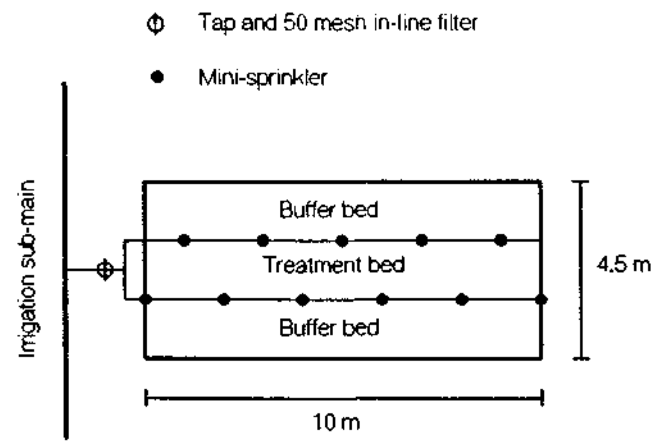


Figure 1. Mini-sprinkler system design for an individual plot in an experiment investigating irrigation scheduling in autumn grown green beans.

Tensiometers were installed 15 cm and 45 cm below ground level in each treatment bed. *Loctronic* tensiometers were used, consisting of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum, while an electronic vacuum gauge attached to the syringe records the vacuum in the tensiometer air gap. Tensiometer readings were recorded daily, usually around 8 am. On the basis of the tensiometer readings, 5 separate irrigation treatments were scheduled:

1. Irrigated twice a week, independent of tensiometer readings.
2. Irrigation when the 15 cm tensiometer had 20 kPa soil water suction.
3. Irrigated once a week, independent of tensiometer readings.
4. Irrigation when the 15 cm tensiometer had 50 kPa soil water suction.
5. Irrigation when the 15 cm tensiometer had 80 kPa soil water suction.

Each plot was irrigated according to its allocated treatment. Plots with the same irrigation treatment were occasionally watered on different days, due to differences in the time for the tensiometers to reach values necessary to trigger irrigation.

Aluminium neutron probe access tubes were installed to depths of 70 cm in each treatment bed, 5 cm inside a bean row and equidistant between 2 neighbouring plants. Neutron moisture meter readings were taken twice a week using a Campbell Pacific Nuclear Hydroprobe. A single reading was taken at 5 depth intervals, commencing 5 cm below the ground surface, incrementing by 10 cm. On each day that the neutron probe measurements were made, 5 standard counts was also conducted in a 200 L drum of water. Calibration equations for the neutron probe data were assumed to be the same as for other experiments at this site.

Weather data, including rainfall, Class A Pan evaporation, maximum and minimum temperatures were recorded daily. The equivalent depths of water applied at each irrigation were measured using rain gauges in each of the experimental plots. The water meter at the irrigation pump was calibrated with the rain gauges, as a further check on the amounts of water applied, particularly when the bushes overgrew the rain gauges.

The heights of the bean plants were measured 20, 32 and 54 days after sowing. Five plants were randomly selected and assessed in each plot. Green beans were machine harvested from a single row in the treatment beds on the 13th May 1991, 67 days after sowing. The fresh weights of beans harvested from each plot were recorded. A rating of the severity of lodging was also determined for each plot, with 0 for no lodging, to a maximum of 5 for plants lying on the ground and the beans unharvestable.

4. Results

Rainfall during the growing period totalled 14.2 mm, mainly comprised of 2 falls of 5 and 6 mm. Most of the crop water requirement was met by irrigation and stored soil water at planting.

The calibration equations for the neutron probe took the following form;

$$V = a + b * FC \qquad \text{Equation (1)}$$

where **V** = volumetric water content (cm^3cm^{-3})
FC = fractional neutron count (reading in soil divided by standard count in water)
a and b are equation parameters

The parameter values and r^2 for the calibration equations for each of the blocks and depth intervals are given in Table 1.

Table 1

Parameters and goodness of fit for calibration equations relating volumetric soil water content to neutron probe readings.

Depth interval cm	Block 1			Block 2			Block 3		
	a	b	r^2	a	b	r^2	a	b	r^2
0-10	0.062	1.199	0.94	0.024	1.147	0.91	0.078	0.964	0.93
10-20	0.087	0.520	0.82	0.076	0.504	0.90	0.086	0.503	0.88
20-30	-0.125	0.829	0.73	-0.196	0.925	0.92	-0.122	0.831	0.96
30-40	-0.060	0.677	0.64	-0.062	0.705	0.73	-0.057	0.726	0.67
40-50	-0.032	0.600	0.46	-0.191	0.878	0.78	0.057	0.516	0.44

All r^2 values were highly significant ($P<0.01$), except for those less than 0.50, which were significant ($P<0.05$).

Using a simple spreadsheet, a daily water balance was calculated for each plot. Rainfall, irrigation, stored soil water, pan evaporation, evapotranspiration and drainage of soil water below 50 cm were determined from planting through to harvest. Details of the calculations are available from the authors.

The tensiometer data for the 5 irrigation treatments (Figures 2-6) follow the expected patterns, rising to the Critical Tensiometer Value (**T** kPa) between irrigation cycles and falling when water was applied. For the purposes of analysing the results, arbitrary **T** values were assigned to the bi-weekly and weekly irrigation treatments (15 and 30 kPa respectively), although these 2 irrigation treatments were not scheduled using these **T** values. In many instances tensiometers reached values higher than those set to trigger irrigation. This was because the value would be slightly less than **T** one day, and by the next day would have risen to more than **T**, the extent depending on weather conditions. Nevertheless, the tensiometers installed at 15 cm tended to range between 5 and 10 kPa above **T**.

Where the green beans were irrigated twice a week, the shallow tensiometer fluctuated between 0-10 kPa soil matric suction for the first 5 weeks of the growing period (Figure 2). For the next 3 weeks the irrigation frequency and quantity was insufficient to maintain a moist soil surface, with the shallow tensiometer peaking at 60 kPa, although the cycle reverted back to 0-15 kPa for the last 3 weeks of the growing period. During the drier period the deeper tensiometers also indicated increasing matric suction at depth, peaking at 30-40 kPa, prior to a steady decline immediately prior to harvesting.

The treatments irrigated with a T value of 20 kPa caused the tensiometers installed at 15 cm to cycle between 0-20 kPa for the first 40 days after planting (Figure 3). As the bean plants began to more rapidly extract soil water, the shallow tensiometers rose to 30 kPa between irrigation, increasing by 10 kPa in less than a day. Due to problems with installation, only one of the 45 cm tensiometers functioned. This tensiometer fluctuated between 0-10 kPa, although it rose to 20 kPa during the period of maximum water uptake. During the growing period, there were 3 notable instances where matric suction of the deep tensiometer fell to around 0 kPa, indicating saturated soil conditions. It was on these occasions that drainage of water beyond the root zone most probably occurred.

During the period 3-7 weeks after planting, the shallow tensiometer on the plots watered on a "weekly" basis (actually around every 5 days for much of the experiment) reached peaks of 60-80 kPa. From 7 weeks until harvest, these peaks in soil matric suction were substantially lower, around 30-40 kPa (Figure 4). The deeper tensiometers showed little evidence of water uptake from 40-50 cm below the soil surface until around 5 weeks after planting. From then until the beans were harvested, there was consistent drying of this part of the soil profile, apart from several apparent drainage events due to excess irrigation.

The shallow tensiometers on the plots irrigated on a **T** value of 50 kPa peaked between 50 and 60 kPa for much of the growing period, although 2 out of the 3 plots had slightly lower maximums from 6 weeks until harvest (Figure 5). While one of the deeper tensiometers was not working, the others showed substantial uptake from the deeper sections of the soil profile, commencing around 5 weeks after sowing. There were also several substantial drainage events during the growing period.

The driest treatment (Figure 6) tended to have high matric suction values in the surface of the soil for most of the growing period, returning to values around 80 kPa very soon after irrigation. The 2 functioning deeper tensiometers in these plots had steadily increasing readings from about 4 weeks after sowing. Although there were reductions in matric suction in these deeper layers after some irrigations, at no stage after 4 weeks did the tensiometers indicate saturated soil conditions.

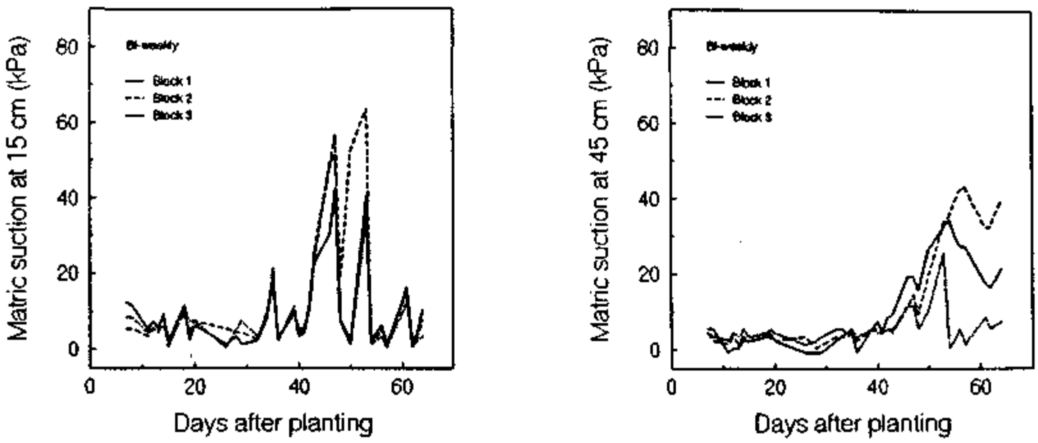


Figure 2. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where green beans were irrigated twice a week.

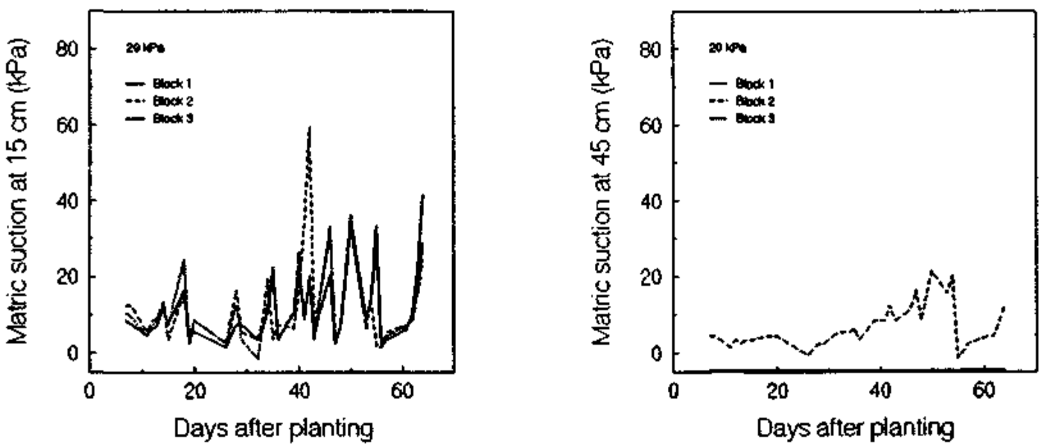


Figure 3. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where green beans were irrigated when soil matric suction at 15 cm exceeded 20 kPa.

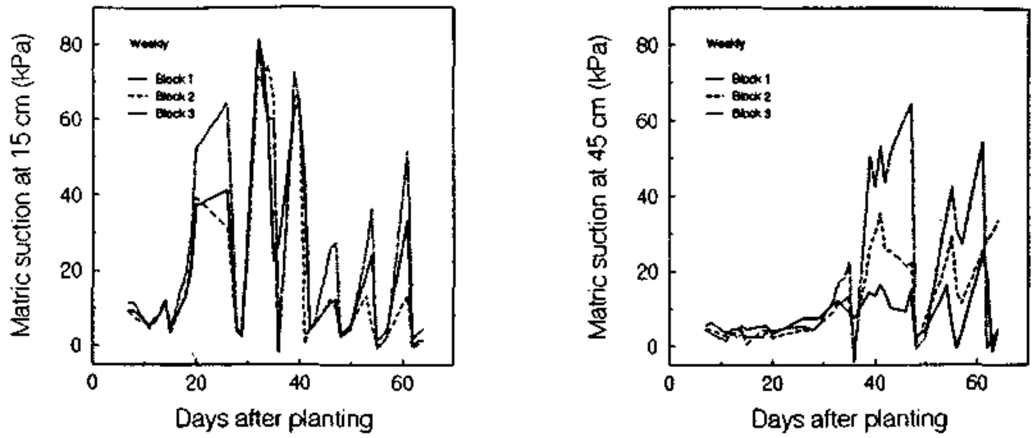


Figure 4. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where green beans were irrigated once a week.

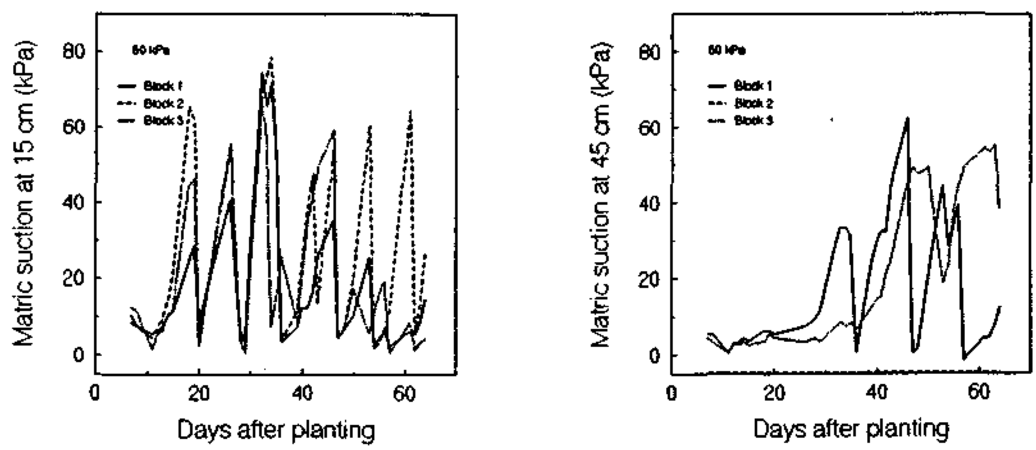


Figure 5. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where green beans were irrigated when soil matric suction at 15 cm exceeded 50 kPa.

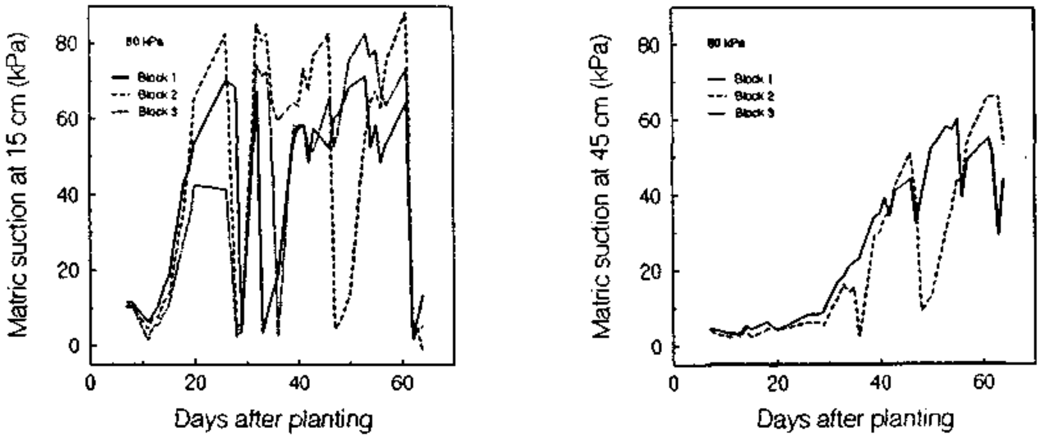


Figure 6. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where green beans were irrigated when soil matric suction at 15 cm exceeded 80 kPa.

There were significantly ($P<0.001$) fewer irrigations as **T** was increased (Table 2). The wettest treatment, where irrigation proceeded twice a week (independent of tensiometer readings) received 19 irrigations during the growing period, while the driest plots were irrigated 10 times. As would be expected, the intervals between irrigations tended increase as the plants developed more extensive root systems, and the weather got cooler. Due to management complications, the average interval for the "weekly" irrigation treatment was less than 7 days for much of the growing period, with the treatment where **T** was set at 80 kPa much closer to a weekly irrigation schedule. The less frequently irrigated tended to receive larger quantities of water at each irrigation (Table 3), particularly in the earlier part of the period.

During the first 4 weeks after sowing, irrigation matched water use relatively closely, resulting in little drainage beyond the potential root zone of the bean plants. About 17 mm were applied to the frequently irrigated treatments during this period, increasing to 25 mm per application in the driest treatment. During the next 3 weeks however, there was slight overwatering of the treatments watered twice weekly or at **T** of 20 kPa, resulting in about 20% drainage loss. This occurred even though only 15 mm were applied at each irrigation. Where 30-33 mm was applied to the weekly and **T** 50 kPa treatments, 30-50% was lost through increased amounts of drainage during this 20 day period. During the final 2 weeks prior to harvesting, only the plots watered on a weekly basis continued to be overwatered (29 mm), compared to the 20 mm irrigation for the other treatments.

Table 2

Mean intervals (days) between irrigations for 5 watering regimes in autumn grown green beans.

Irrigation treatment	Growth period (days after planting)			Total number of irrigations
	0-30	31-50	41-67	
Bi-weekly	3.0 a	3.3 a	5.7 a	19.0 d
20 kPa	3.8 b	3.3 a	5.7 a	17.0 c
Weekly	4.8 c	5.0 a	8.5 ab	12.3 b
50 kPa	5.1 cd	4.1 a	7.6 ab	13.3 b
80 kPa	5.7 d	7.2 b	10.4 b	10.3 a

Table 3

Mean irrigation quantities and drainage losses for 5 watering regimes in autumn grown green beans.

Irrigation treatment	Growth period (Days after planting)					
	0-30		31-50		51-67	
	Irrig. (mm)	Drain. (mm)	Irrig. (mm)	Drain. (mm)	Irrig. (mm)	Drain. (mm)
Bi-weekly	16.6 a	0.8 a	15.9 a	4.2 a	21.7 a	1.9 a
20 kPa	18.5 b	1.5 a	14.9 a	3.2 a	20.8 a	1.7 a
Weekly	23.9 cd	2.3 a	33.2 b	11.9 b	29.5 b	7.4 b
50 kPa	23.4 c	1.8 a	31.3 b	17.0 b	20.4 a	0.7 a
80 kPa	25.3 d	3.5 a	20.3 a	1.8 a	22.2 a	0.0 a

A summary of the total growing period water balance for each of the irrigation treatments (Figure 7) shows curvilinear relationships between the Critical Tensiometer Value (**T** kPa), Irrigation (**I** mm), Total Evapotranspiration (**ET** mm) and Total Drainage (**D** mm), where;

$\mathbf{I} = 206 + 5.77\ \mathbf{T} - 0.0718\ \mathbf{T}^2$ $\quad r^2 = 0.83^{***}$ $\quad$ Equation (2)

$\mathbf{ET} = 233 - 1.24\ \mathbf{T} + 0.00815\ \mathbf{T}^2$ $\quad r^2 = 0.48^{*}$ $\quad$ Equation (3)

$\mathbf{D} = -46.0 + 5.76\ \mathbf{T} - 0.0605\ \mathbf{T}^2$ $\quad r^2 = 0.64^{**}$ $\quad$ Equation (4)

Due to the increased quantities of water applied when irrigating the weekly and **T** 50 kPa treatments during the middle part of the growing period, the overall depths of irrigation were substantially greater on these plots compared to the other treatments. Most of this additional water was lost through drainage beyond the root zone. Notwithstanding, there was still a significant trend for total evapotranspiration to decline as **T** was increased, although the overall difference between the beans irrigated 19 times as opposed to 10 times was only 30 mm (Figure 7).

Differences in cumulative evapotranspiration became apparent as early as 3 weeks after sowing. The treatment where **T** was set at 80 kPa had lower ET rates from 2-4 weeks after planting, however it did not fall further behind the other treatments until the last

3 weeks of the growing period. It was also during this latter stage that the beans watered at a T value of 50 kPa had lower ET rates than the more frequently watered plots (Figure 8). It is likely that soil evaporation contribution to total evapotranspiration was slightly higher in the more frequently irrigated treatments, where the soil surface was wet for longer periods.

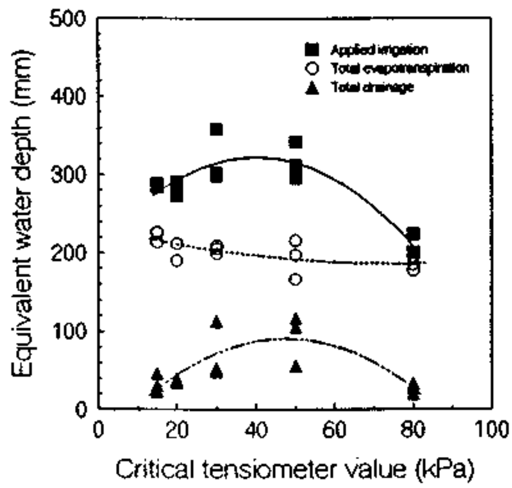


Figure 7. Changes in quantities of irrigation, total evapotranspiration and drainage losses as the Critical Tensiometer Value increased.

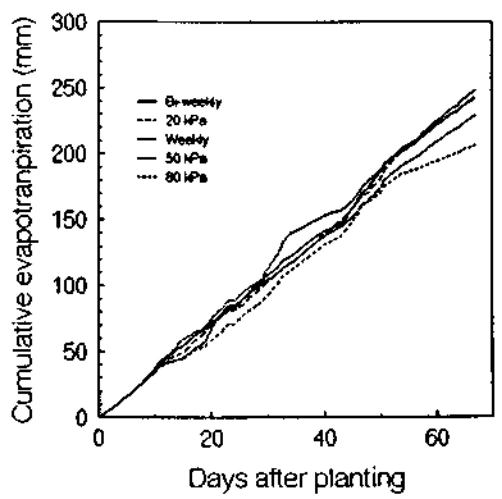


Figure 8. Reductions in cumulative evapotranspiration as the Critical Tensiometer Value increased.

By 32 days after sowing, the bean plants on the plots watered twice a week, or a T value of 20 kPa, were significantly taller than plants under the other 3 irrigation regimes

(Figure 9). When the plant heights were measured 8 weeks after sowing, the plants watered once a week had grown as tall as the 2 former treatments, while there was still a decline in height as **T** increased to 50 and 80 kPa

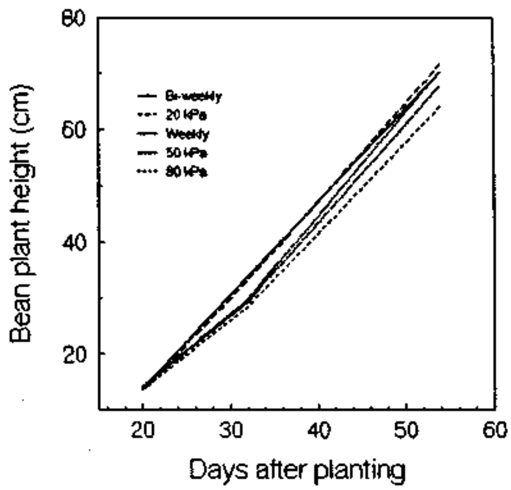


Figure 9. Increasing the Critical Tensiometer Value reduced the heights of autumn grown green beans plants.

There were non-significant trends for bean yields (Y t/ha) to decline as **T** increased or **ET** was reduced (Figure 10). Any reduction in yields was mainly associated with the driest treatments, however due to the variability in yields, no conclusive differences were apparent. Overall production in this experiment was very high, at least 2-3 times grower averages. There was increased potential for lodging (L) of the bean crop in the well-watered plots, probably due to the taller plants and the wetter soil conditions (figure 11). We did not have any problems in harvesting the beans in this experiment. Some processing field staff expressed concern that adverse rainfall during the 10 days prior to harvesting would have caused severe losses of production in the more frequently irrigated treatments.

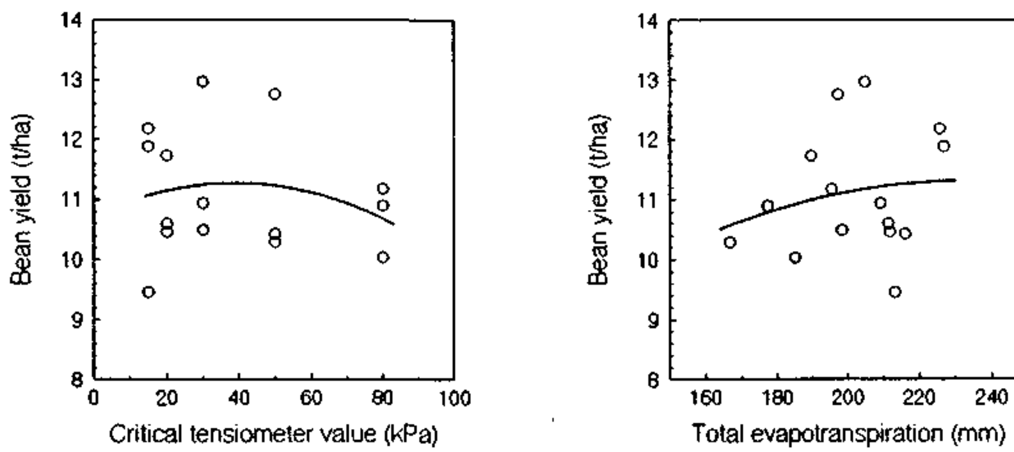


Figure 10. The total yield of green beans was not significantly affected by altering either the Critical Tensiometer Value or the total evapotranspiration of autumn grown green beans.

$Y = 10.8 + 0.0273\,T - 0.000351\,T^2$ $r^2 = 0.04^{ns}$ Equation (5)

$Y = 2.22 + 0.0782\,ET - 0.000168\,T^2$ $r^2 = 0.04^{ns}$ Equation (6)

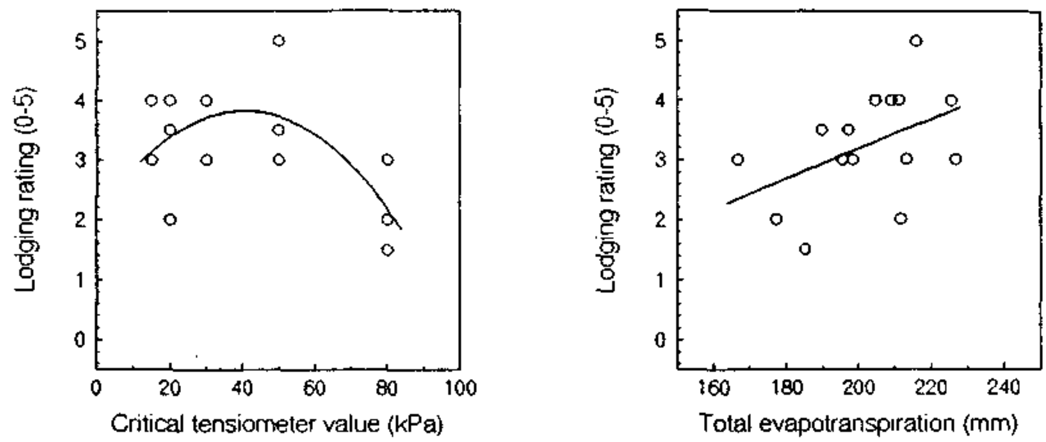


Figure 11. The potential for lodging problems in green beans was increased by reducing the Critical Tensiometer Value, or increasing the total evapotranspiration of autumn grown green beans.

$L = 2.09 + 0.0857\,T - 0.00106\,T^2$ $\quad r^2 = 0.40^{*}$ $\quad$ Equation (7)

$L = -1.82 + 0.0250\,ET$ $\quad r^2 = 0.22^{ns}$ $\quad$ Equation (8)

5. Discussion and conclusions

The tensiometer system used in this experiment proved useful for scheduling irrigation. It was easy to install and use, gave accurate, reliable readings, required little maintenance and was relatively cheap. The neutron probe needed intensive calibration to give accurate readings in the surface soil, where most evaporation and plant water use occurred. The neutron probe provided useful information for deriving daily water balances, however the intense nature of our monitoring would be neither appropriate nor possible for most farmers or consultants. Given the deeper rooting habit of green beans compared to other vegetables, such as brassicas or lettuce, the deeper tensiometer should probably be installed at 60 cm, compared to the 45 cm depth used in this experiment. Similarly, neutron probe readings should be taken to 70 cm, rather than 50 cm below the soil surface, although there appeared to be little uptake of water from the lower parts of the soil profile in this instance.

One problem with the tensiometer system was determining the correct quantities (as opposed to frequencies) of irrigation to apply to avoid excessive losses through drainage beyond the root zone. Unlike the neutron probe, tensiometers do not give immediate estimates of soil water deficits within the root zone, so the amount of irrigation applied relies to some extent on previous experience with the particular soil type/crop combination. As this was one of the first irrigation experiments on this site, we would anticipate that the same magnitude of overwatering would not occur in future. In most instances we would be aiming to lose about 10% of the applied irrigation as drainage.

Although the systems based on regular irrigation once or twice a week produced maximum bean yields in this experiment, there are a number of disadvantages associated with this method. The lack of flexibility makes it more difficult to take into account periods of changing evaporative demand, or rainfall, when scheduling irrigation. Without some measure of the actual water status of the soil, it is difficult to determine the amount of water required at each irrigation.

The results from this experiment suggest that Critical Tensiometer Values for autumn grown green beans is probably around 35-40 kPa, possibly even 50 kPa during the early vegetative phase. Under this criteria, irrigation would be applied about every 5-5.5 days for the first 7 weeks after planting, reducing in frequency to every 6-7 days until harvest (due to the deeper rooting of the older green beans plants, and the reduced evaporative demand). On the black earth soil types, it is probable that 17-20 mm would be applied at each irrigation for the first 7 weeks, increasing to 20-23 mm per irrigation for the last 3 weeks. Given this sequence, a total of 12-13 irrigations (total about 250 mm) would be needed to obtain optimum green beans yields and quality while minimising irrigation costs and drainage losses. Obviously any rainfall during the intervening period would reduce these requirements, although there may still be a need to irrigate for other purposes, such as fertiliser or pesticide incorporation. The target evapotranspiration for the growing season appeared to be around 210 mm, although this would obviously depend on cultivar and growing conditions (both weather and agronomic). A Critical Tensiometer Value of around 40 kPa is much lower than overseas values for green beans (75-200 kPa), emphasising the need for local research.

Increased irrigation frequency would enhance the risk of fertiliser (and pesticide) leaching, as well as the potential for disease outbreaks. There is also a potential problem with lodging, from the development of large bushes with massive quantities of beans, which are unable to be supported by a weak stem. Careful attention to crop nutrition and pest management, as well as precise monitoring of the amounts of water applied at each irrigation, would be required. There may be a case for selecting cultivars with a stronger bush habit, to reduce lodging losses.

We intend to conduct further experiments investigating irrigation scheduling techniques and application methods for green bean production. In these experiments we will be observing crop performance under the irrigation regime suggested above, paying particular attention to monitoring cultivar selection, nutrition and disease management.

EXPERIMENT REPORT

1. **Report** **Final** **Date of Report:** 3-2-92

Initiation Date: 25-1-91 **Completion Date:** 11-6-91

Project Number: S8902

Project Title: Irrigation scheduling in vegetables

Experiment Number: S8902.03 **Officer Responsible:** Craig Henderson

Experiment Title: Irrigation scheduling for autumn grown lettuce.

2. Experiment Objectives

This experiment investigated the critical tensiometer values for maximum lettuce production and evaluated crop water use. The efficiency of irrigation was examined by determining the quantities of applied water that drained beyond the root zones during the growing period.

3. Summary of Results

The experiment was conducted at Gatton Research Station, from April-June 1991. Lettuce (cv. *Yatesdale*) were grown using standard agronomy, with 5 irrigation treatments replicated 3 times in a RCB design. Plots were 4.5 m wide and 10 m long, with a total experimental area of 0.07 ha. The five irrigation treatments involved irrigating twice or once a week, or commencing irrigation at 3 different Critical Tensiometer Values (**T** kPa), using tensiometers installed 15 cm below ground level in each plot. The **T** values were 20, 50, and 80 kPa. Each plot was independently watered using a mini-sprinkler system that gave uniform application across the treatment beds, with no incursion into adjacent plots. The total amounts of irrigation, lettuce water use, drainage losses and mean lettuce head size were reduced by increasing **T**, or reducing irrigation frequency from twice to once a week. Drainage losses tended to be higher on the areas watered at set time intervals, rather than scheduled with tensiometers. Lettuce heads were largest where the crop was irrigated twice a week. There was a non significant trend for the number of marketable lettuce to decline with **T**, possibly due to increased incidence of Downy Mildew in the more frequently watered plots. From the results, we believe that optimum yields will be achieved where **T** is set between 15 and 18 kPa for the autumn grown lettuce. Under this watering regime, lettuce would initially be irrigated every 2.5-3 days for the first 20 days after transplanting, reducing in frequency to every 4-5 days until harvest, with 13-17 mm applied at each irrigation. The lettuce would use around 210 mm of water for maximum production, with a further 30 mm drainage. Closer plant spacings may reduce evapotranspiration through less soil evaporation.

EXPERIMENT REPORT

Irrigation scheduling for autumn grown lettuce

by C. Henderson and M. Webber
Department of Primary Industries
Gatton Research Station

Experiment No. S8902.03 17.4.91-11.6.91

1. Relevance to Industry

In many regions, including the Lockyer Valley, irrigation demands regularly exceed the reliable capacity of the water supply, resulting in scarcity or reliance on poorer quality water. In many vegetable enterprises irrigation is a significant proportion of overall production costs. Shallow rooted vegetables are substantial users of water; for example brassicas and lettuce require 2-4 ML per hectare per crop. Until recently, the frequency and amount of irrigation was relatively ad hoc, based on tradition and grower experience, combined with superficial observations of plant or soil conditions.

Some vegetable growers use tensiometers or neutron probes to monitor soil water status and schedule irrigations. Both methods have advantages and disadvantages, however tensiometers appear to have the best immediate potential for use in shallow rooted vegetables.

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 overwatering, problems with leaching of nutrients and pesticides into groundwater (and beyond the zone of usefulness) are reduced, as well as a decrease in disease levels.

2. Objectives

This experiment investigated the critical tensiometer values for maximum lettuce production, and evaluated crop water use. The efficiency of irrigation was examined by determining the quantities of applied water that drained beyond the root zones during the growing period.

3. Materials and methods

The experiment was conducted on a black earth soil (*Ug5.15*) at Gatton Research Station (lat 27°33'S, long 152°20'E). The experimental design was a randomised complete block, with 5 irrigation treatments replicated 3 times. Each plot was 3 beds (2 rows of lettuce per 1.5 m bed) wide and 10 m long.

The soil was prepared as per standard practice for lettuce. Lettuce seedlings (cv. *Yatesdale*) were transplanted on the 17th April 1991, with 0.7 m between the rows and 0.33 m intra-row spacing. A total of 450 kg/ha of compound fertiliser (59 kg N, 10 kg P, 60 kg K, 85 kg S) was applied immediately before planting. One sidedressing of 60 kg/ha N (as urea) was broadcast on 9th May 1991. Molybdenum (0.042 kg/ha as sodium molybdate) and boron (0.031 kg/ha as hydrated sodium octoborate) were sprayed on the 7th May 1991. Calcium nitrate was sprayed at 0.8 kg/ha over the experiment on the 29th May 1991. One application of propyzamide (2.25 kg a.c./ha) was sprayed over the area 15 days after transplanting and incorporated with 23 mm of irrigation. Insects were controlled with regular applications of insecticides, including dimethoate, methidathion, cypermethrin, mevinphos, *Bacillis thuringiensis*, and methomyl. The lettuce were sprayed with a fungicide containing 1.6 kg/ha of mancozeb and 0.1 kg/ha of metalaxyl on the 4th June, in an attempt to control an outbreak of Downy Mildew.

For the first week after transplanting the whole area was irrigated with standard solid-set pipes and overhead sprinklers. After this first week, systems of mini-sprinklers were installed to individually water each plot. A schematic of the individual plot layout is given in Figure 1. Each plot consisted of 3 beds of lettuce side by side. The central bed was the treatment area, while the two outside beds were buffer zones. Lines of mini-sprinklers was installed down the 2 outer edges of the treatment beds, with 2 m between each sprinkler within a line. The sprinklers in the 2 lines were offset by 1 m, to give a staggered pattern down the bed (Figure 1). Each sprinkler was mounted on a 1 m high stake, and had an output radius of about 2 m and volume of 70 L/hr at 130 kPa operating pressure. Using this system, the irrigation was relatively uniform across the treatment bed, with no drift into neighbouring treatment beds. The application rate was around 20 mm/hr over the treatment beds. An electronic timing system was used to commence irrigation at 2 am on the appropriate days, to avoid windy conditions often prevalent during daylight hours.

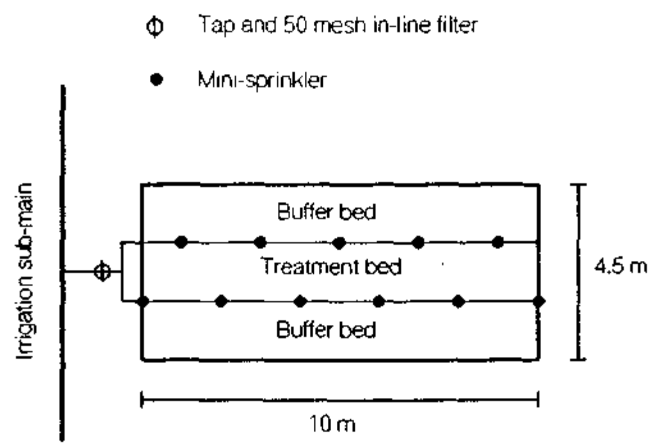


Figure 1. Mini-sprinkler system design for an individual plot in an experiment investigating irrigation scheduling in autumn grown lettuce.

Tensiometers were installed 15 cm and 45 cm below ground level in each treatment bed. *Loctronic* tensiometers were used, consisting of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum, while an electronic vacuum gauge attached to the syringe records the vacuum in the tensiometer air gap. Tensiometer readings were recorded daily, usually around 8 am. On the basis of the tensiometer readings, 5 separate irrigation treatments were scheduled:

1. Irrigated twice a week, independent of tensiometer readings.
2. Irrigation when the 15 cm tensiometer had 20 kPa soil water suction.
3. Irrigated once a week, independent of tensiometer readings.
4. Irrigation when the 15 cm tensiometer had 50 kPa soil water suction.
5. Irrigation when the 15 cm tensiometer had 80 kPa soil water suction.

Each plot was irrigated according to its allocated treatment. Plots with the same irrigation treatment were occasionally watered on different days, due to differences in the time for the tensiometers to reach values necessary to trigger irrigation.

Aluminium neutron probe access tubes were installed to depths of 70 cm in each treatment bed, 5 cm inside a lettuce row and equidistant between 2 neighbouring plants. Neutron moisture meter readings were taken twice a week using a Campbell Pacific Nuclear Hydroprobe. A single reading was taken at 5 depth intervals, commencing 5 cm below the ground surface, incrementing by 10 cm. On each day that the neutron probe measurements were made, 5 standard counts was also conducted in a 200 L drum of water.

After the lettuce were harvested, the neutron probe was calibrated for each of the 5 depth intervals. The lettuce plants were grown for 2 weeks after harvesting, to partially dry the soil profile. Concurrent gravimetric soil water samples and probe measurements were taken at the appropriate depths. The area was then irrigated to saturation, and resampled the following day. In both instances, samples were only taken from the treatments watered twice a week, with 2 gravimetric profiles and neutron probe profiles per bed. Volumetric soil water content vs neutron probe count (expressed as a fraction of the standard count) calibrations were determined for each depth interval, for each of the three experimental blocks. The equations were developed from only 4 data points per calibration, for the 0-10 and 10-20 cm depth intervals, however equations obtained from other experiments on the same site were used for the deeper intervals.

Weather data, including rainfall, Class A Pan evaporation, maximum and minimum temperatures were recorded daily. The equivalent depths of water applied at each irrigation were measured using rain gauges in each of the experimental plots. The water meter at the irrigation pump was calibrated with the rain gauges, as a further check on the amounts of water applied.

The heights and widths of the lettuce plants were measured at weekly intervals, commencing 2 weeks after transplanting and continuing until the 30th May 1991. Five plants were randomly selected and assessed in each plot. Lettuce were harvested from the treatment beds on the 11th June 1991. For each plot the number of marketable heads were counted, and 2 samples containing 12 lettuce were weighed.

4. Results

Rainfall during the growing period totalled 35.6 mm, including events of 12.8 mm on the 16th May, 8 mm on 29th May and 8.8 mm over 4 days, commencing 5th June 1991. Most of the crop water requirement was met by irrigation and stored soil water at transplanting.

The calibration equations for the neutron probe took the following form;

$$\mathbf{V} = a + b * \mathbf{FC} \qquad \text{Equation (1)}$$

where $\mathbf{V}$ = volumetric water content (cm^3cm^{-3})
$\mathbf{FC}$ = fractional neutron count (reading in soil divided by standard count in water)
a and b are equation parameters

The parameter values and r^2 for the calibration equations for each of the blocks and depth intervals are given in Table 1.

Table 1

Parameters and goodness of fit for calibration equations relating volumetric soil water content to neutron probe readings.

Depth interval cm	Block 1			Block 2			Block 3		
	a	b	r^2	a	b	r^2	a	b	r^2
0-10	-0.717	1.873	-	-0.421	1.511	-	-0.249	1.209	-
10-20	-1.079	2.294	-	-0.620	1.662	-	-0.479	1.440	-
20-30	-0.125	0.829	0.73	-0.196	0.925	0.92	-0.122	0.831	0.96
30-40	-0.060	0.677	0.64	-0.062	0.705	0.73	-0.057	0.726	0.67
40-50	-0.032	0.600	0.46	-0.191	0.878	0.78	0.057	0.516	0.44

All r^2 values were highly significant ($P<0.01$), except for those less than 0.50, which were significant ($P<0.05$).

Using a simple spreadsheet, a daily water balance was calculated for each plot. Rainfall, irrigation, stored soil water, pan evaporation, evapotranspiration and drainage of soil water below 50 cm were determined from transplanting through to harvest. Details of the calculations are available from the authors.

The tensiometer data for the 5 irrigation treatments (Figures 2-6) follow the expected patterns, rising to the Critical Tensiometer Value (**T** kPa) between irrigation cycles and falling when water was applied. For the purposes of analysing the results, arbitrary **T** values were assigned to the bi-weekly and weekly irrigation treatments (12 and 22 kPa respectively), although these 2 irrigation treatments were not scheduled using these **T** values. In many instances tensiometers reached values slightly higher than those set to trigger irrigation. This was because the value would be slightly less than **T** one day, and by the next day would have risen to more than T, the extent depending on weather conditions. Nevertheless, the tensiometers installed at 15 cm tended to range between 1 and 3 kPa above **T**.

During the growing period, there was high evaporative demand for the first 3 weeks after transplanting (4-8 mm of pan evaporation per day), which declined during the remainder of the period (1-4 mm pan evaporation). This was reflected in the treatments that were irrigated on bi-weekly or weekly schedules, with the shallow tensiometers reaching higher values during the first part of the season when compared with later (Figures 2 and 4).

Where the lettuce were irrigated twice a week, the whole 0-50 cm of the soil profile remained relatively wet from about 3 weeks after transplanting. The deeper tensiometers in this treatment frequently recorded negative matric suction values, indicating saturated soil conditions, with a high likelihood of drainage of water beyond the active root zone on those occasions (Figure 2). Although less frequent, there were also instances of saturated profiles occurring in the treatments watered once a week (Figure 4).

Shallow tensiometer readings for the treatment where **T** was 20 kPa consistently fluctuated between 0-20 kPa. When compared with the treatments watered on a set-time basis, soil conditions were wetter during the first 3 weeks after transplanting and drier for the remainder of the growing period (Figure 3). The deeper tensiometers stayed between 5-10 kPa for most of the latter part of the period, indicating less saturation and hence probably less drainage. The treatment with **T** set at 50 kPa gave similar tensiometer patterns to those where **T** was 20 kPa, although the peaks of matric suction in the former were greater, as expected (Figure 5). There was substantial drying of the surface around 6 weeks after transplanting, although an irrigation at that time fully wet the whole profile, with some drainage beyond the root zone. Apart from this single instance, the deeper tensiometers in this treatment generally registered around 10 kPa of matric suction.

The driest treatment, with **T** at 80 kPa, showed substantial increases in matric suction from about 30 days after transplanting, with the readings from the deeper tensiometers also starting to rise at that time (Figure 6). The irrigation at 6 weeks after transplanting did not fully wet the soil profiles, resulting in only a temporary drop in the shallow tensiometers, while the deeper parts of the profile continued to dry virtually unabated.

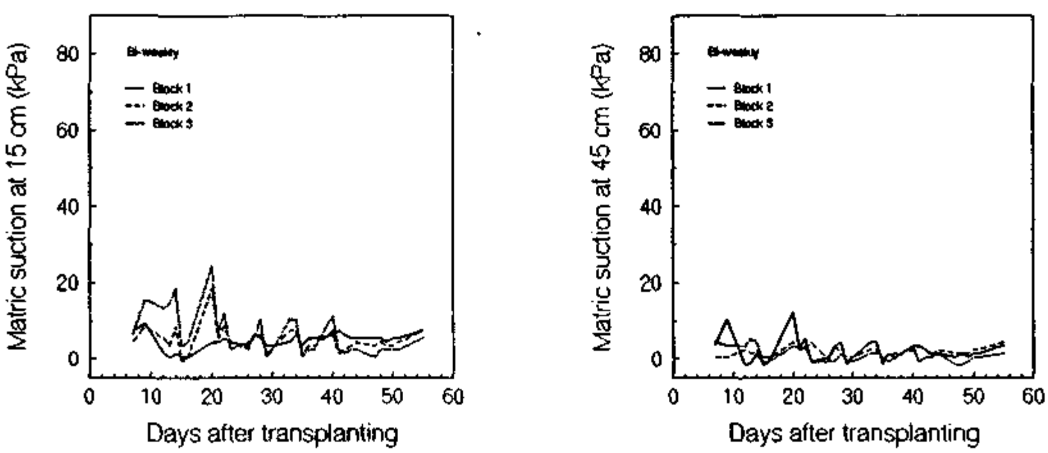


Figure 2. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where lettuce was irrigated twice a week.

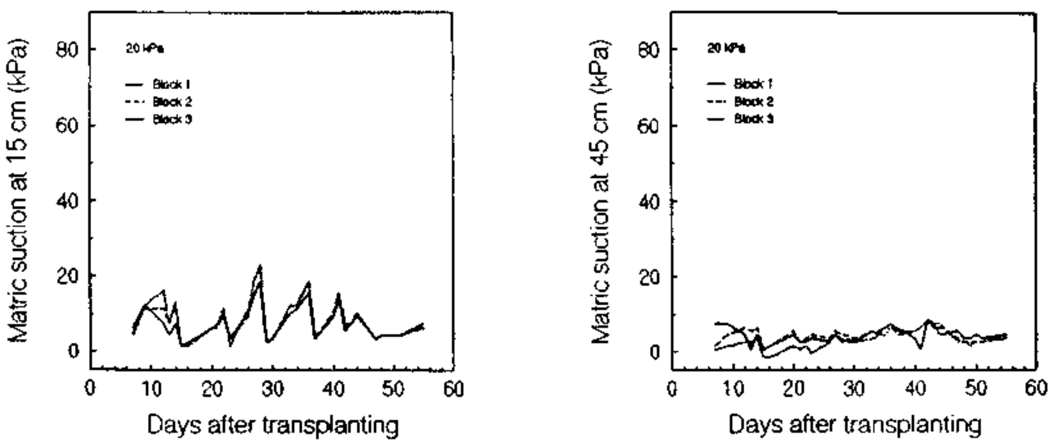


Figure 3. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where lettuce was irrigated when soil matric suction at 15 cm exceeded 20 kPa.

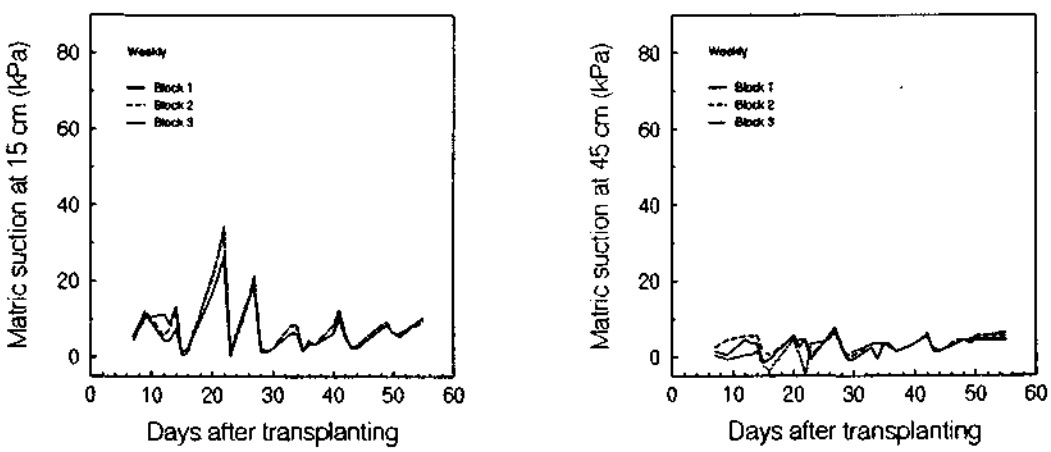


Figure 4. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where lettuce was irrigated once a week.

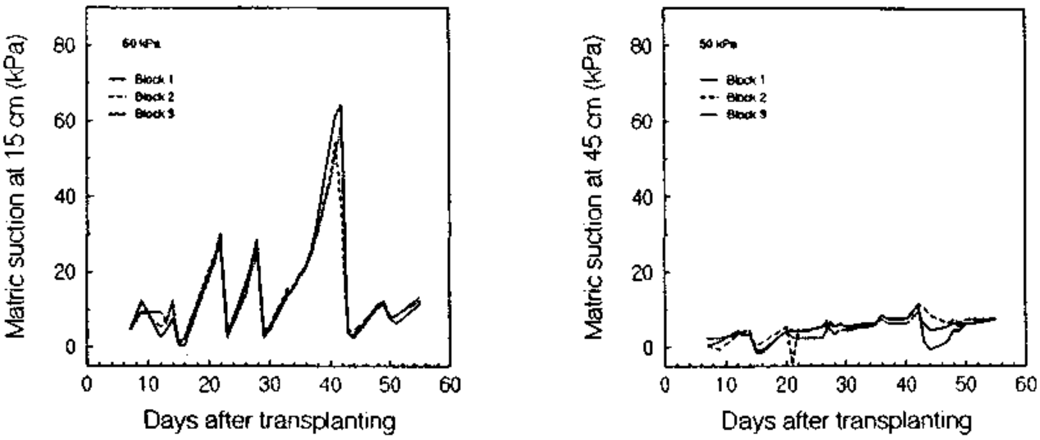


Figure 5. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where lettuce was irrigated when soil matric suction at 15 cm exceeded 50 kPa.

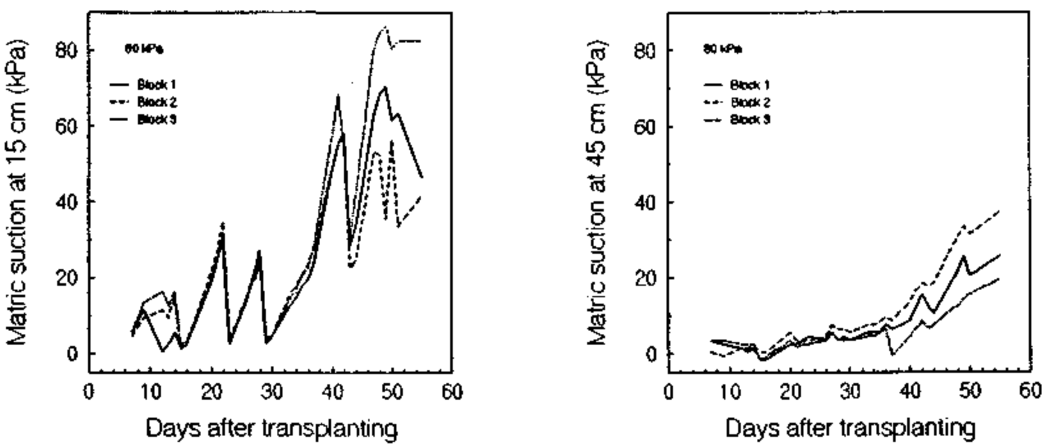


Figure 6. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where lettuce was irrigated when soil matric suction at 15 cm exceeded 80 kPa.

There were significantly ($P<0.001$) fewer irrigations as T was increased (Table 2). The wettest treatment, where irrigation proceeded twice a week (independent of tensiometer readings) received 16 irrigations during the growing period, while the driest plots were irrigated 7 times. There were smaller differences in quantities of water applied at each irrigation (Table 3). During the first 20 days after transplanting, most irrigations were around 25 mm, with an average 25% drainage losses across all treatments. This was mainly due to overwatering with the solid-set sprinklers immediately after transplanting, as well as when the propyzamide herbicide was incorporated 15 days after transplanting.

Although similar amounts of water were applied at each irrigation during the 21-40 day period, there were significant differences in drainage losses between the treatments irrigated on a set-time basis and those scheduled with tensiometers. The former had drainage losses amounting to 30-50% of the quantities applied via irrigation, while the tensiometer regulated treatments lost 10-25%. These contrasts were more pronounced during the last part of the growing season.

Table 2

Mean intervals (days) between irrigations for 5 watering regimes in autumn grown lettuce.

Irrigation treatment	Growth period (days after transplanting)			Total number of irrigations
	0-20	21-40	41-55	
Bi-weekly	2.9 a	5.0 a	7.5 a	13 d
20 kPa	2.9 a	10.0 c	15.0 a	10 c
Weekly	3.3 b	6.7 b	15.0 a	10 c
50 kPa	3.3 b	15.0 d	15.0 a	8 b
80 kPa	3.3 b	15.0 d	-	7 a

Table 3

Mean irrigation quantities and drainage losses for 5 watering regimes in autumn grown lettuce.

Irrigation treatment	Growth period (Days after transplanting)					
	0-20		21-40		41-55	
	Irrig. (mm)	Drain. (mm)	Irrig. (mm)	Drain. (mm)	Irrig. (mm)	Drain. (mm)
Bi-weekly	23.6 a	5.6 a	16.0 a	5.0 b	24.0 c	9.5 b
20 kPa	23.9 a	6.5 b	17.0 b	4.1 b	33.0 d	1.8 a
Weekly	25.5 b	6.8 b	20.0 d	9.7 c	17.0 b	9.3 b
50 kPa	25.5 b	6.5 b	19.0 c	0.0 a	17.0 b	1.7 a
80 kPa	25.5 b	6.5 b	19.0 c	1.0 a	0.0 a	0.0 a

A summary of the total growing period water balance for each of the irrigation treatments (Figure 7) shows curvilinear relationships between the Critical Tensiometer Value (**T** kPa), Irrigation (**I** mm), Total Evapotranspiration (**ET** mm) and Total Drainage (**D** mm), where;

$\mathbf{I} = 311 - 4.02\ \mathbf{T} + 0.0288\ \mathbf{T}^2$ $\quad r^2 = 0.96^{***}$ $\quad$ Equation (2)

$\mathbf{ET} = 216 - 2.59\ \mathbf{T} + 0.0233\ \mathbf{T}^2$ $\quad r^2 = 0.67^{**}$ $\quad$ Equation (3)

$\mathbf{D} = 97 - 1.71\ \mathbf{T} + 0.0125\ \mathbf{T}^2$ $\quad r^2 = 0.75^{***}$ $\quad$ Equation (4)

There was substantially more irrigation applied to the areas watered twice a week compared to the other treatments (Figure 7). Although a proportion was lost through increased drainage, there was still a significant trend for greater evapotranspiration in those areas. Differences in cumulative evapotranspiration became apparent as early as 10 days after transplanting, with most divergence occurring after 30 days (Figure 8). There was little separation between the other 4 treatments until about 10 days prior to harvesting, when ET in the drier plots became noticeably reduced.

The lettuce did not achieve full canopy cover within the row until about 28 days after transplanting. At the same time, because of the 0.7 m inter-row spacing, there was still 35-40 cm of bare soil between the rows. It is likely that soil evaporation contributed to a substantial fraction of total evapotranspiration, particularly in more frequently irrigated treatments, where the soil surface was wet for longer periods.

Most drainage in this experiment occurred during the first part of the growing period, although there was also some further drainage from the set-time based treatments right up until harvesting.

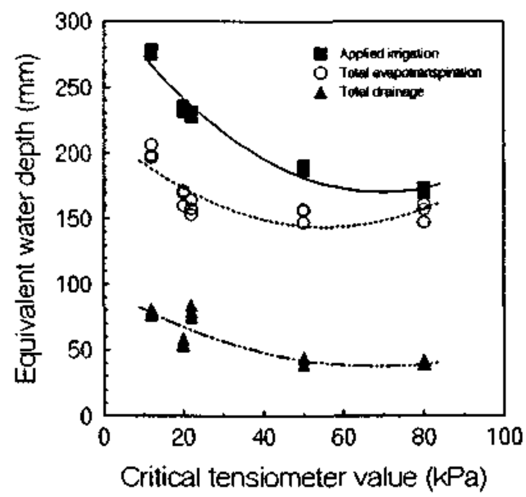


Figure 7. Changes in quantities of irrigation, total evapotranspiration and drainage losses as the Critical Tensiometer Value increased.

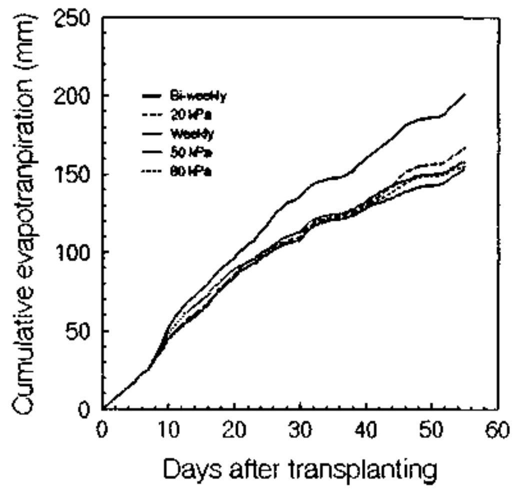


Figure 8. Reductions in cumulative evapotranspiration as the Critical Tensiometer Value increased.

It was difficult to detect differences in lettuce height between the irrigation treatments during the growing period, although there was a trend for the wetter plots to have shorter lettuce during the middle part of the growing season, while the plants were taller than average immediately prior to harvesting. There was also a minor trend for the more frequently irrigated lettuce to be slightly wider for the latter half of the growing period (Figure 9).

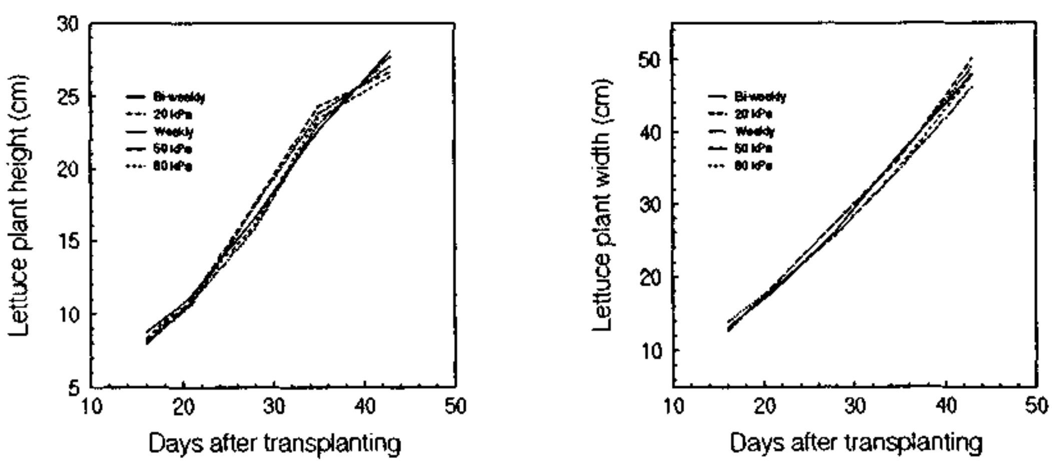


Figure 9. Increasing the Critical Tensiometer Value resulted in only slight differences in heights and diameters of autumn grown lettuce plants.

There was a non-significant trend for the numbers of marketable lettuce (**L** '000/ha) to decline in the more frequently irrigated areas, i.e. as **T** was reduced or **ET** increased (Figure 10). There was a severe incidence of Downy Mildew in the latter 3 weeks of the experiment, which appeared to be the main factor causing the substantial variability in marketable lettuce within each treatment.

There were significant increases in the mean size of the lettuce heads (**W** kg) as **T** was reduced or **ET** rose (Figure 11). Much of the decline in mean head weight occurred as the irrigation timing shifted from twice to once a week, with further reductions in head size as irrigation became even less frequent. Due to the considerable variation in the numbers of marketable lettuce, there were no significant effects of irrigation treatment on overall lettuce yields (**Y** t/ha), as shown in Figure 12.

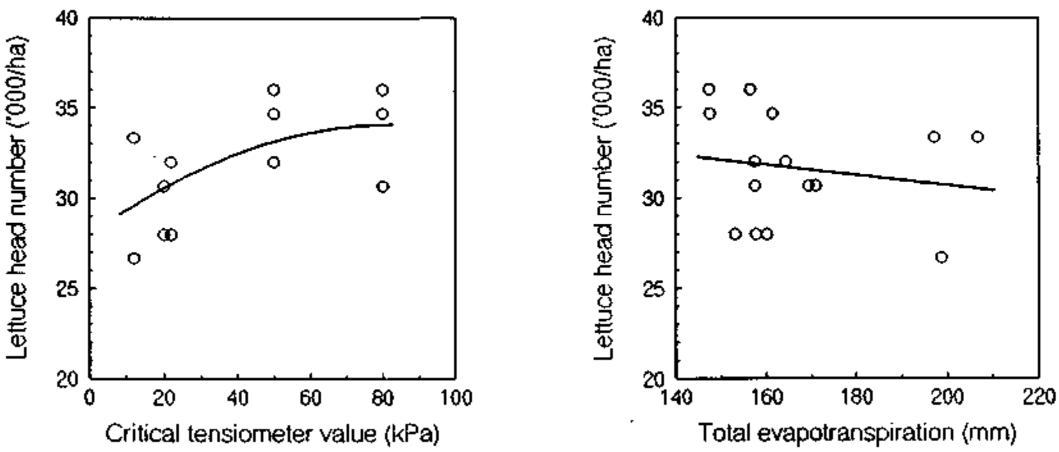


Figure 10. The number of marketable lettuce heads was not significantly affected by altering either the Critical Tensiometer Value or the total evapotranspiration of autumn grown lettuce.

$\mathbf{L} = 28.0 + 0.148\,\mathbf{T} - 0.000899\,\mathbf{T}^2$ $r^2 = 0.33^{ns}$ Equation (5)

$\mathbf{L} = 36.4 - 0.0282\,\mathbf{ET}$ $r^2 = 0.03^{ns}$ Equation (6)

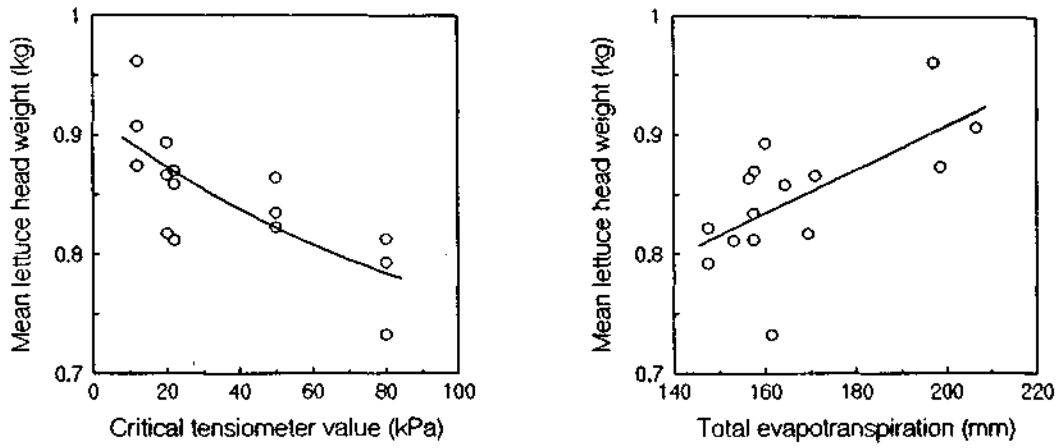


Figure 11. The mean weight of marketable lettuce heads was increased by reducing the Critical Tensiometer Value, or increasing the total evapotranspiration of autumn grown lettuce.

$W = 0.92 - 0.00223\,T + 0.00000731\,T^2$ $r^2 = 0.56^{**}$ Equation (7)

$W = 0.54 + 0.00185\,ET$ $r^2 = 0.41^{*}$ Equation (8)

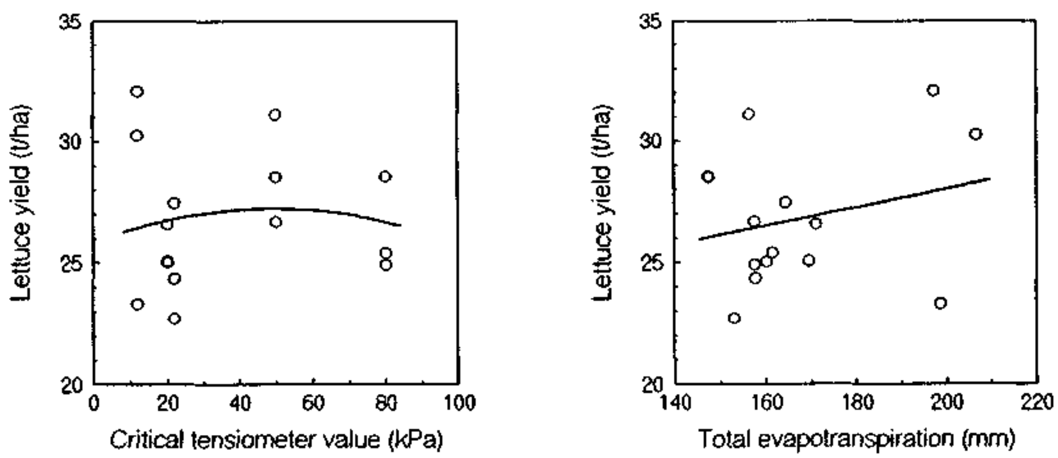


Figure 12. The total yield of marketable lettuce heads was not significantly affected by altering either the Critical Tensiometer Value or the total evapotranspiration of autumn grown lettuce.

$Y = 25.8 + 0.0576\,T - 0.000588\,T^2$ $r^2 = 0.01^{ns}$ Equation (9)

$Y = 20.6 + 0.0372\,ET$ $r^2 = 0.06^{ns}$ Equation (10)

5. Discussion and conclusions

The tensiometer system used in this experiment proved useful for scheduling irrigation. It was easy to install and use, gave accurate, reliable readings, required little maintenance and was relatively cheap. The neutron probe needed intensive calibration to give accurate readings in the surface soil, where most evaporation and plant water use occurred. The neutron probe provided useful information for deriving daily water balances, however the intense nature of our monitoring would be neither appropriate nor possible for most farmers or consultants.

One problem with the tensiometer system was determining the correct quantities (as opposed to frequencies) of irrigation to apply to avoid excessive losses through drainage beyond the root zone. Unlike the neutron probe, tensiometers do not give immediate estimates of soil water deficits within the root zone, so the amount of irrigation applied relies to some extent on previous experience with the particular soil type/crop combination. In most instances we would be aiming to lose about 10% of the applied irrigation as drainage.

Although the system based on regular irrigation twice a week produced the maximum size of lettuce heads in this experiment, there are a number of disadvantages associated with this method. The lack of flexibility makes it more difficult to take into account periods changing evaporative demand, or rainfall, when scheduling irrigation. Without some measure of the actual water status of the soil, it is difficult to determine the amount of water required at each irrigation. In this experiment, the uncertainty resulted in substantial losses from drainage beyond the root zone on numerous occasions throughout the growing season.

The outbreak of Downy Mildew in this experiment had an adverse affect on the variability of yield data within irrigation treatments. In hindsight, preventative sprays may have reduced the problems associated with this disease. The results suggest that lettuce grown during autumn in the Lockyer Valley may require irrigation about every 4 days, if maximum yields are to be obtained. If irrigation was undertaken at this frequency, then disease problems would probably be exacerbated, requiring more careful monitoring and management.

The inter-row spacing for lettuce at Gatton Research Station is much wider than in commercial grower operations, mainly due to machinery limitations. As a consequence, full canopy cover is never achieved, which results in less efficient use of irrigation water, due to a greater proportion of soil evaporation compared to transpiration. This would be more pronounced with increased frequency of irrigation, where the surface soil remains wetter for longer periods. Closer plant spacings would be one method of reducing this problem.

Increased irrigation frequency would also enhance the risk of fertiliser (and pesticide) leaching, therefore careful attention to crop nutrition and pest management, as well as precise monitoring of the amounts of water applied at each irrigation, would be required.

The results from this experiment suggest that Critical Tensiometer Values for autumn grown lettuce may be slightly lower than for winter lettuce, probably due to higher evaporative demand during much of the growing period of the former. Our experiences suggest a **T** value of 15-18 kPa may be optimum for lettuce grown during the April-June period. Under this criteria, irrigation would be applied every 2.5-3 days for the first 20 days after transplanting, reducing in frequency to every 4-5 days until harvest (due to the deeper rooting of the older lettuce plants, and the reduced evaporative demand). On the black earth soil types, it is probable that 13-17 mm would be applied at each irrigation. Given this sequence, a total of around 16 irrigations (about 240 mm) would be needed to obtain optimum lettuce yields and quality while minimising irrigation costs and drainage losses. Obviously any rainfall during the intervening period would reduce these requirements, although there may still be a need to irrigate for other purposes, as mentioned previously. The target evapotranspiration for the growing season appeared to be around 210 mm, although this would obviously depend on cultivar and growing conditions (both weather and agronomic). There is probably scope for reducing this required ET with closer plantings. A Critical Tensiometer Value of around 18 kPa is much lower than overseas values for lettuce (40-60 kPa), emphasising the need for local research.

We intend to conduct further experiments investigating irrigation scheduling techniques and application methods for lettuce production. In these experiments we will be attempting closer plantings, as well as monitoring cultivar selection, nutrition and disease management more closely, in order to confirm our hypotheses from the experiment reported on here.

EXPERIMENT REPORT

1. **Report** **Final** **Date of Report: 10-1-92**

Initiation Date: 25-1-91 **Completion Date:** 10-09-91

Project Number: S8902

Project Title: Irrigation scheduling in vegetables

Experiment Number: S8902.04 **Officer Responsible:** Craig Henderson

Experiment Title: Irrigation scheduling for winter grown broccoli.

2. Experiment Objectives

This experiment investigated the critical tensiometer values for maximum broccoli production, and evaluated crop water use. The efficiency of irrigation was examined by determining the quantities of applied water that drained beyond the root zones during the growing period.

3. Summary of Results

The experiment was conducted at Gatton Research Station, from June-September 1991. Broccoli (cv. *Pacific*) were grown using standard agronomy, with 5 irrigation treatments replicated 3 times in a RCB design. Plots were 4.5 m wide and 10 m long, with a total experimental area of 0.07 ha. The five irrigation treatments involved commencing irrigation at different Critical Tensiometer Values (**T** kPa) for a tensiometer installed 15 cm below ground level in each plot. The **T** values were 20, 30, 50, 80 and 90 kPa. Each plot was independently watered using a mini-sprinkler system that gave uniform application across the treatment beds, with no incursion into adjacent plots. The number and total amounts of irrigation, broccoli water use, marketable broccoli heads and mean broccoli head size all declined as **T** increased. Optimum broccoli yields occurred when **T** was between 30 and 40 kPa for the growing period. Under this watering regime, the broccoli was initially irrigated every 6 days for the first 50 days after transplanting, increasing in frequency to every 5 days until harvest. Initial irrigations were around 15 mm, increasing to 20-25 mm after about 30 days. The broccoli used around 230 mm of water for maximum production, with a further 60 mm lost to through drainage. More refined irrigation scheduling should reduce this drainage loss to around 10% of the total irrigation applied.

EXPERIMENT REPORT

Irrigation scheduling for winter grown broccoli

by C. Henderson and M. Webber
Department of Primary Industries
Gatton Research Station

Experiment No. S8902.04 20.6.91-10.9.91

1. Relevance to Industry

In many regions, including the Lockyer Valley, irrigation demands regularly exceed the reliable capacity of the water supply, resulting in scarcity or reliance on poorer quality water. In many vegetable enterprises irrigation is a significant proportion of overall production costs. Shallow rooted vegetables are substantial users of water; for example brassicas and lettuce require 2-4 ML per hectare per crop. Until recently, the frequency and amount of irrigation was relatively ad hoc, based on tradition and grower experience, combined with superficial observations of plant or soil conditions.

Some vegetable growers use tensiometers or neutron probes to monitor soil water status and schedule irrigations. Both methods have advantages and disadvantages, however tensiometers appear to have the best immediate potential for use in shallow rooted vegetables.

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 overwatering, problems with leaching of nutrients and pesticides into groundwater (and beyond the zone of usefulness) are reduced, as well as a decrease in disease levels.

2. Objectives

This experiment investigated the critical tensiometer values for maximum broccoli production, and evaluated crop water use. The efficiency of irrigation was examined by determining the quantities of applied water that drained beyond the root zones during the growing period.

3. Materials and methods

The experiment was conducted on a black earth soil (*Ug5.15*) at Gatton Research Station (lat 27°33'S, long 152°20'E). The experimental design was a randomised complete block, with 5 irrigation treatments replicated 3 times. Each plot was 3 beds (2 rows of broccoli per 1.5 m bed) wide and 10 m long.

The soil was prepared as per standard practice for broccoli. Broccoli seedlings (cv. *Pacific*) were transplanted on the 20th June 1991, with 0.7 m between the rows and 0.33 m intra-row spacing. A total of 450 kg/ha of compound fertiliser (59 kg N, 10 kg P, 60 kg K, 85 kg S) was applied immediately before planting. Two sidedressings of 60 kg/ha N (as urea) were broadcast on 9th July and 20th August 1991. Molybdenum (0.042 kg/ha as sodium molybdate) and boron (0.031 kg/ha as hydrated sodium octoborate) were sprayed on the 8th July 1991, and again on the 25th July 1991. Propachlor herbicide at 4.8 kg of active constituent per hectare was sprayed over the area immediately after transplanting and incorporated with 25 mm of irrigation. Insects were controlled with regular applications of insecticides, including fenvalerate, *Bacillis thuringiensis*, methomyl and esfenvalerate.

During the first week after transplanting the whole area was irrigated with standard solid set pipes and overhead sprinklers. After this first week, a system of mini-sprinklers was installed to individually water each plot. A schematic of the individual plot layout is given in Figure 1. Each plot consisted of 3 beds of broccoli side by side. The central bed was the treatment area, while the two outside beds were buffer zones. Lines of mini-sprinklers was installed down the 2 outer edges of the treatment beds, with 2 m between each sprinkler within a line. The sprinklers in the 2 lines were offset by 1 m, to give a staggered pattern down the bed (Figure 1). Each sprinkler was mounted on a 1 m high stake, and had an output radius of about 2 m and volume of 70 L/hr at 130 kPa operating pressure. Using this system, the irrigation was relatively uniform across the treatment bed, with no drift into neighbouring treatment beds. The application rate was around 20 mm/hr over the treatment beds. An electronic timing system was used to commence irrigation at 2 am on the appropriate days, to avoid windy conditions often prevalent during daylight hours.

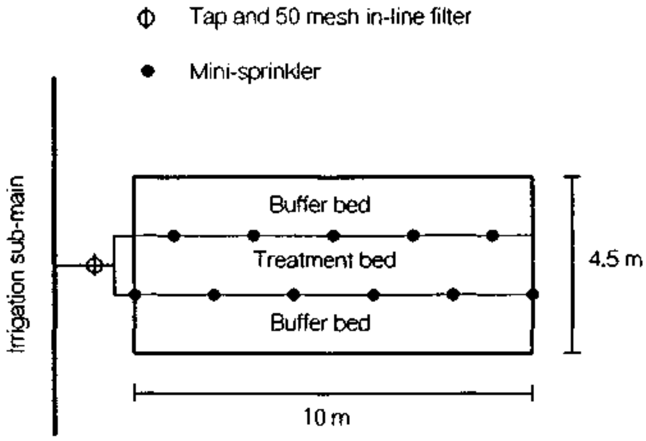


Figure 1. Mini-sprinkler system design for an individual plot in an experiment investigating irrigation scheduling in winter grown broccoli.

Tensiometers were installed 15 cm and 45 cm below ground level in each treatment bed. *Loctronic* tensiometers were used, consisting of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum, while an electronic vacuum gauge attached to the syringe records the vacuum in the tensiometer air gap. Tensiometer readings were recorded daily, usually around 8 am. On the basis of the tensiometer readings, 5 separate irrigation treatments were scheduled:

1. Irrigation when the 15 cm tensiometer had 20 kPa soil water suction.
2. Irrigation when the 15 cm tensiometer had 30 kPa soil water suction.
3. Irrigation when the 15 cm tensiometer had 50 kPa soil water suction.
4. Irrigation when the 15 cm tensiometer had 80 kPa soil water suction.
5. Irrigation when the 15 cm tensiometer had 90 kPa soil water suction.

Each plot was irrigated according to its allocated treatment. Plots with the same irrigation treatment were often watered on different days, due to differences in the time for the tensiometers to reach values necessary to trigger irrigation.

Aluminium neutron probe access tubes were installed to a depth of 70 cm in each treatment bed, 5 cm inside a broccoli row and equidistant between 2 neighbouring plants. Neutron moisture meter readings were taken twice a week using a Campbell Pacific Nuclear Hydroprobe. A single reading was taken at 5 depth intervals, commencing 5 cm below the ground surface, incrementing by 10 cm. On each day that the neutron probe measurements were made, 5 standard counts was also conducted in a 200 L drum of water.

After the broccoli were harvested, the neutron probe was calibrated for each of the 5 depth intervals. The broccoli plants were grown for 2 weeks after harvesting, to partially dry the soil profile. Concurrent gravimetric soil water samples and probe measurements were taken at the appropriate depths. The area was then irrigated to saturation, and resampled the following day. In both instances, samples were taken from each treatment bed, with one gravimetric profile and neutron probe profile per bed. Volumetric soil water content vs neutron probe count (expressed as a fraction of the standard count) calibrations were determined for each depth interval, for each of the three experimental blocks. The calibration equations were developed by pooling the data from the 5 plots that made up an experimental block, to give 10 data points per calibration.

Weather data, including rainfall, Class A Pan evaporation, maximum and minimum temperatures were recorded daily. The equivalent depths of water applied at each irrigation were measured using rain gauges in each of the experimental plots. The water meter at the irrigation pump was calibrated with the rain gauges, so that when the broccoli plants overgrew the rain gauges, the depths of water applied to each plot could still be determined.

The height and widths of the broccoli plants were measured at weekly intervals, from transplanting until maturity. Five plants were randomly selected and assessed in each plot. Broccoli were harvested from the treatment beds as the heads became mature. Harvesting took place on the 3rd, 6th and 10th September 1991. On each occasion the number of heads were counted, and the total weight of heads for the plot determined.

4. Results

Rainfall during the growing period was only 16.7 mm, including a single fall of 11.3 mm. This meant that virtually the total water requirement of the crop was met by irrigation and stored soil water at transplanting.

The calibration equations for the neutron probe took the following form;

$$V = a + b * FC \qquad \text{Equation (1)}$$

where V = volumetric water content (cm^3cm^{-3})
FC = fractional neutron count (reading in soil divided by standard count in water)
a and b are equation parameters

The parameter values and r^2 for the calibration equations for each of the blocks and depth intervals are given in Table 1.

Table 1

Parameters and goodness of fit for calibration equations relating volumetric soil water content to neutron probe readings.

Depth interval cm	Block 1			Block 2			Block 3		
	a	b	r^2	a	b	r^2	a	b	r^2
0-10	0.062	1.199	0.94	0.024	1.147	0.91	0.078	0.964	0.93
10-20	0.087	0.520	0.82	0.076	0.504	0.90	0.086	0.503	0.88
20-30	-0.125	0.829	0.73	-0.196	0.925	0.92	-0.122	0.831	0.96
30-40	-0.060	0.677	0.64	-0.062	0.705	0.73	-0.057	0.726	0.67
40-50	-0.032	0.600	0.46	-0.191	0.878	0.78	0.057	0.516	0.44

All r^2 values were highly significant ($P<0.01$), except for those less than 0.50, which were significant ($P<0.05$).

Using a simple spreadsheet, a daily water balance was calculated for each plot. Rainfall, irrigation, stored soil water, pan evaporation, evapotranspiration and drainage of soil water below 50 cm were determined from transplanting through to harvest. Details of the calculations are available from the authors.

The tensiometer data for the 5 irrigation treatments (Figures 2-6) follow the expected patterns, rising to the Critical Tensiometer Value (T kPa) between irrigation cycles, and falling when water was applied. In many instances tensiometers reached values slightly higher than those set to trigger irrigation. This was because the value would be slightly less than **T** one day, and by the next day would have risen to more than **T**, the extent depending on weather conditions. Nevertheless, the tensiometers installed at 15 cm tended to range between 3 and 5 kPa above **T**. For treatments where irrigations were triggered at 20 or 30 kPa in the shallow tensiometers, there was few changes in readings from the deeper tensiometers. Slight reductions after substantial irrigations indicated drainage past the root zone. In the less well watered treatments (Figures 4-6), there was greater drying out of the soil profile at 45 cm. Note that the deeper tensiometer in the 80 kPa treatment in Block 2 was not operating correctly for most of the experiment.

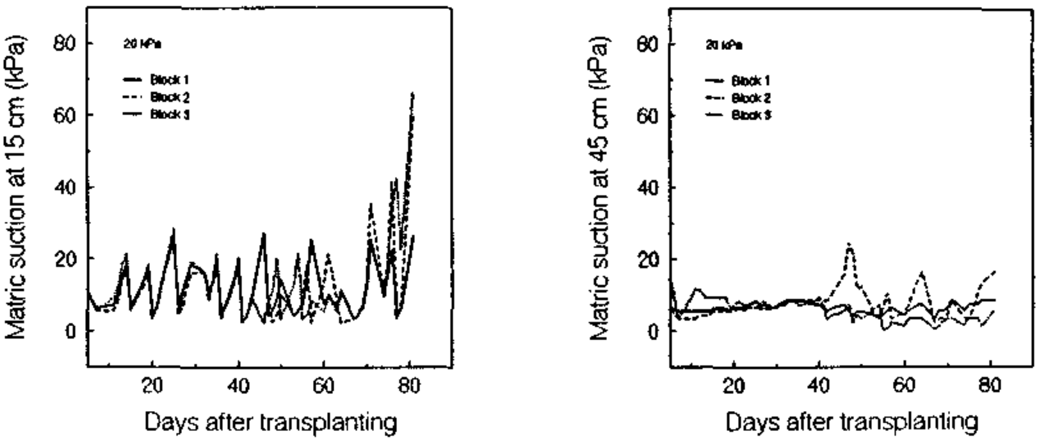


Figure 2. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where broccoli was irrigated when soil matric suction at 15 cm exceeded 20 kPa.

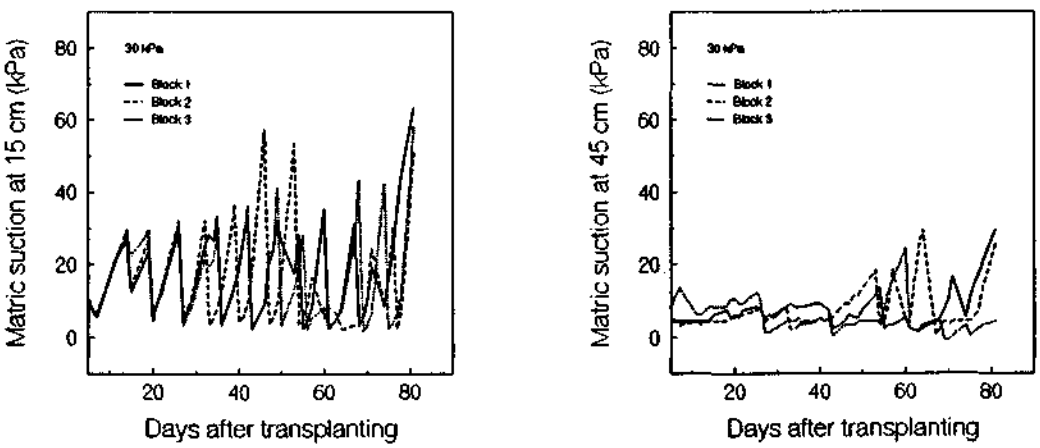


Figure 3. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where broccoli was irrigated when soil matric suction at 15 cm exceeded 30 kPa.

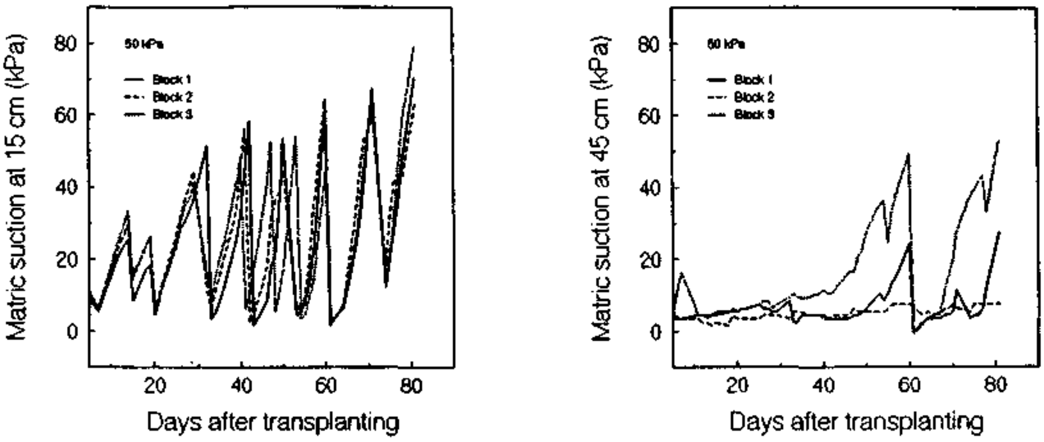


Figure 4. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where broccoli was irrigated when soil matric suction at 15 cm exceeded 50 kPa.

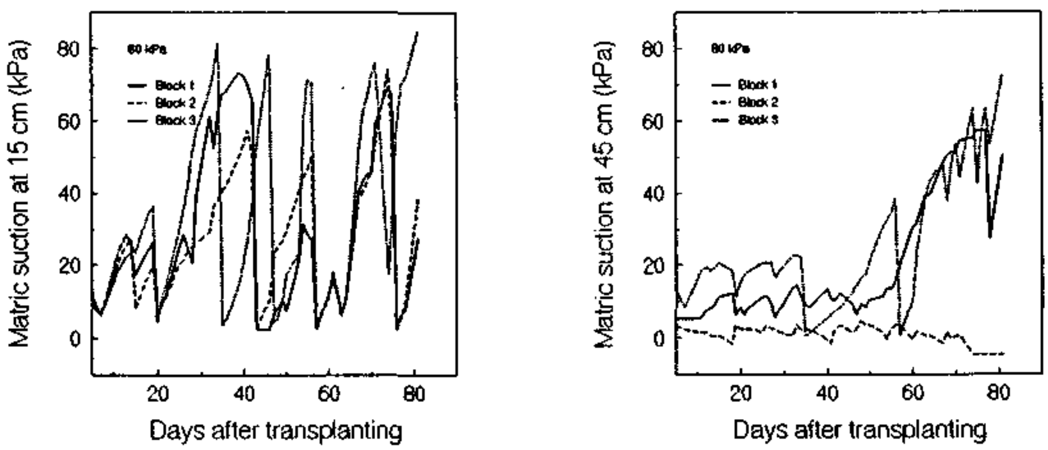


Figure 5. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where broccoli was irrigated when soil matric suction at 15 cm exceeded 80 kPa.

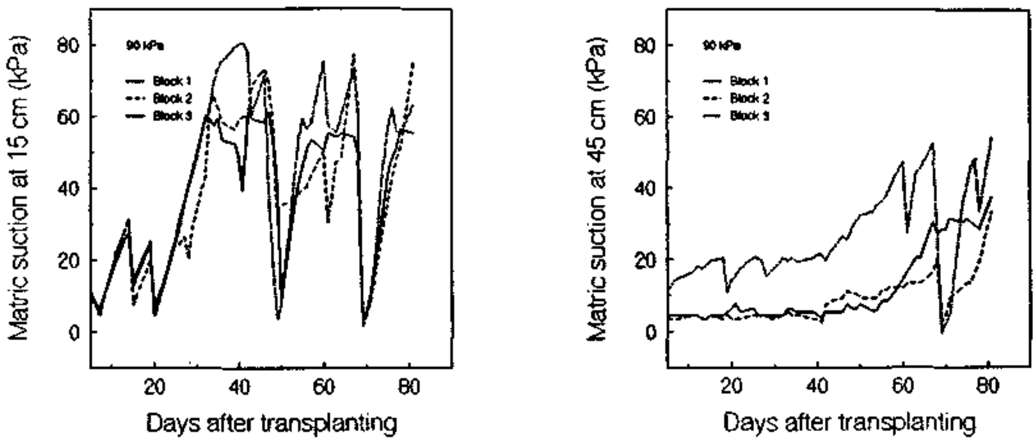


Figure 6. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where broccoli was irrigated when soil matric suction at 15 cm exceeded 90 kPa.

There were significantly ($P<0.01$) fewer irrigations as T was increased (Table 2). The wettest treatment received around 17 irrigations during the growing period, while the driest was irrigated only 7 times. There were less differences in quantities of water applied at each irrigation (Table 3). During the first 30 days after transplanting, most irrigations were around 15 mm, with no drainage losses. For the remainder of the growing period 25-28 mm were applied at each watering. Exceptions were for the 80 and 90 kPa treatments, which received slightly more water per irrigation during the 31-60 day period. Losses due to drainage beyond the root zone were generally around 10% of the water applied for treatments where T was 50, 80 or 90 kPa. For one irrigation of the 80 kPa treatment substantial overwatering resulted in a 30% drainage loss (Table 3). Drainage was more appreciable in the more frequently irrigated treatments, with 20% losses between 31 and 60 days after transplanting, and 30% in the later period.

Table 2

Mean intervals (days) between irrigations for 5 watering regimes in winter grown broccoli.

Irrigation treatment	Growth period (days after transplanting)			Total number of irrigations
	0-30	31-60	61-82	
20 kPa	4.5 a	5.3 a	5.1 a	16.7 e
30 kPa	6.0 a	7.5 ab	5.1 a	13.3 d
50 kPa	6.5 b	11.7 ab	7.3 b	10.3 c
80 kPa	7.5 c	16.7 b	9.8 c	8.7 b
90 kPa	7.5 c	30.0 c	11.0 c	7.0 a

Table 3

Mean irrigation quantities and drainage losses for 5 watering regimes in winter grown broccoli.

Irrigation treatment	Growth period (Days after transplanting)					
	0-30		31-60		61-82	
	Irrig. (mm)	Drain. (mm)	Irrig. (mm)	Drain. (mm)	Irrig. (mm)	Drain. (mm)
20 kPa	14.2 a	0	22.1 a	5.5 ab	26.2 a	10.7 b
30 kPa	15.1 a	0	27.2 ab	5.3 ab	27.6 a	9.7 b
50 kPa	14.4 a	0	25.4 ab	1.9 a	28.0 a	4.0 a
80 kPa	14.8 a	0	38.0 c	9.6 b	25.9 a	2.9 a
90 kPa	15.8 a	0	30.7 bc	0.0 a	27.5 a	2.1 a

A summary of the total growing period water balance for each of the irrigation treatments (Figure 7) shows curvilinear relationships between the Critical Tensiometer Value (T kPa), Irrigation (I mm), Total Evapotranspiration (ET mm) and Total Drainage (D mm), where;

$\mathbf{I} = 412 - 4.34\ \mathbf{T} + 0.0177\ \mathbf{T}^2$ $r^2 = 0.90^{***}$ Equation (2)

$\mathbf{ET} = 248 - 0.346\ \mathbf{T} - 0.00696\ \mathbf{T}^2$ $r^2 = 0.78^{***}$ Equation (3)

$\mathbf{D} = 140 - 3.34\ \mathbf{T} + 0.0215\ \mathbf{T}^2$ $r^2 = 0.84^{***}$ Equation (4)

Although substantial amounts of the extra water applied to the 20 and 30 kPa treatments were lost through increased drainage (Figure 7), there was still a significant trend for greater evapotranspiration in these well-watered areas. Note that differences in the cumulative evapotranspiration between the irrigation treatments did not become noticeable until 30 days after transplanting, when full canopy cover had occurred (Figure 8). This indicates the differences in total evapotranspiration were mainly due to increased transpiration by broccoli on the well watered plots, rather than differences in soil evaporation.

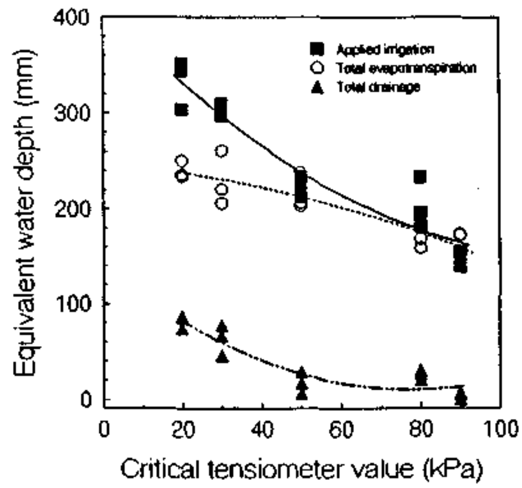


Figure 7. Reductions in quantities of irrigation, total evapotranspiration and drainage losses as the Critical Tensiometer Value was increased.

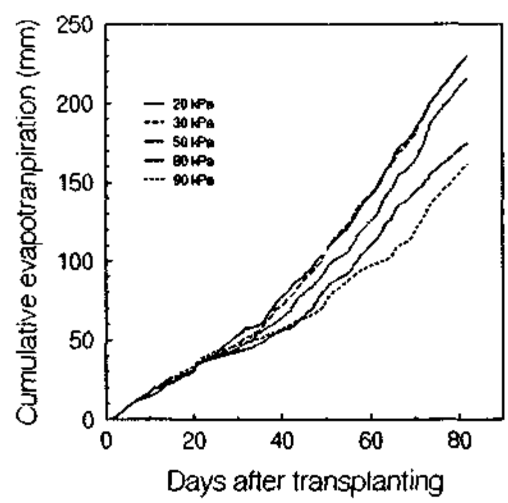


Figure 8. Reductions in cumulative evapotranspiration as the Critical Tensiometer Value was increased.

Differences in the growth of the broccoli plants were not apparent until about 50 days after transplanting, when plants on the less frequently irrigated plots were measurably smaller. The diameter of plants was a more sensitive measure of plant growth than height (Figure 9). Differences in plant size between the irrigation treatments were maintained until the broccoli were harvested. Broccoli plants on plots with **T** greater than 50 kPa were smaller than the well-watered plants.

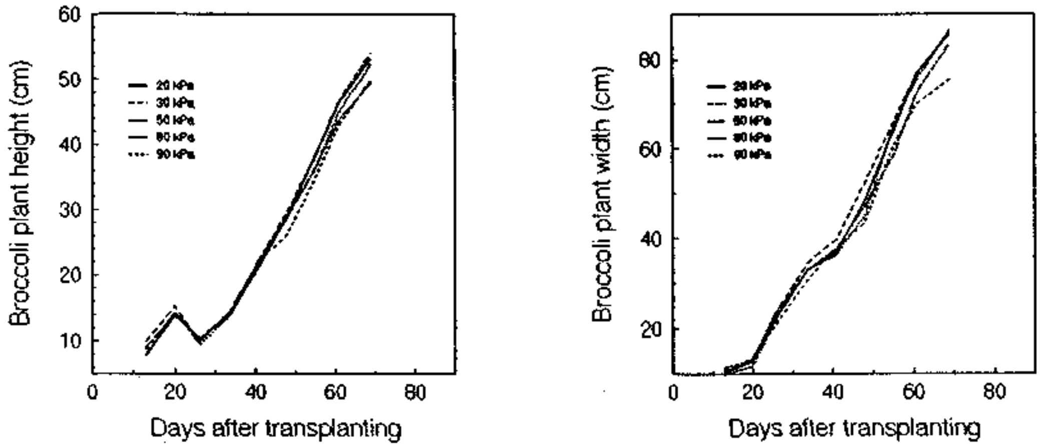
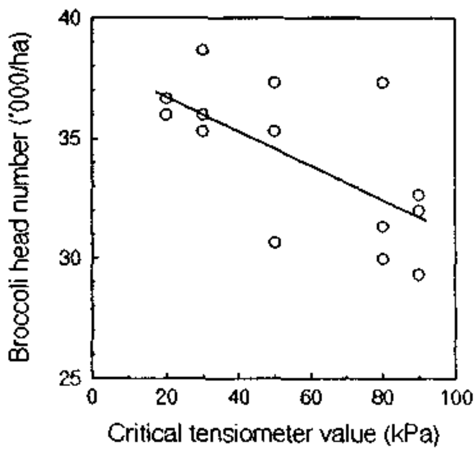


Figure 9. Increasing the Critical Tensiometer Value caused slight reductions in the height and diameter of winter grown broccoli plants.

There were significant linear relationships between the number of broccoli heads harvested (**B** '000/ha) and both **T** or **ET**. The number of harvested heads was consistently greater than 35000/ha where **T** was less than 50 kPa, or **ET** more than 210 mm (Figure 10). There were more substantial declines in overall broccoli yields (**Y** t/ha) as **T** increased or **ET** decreased (Figure 11). This was associated with marked reductions in mean broccoli head weights (**W** g), as shown in Figure 12. Heads harvested from the plots watered where **T** was 50 kPa or higher were substantially poorer quality than heads from more frequently watered plants. Irrigation treatment had no significant effect on the timing of the broccoli harvest, as shown by the proportion of the yields obtained in the first of the 3 cuttings (Figure 13).



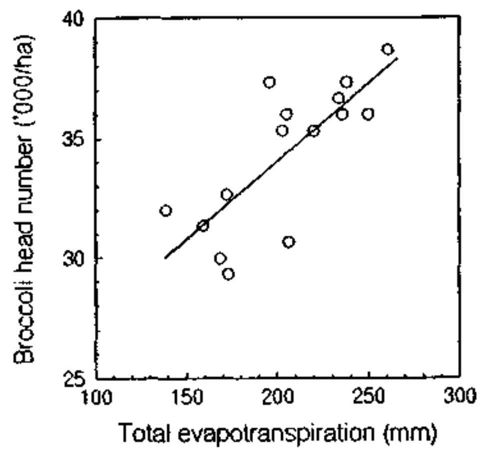


Figure 10. The number of marketable broccoli heads was increased by reducing the Critical Tensiometer Value, or increasing the total evapotranspiration of winter grown broccoli.

$\mathbf{B} = 38.2 - 0.0716\ \mathbf{T}$ $\quad r^2 = 0.45^{**}$ Equation (5)

$\mathbf{B} = 21.1 + 0.0648\ \mathbf{ET}$ $\quad r^2 = 0.60^{***}$ Equation (6)

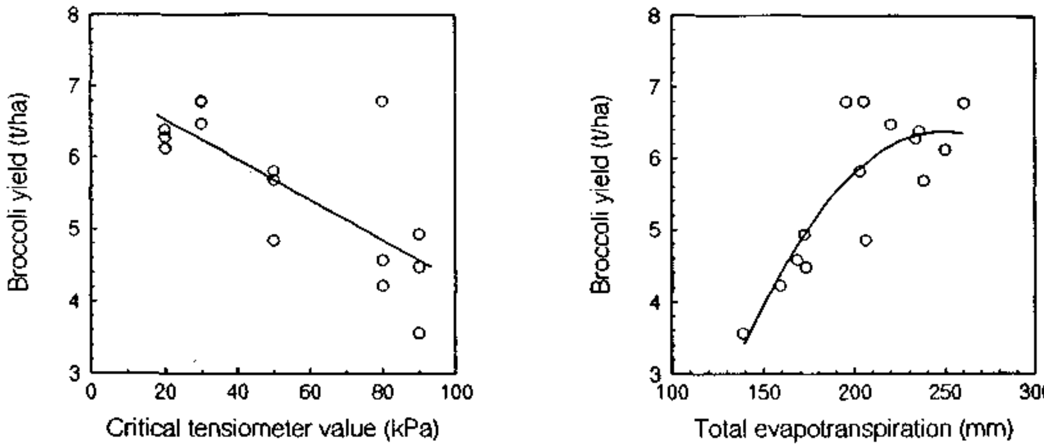


Figure 11. The total yield of marketable broccoli heads was increased by reducing the Critical Tensiometer Value, or increasing the total evapotranspiration of winter grown broccoli.

$$Y = 7.10 - 0.0282\ T \qquad r^2 = 0.56^{***} \qquad \text{Equation (7)}$$

$$Y = -9.14 + 0.125\ ET - 0.000251\ ET^2 \qquad r^2 = 0.73^{***} \qquad \text{Equation (8)}$$

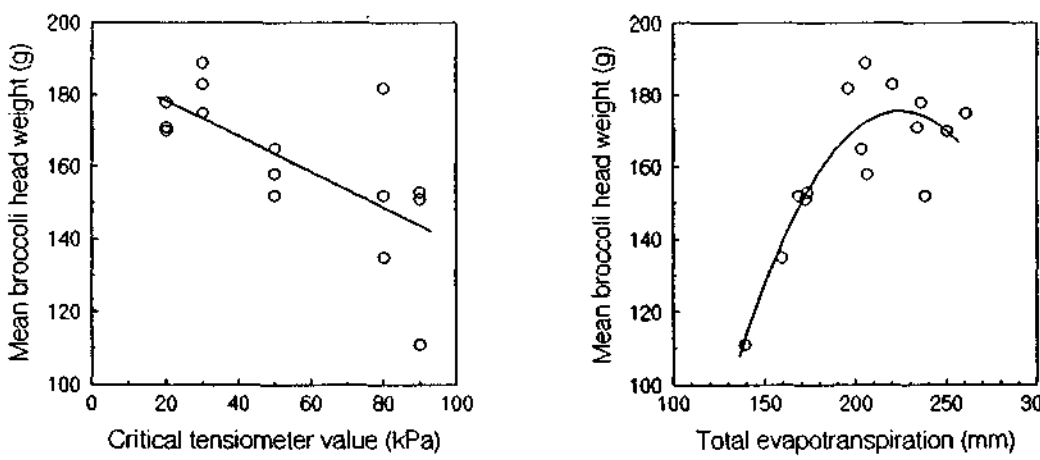


Figure 12. The mean weight of marketable broccoli heads was increased by reducing the Critical Tensiometer Value, or increasing the total evapotranspiration of winter grown broccoli.

$$W = 188 - 0.496\ T \qquad r^2 = 0.47^{**} \qquad \text{Equation (9)}$$

$$W = -260 + 3.89\ ET - 0.00866\ ET^2 \qquad r^2 = 0.76^{***} \qquad \text{Equation (10)}$$

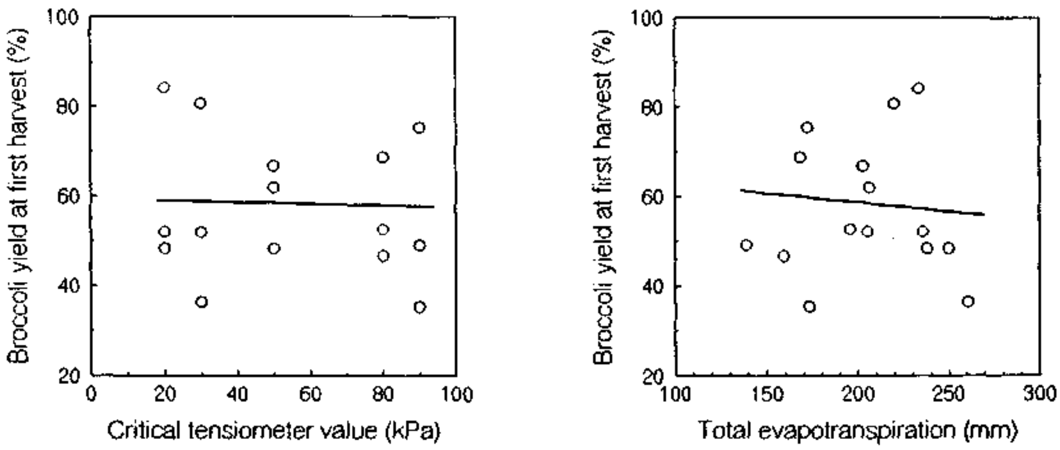


Figure 13. Neither Critical Tensiometer Value nor total evapotranspiration affect the percentage of marketable broccoli heads harvested in the first cut of a 3 cut harvesting period in winter grown broccoli.

5. Discussion and conclusions

The tensiometer system used in this experiment proved useful for scheduling irrigation. It was easy to install and use, gave accurate, reliable readings, required little maintenance and was relatively cheap. The neutron probe needed intensive calibration to give accurate readings in the surface soil, where most evaporation and plant water use occurred. The neutron probe provided useful information for deriving daily water balances, however the intense nature of our monitoring would be neither appropriate nor possible for most farmers or consultants.

One problem with the tensiometer system was determining the correct quantities (as opposed to frequencies) of irrigation to apply to avoid excessive losses through drainage beyond the root zone. Unlike the neutron probe, tensiometers do not give immediate estimates of soil water deficits within the root zone, so the amount of irrigation applied relies to some extent on previous experience with the particular soil type/crop combination. In most instances we would be hoping to lose about 10% of the applied irrigation as drainage, rather than the 20% that occurred in the 30 kPa irrigation treatment.

Although production in this experiment was only moderate, particularly with regard to broccoli head size (maximum 200 g), there was still a clear indication of the irrigation regime for maximising production under the dry winter growing conditions. Optimum yields occurred when the Critical Tensiometer Value (for the shallow tensiometer) was around 30-40 kPa. Using this criteria, irrigation would be applied every 6-7 days for the first 50 days after transplanting, increasing in frequency to every 5 days until harvest. On the black earth soil types, it is probable that around 15 mm would be applied at each irrigation for the first 30 days, increasing to 20-25 mm per irrigation until harvest. Obviously any rainfall during the intervening period would reduce these requirements. Given this sequence, a total of 13 irrigations (around 260 mm) would be needed to obtain optimum broccoli yields and quality while minimising irrigation costs and drainage losses. The target evapotranspiration for the growing season appeared to be around 220-230 mm, although this would obviously depend on cultivar and growing conditions (both weather and agronomic). This Critical Tensiometer Value of around 35 kPa is somewhat lower than overseas values for broccoli (45-60 kPa), emphasising the need for local research.

We intend to conduct further experiments investigating irrigation scheduling techniques and application methods for brassica production.

EXPERIMENT REPORT

1. Report **Final** **Date of Report:** 28-1-92

Initiation Date: 25-1-91 **Completion Date:** 9-09-91

Project Number: S8902

Project Title: Irrigation scheduling in vegetables

Experiment Number: S8902.05 **Officer Responsible:** Craig Henderson

Experiment Title: Irrigation scheduling for winter grown lettuce.

2. Experiment Objectives

This experiment investigated the critical tensiometer values for maximum lettuce production and evaluated crop water use. The efficiency of irrigation was examined by determining the quantities of applied water that drained beyond the root zones during the growing period.

3. Summary of Results

The experiment was conducted at Gatton Research Station, from June-September 1991. Lettuce (cv. *Oxley*) were grown using standard agronomy, with 5 irrigation treatments replicated 3 times in a RCB design. Plots were 4.5 m wide and 10 m long, with a total experimental area of 0.07 ha. The five irrigation treatments involved commencing irrigation at different Critical Tensiometer Values (**T** kPa), using tensiometers installed 15 cm below ground level in each plot. The **T** values were 20, 30, 50, 65 and 80 kPa. Each plot was independently watered using a mini-sprinkler system that gave uniform application across the treatment beds, with no incursion into adjacent plots. While the number and total amounts of irrigation and lettuce water use were reduced by increasing **T**, marketable lettuce heads and mean lettuce head size were unaffected. There was a non significant trend for head size to increase with **T**. A severe outbreak of Lettuce Necrotic Yellows Virus occurred in this experiment, as well as suspected problems with plant spacing and nitrogen nutrition. Notwithstanding the results, we still believe that optimum lettuce yields will be achieved where **T** is held between 20 and 30 kPa for the growing period. Under this watering regime, lettuce would initially be irrigated every 4-5 days (15 mm per irrigation) for the first 30 days after transplanting, reducing in frequency to every 5-6 days (20 mm per irrigation) until harvest. The lettuce would use around 220 mm of water for maximum production, with a further 30 mm drainage. Closer plant spacings may reduce evapotranspiration through less soil evaporation.

EXPERIMENT REPORT

Irrigation scheduling for winter grown lettuce

by C. Henderson and M. Webber
Department of Primary Industries
Gatton Research Station

Experiment No. S8902.05 20.6.91-9.9.91

1. Relevance to Industry

In many regions, including the Lockyer Valley, irrigation demands regularly exceed the reliable capacity of the water supply, resulting in scarcity or reliance on poorer quality water. In many vegetable enterprises irrigation is a significant proportion of overall production costs. Shallow rooted vegetables are substantial users of water; for example brassicas and lettuce require 2-4 ML per hectare per crop. Until recently, the frequency and amount of irrigation was relatively ad hoc, based on tradition and grower experience, combined with superficial observations of plant or soil conditions.

Some vegetable growers use tensiometers or neutron probes to monitor soil water status and schedule irrigations. Both methods have advantages and disadvantages, however tensiometers appear to have the best immediate potential for use in shallow rooted vegetables.

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 overwatering, problems with leaching of nutrients and pesticides into groundwater (and beyond the zone of usefulness) are reduced, as well as a decrease in disease levels.

2. Objectives

This experiment investigated the critical tensiometer values for maximum lettuce production, and evaluated crop water use. The efficiency of irrigation was examined by determining the quantities of applied water that drained beyond the root zones during the growing period.

3. Materials and methods

The experiment was conducted on a black earth soil (*Ug5.15*) at Gatton Research Station (lat 27°33'S, long 152°20'E). The experimental design was a randomised complete block, with 5 irrigation treatments replicated 3 times. Each plot was 3 beds (2 rows of lettuce per 1.5 m bed) wide and 10 m long.

The soil was prepared as per standard practice for lettuce. Lettuce seedlings (cv. *Oxley*) were transplanted on the 20th June 1991, with 0.7 m between the rows and 0.33 m intra-row spacing. A total of 450 kg/ha of compound fertiliser (59 kg N, 10 kg P, 60 kg K, 85 kg S) was applied immediately before planting. One sidedressing of 60 kg/ha N (as urea) was broadcast on 20th August 1991. Molybdenum (0.042 kg/ha as sodium molybdate) and boron (0.031 kg/ha as hydrated sodium octoborate) were sprayed on the 8th July 1991, and again on the 25th July 1991. Calcium nitrate was sprayed at 0.8 kg/ha over the experiment on the 22nd August 1991. One application of chlorthal-dimethyl herbicide (11.25 kg a.c./ha) was sprayed over the area immediately after transplanting and incorporated with 25 mm of irrigation. Insects were controlled with regular applications of insecticides, including fenvalerate, *Bacillis thuringiensis*, methomyl and esfenvalerate.

For the first week after transplanting the whole area was irrigated with standard solid-set pipes and overhead sprinklers. After this first week, systems of mini-sprinklers were installed to individually water each plot. A schematic of the individual plot layout is given in Figure 1. Each plot consisted of 3 beds of lettuce side by side. The central bed was the treatment area, while the two outside beds were buffer zones. Lines of mini-sprinklers was installed down the 2 outer edges of the treatment beds, with 2 m between each sprinkler within a line. The sprinklers in the 2 lines were offset by 1 m, to give a staggered pattern down the bed (Figure 1). Each sprinkler was mounted on a 1 m high stake, and had an output radius of about 2 m and volume of 70 L/hr at 130 kPa operating pressure. Using this system, the irrigation was relatively uniform across the treatment bed, with no drift into neighbouring treatment beds. The application rate was around 20 mm/hr over the treatment beds. An electronic timing system was used to commence irrigation at 2 am on the appropriate days, to avoid windy conditions often prevalent during daylight hours.

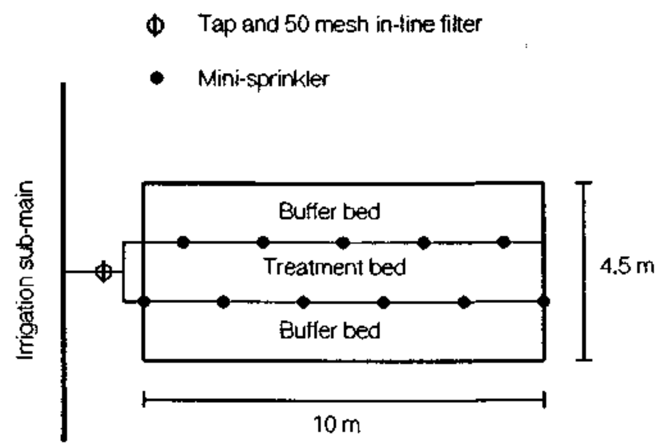


Figure 1. Mini-sprinkler system design for an individual plot in an experiment investigating irrigation scheduling in winter grown lettuce.

Tensiometers were installed 15 cm and 45 cm below ground level in each treatment bed. *Loctronic* tensiometers were used, consisting of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum, while an electronic vacuum gauge attached to the syringe records the vacuum in the tensiometer air gap. Tensiometer readings were recorded daily, usually around 8 am. On the basis of the tensiometer readings, 5 separate irrigation treatments were scheduled:

1. Irrigation when the 15 cm tensiometer had 20 kPa soil water suction.
2. Irrigation when the 15 cm tensiometer had 30 kPa soil water suction.
3. Irrigation when the 15 cm tensiometer had 50 kPa soil water suction.
4. Irrigation when the 15 cm tensiometer had 65 kPa soil water suction.
5. Irrigation when the 15 cm tensiometer had 80 kPa soil water suction.

Each plot was irrigated according to its allocated treatment. Plots with the same irrigation treatment were often watered on different days, due to differences in the time for the tensiometers to reach values necessary to trigger irrigation.

Aluminium neutron probe access tubes were installed to depths of 70 cm in each treatment bed, 5 cm inside a lettuce row and equidistant between 2 neighbouring plants. Neutron moisture meter readings were taken twice a week using a Campbell Pacific Nuclear Hydroprobe. A single reading was taken at 5 depth intervals, commencing 5 cm below the ground surface, incrementing by 10 cm. On each day that the neutron probe measurements were made, 5 standard counts was also conducted in a 200 L drum of water.

After the lettuce were harvested, the neutron probe was calibrated for each of the 5 depth intervals. The lettuce plants were grown for 2 weeks after harvesting, to partially dry the soil profile. Concurrent gravimetric soil water samples and probe measurements were taken at the appropriate depths. The area was then irrigated to saturation, and resampled the following day. In both instances, samples were taken from each treatment bed, with one gravimetric profile and neutron probe profile per bed. Volumetric soil water content vs neutron probe count (expressed as a fraction of the standard count) calibrations were determined for each depth interval, for each of the three experimental blocks. The calibration equations were developed by pooling the data from the 5 plots that made up an experimental block, to give 10 data points per calibration.

Weather data, including rainfall, Class A Pan evaporation, maximum and minimum temperatures were recorded daily. The equivalent depths of water applied at each irrigation were measured using rain gauges in each of the experimental plots. The water meter at the irrigation pump was calibrated with the rain gauges, as a further check on the amounts of water applied.

The heights and widths of the lettuce plants were measured at weekly intervals, from transplanting until maturity. Five plants were randomly selected and assessed in each plot. Lettuce were harvested from the treatment beds on the 9th September 1991. For each plot the number of marketable heads were counted, and 2 samples containing 12 lettuce were weighed.

4. Results

Rainfall during the growing period was only 16.7 mm, including a single fall of 11.3 mm. This meant that virtually the total water requirement of the crop was met by irrigation and stored soil water at transplanting.

The calibration equations for the neutron probe took the following form;

$$\mathbf{V} = a + b * \mathbf{FC} \qquad \text{Equation (1)}$$

where $\mathbf{V}$ = volumetric water content (cm^3cm^{-3})
$\mathbf{FC}$ = fractional neutron count (reading in soil divided by standard count in water)
a and b are equation parameters

The parameter values and r^2 for the calibration equations for each of the blocks and depth intervals are given in Table 1.

Table 1

Parameters and goodness of fit for calibration equations relating volumetric soil water content to neutron probe readings.

Depth interval cm	Block 1			Block 2			Block 3		
	a	b	r^2	a	b	r^2	a	b	r^2
0-10	0.062	1.199	0.94	0.024	1.147	0.91	0.078	0.964	0.93
10-20	0.087	0.520	0.82	0.076	0.504	0.90	0.086	0.503	0.88
20-30	-0.125	0.829	0.73	-0.196	0.925	0.92	-0.122	0.831	0.96
30-40	-0.060	0.677	0.64	-0.062	0.705	0.73	-0.057	0.726	0.67
40-50	-0.032	0.600	0.46	-0.191	0.878	0.78	0.057	0.516	0.44

All r^2 values were highly significant ($P<0.01$), except for those less than 0.50, which were significant ($P<0.05$).

Using a simple spreadsheet, a daily water balance was calculated for each plot. Rainfall, irrigation, stored soil water, pan evaporation, evapotranspiration and drainage of soil water below 50 cm were determined from transplanting through to harvest. Details of the calculations are available from the authors.

The tensiometer data for the 5 irrigation treatments (Figures 2-6) follow the expected patterns, rising to the Critical Tensiometer Value (**T** kPa) between irrigation cycles and falling when water was applied. In many instances tensiometers reached values slightly higher than those set to trigger irrigation. This was because the value would be slightly less than **T** one day, and by the next day would have risen to more than **T**, the extent depending on weather conditions. Nevertheless, the tensiometers installed at 15 cm tended to range between 3 and 5 kPa above **T**.

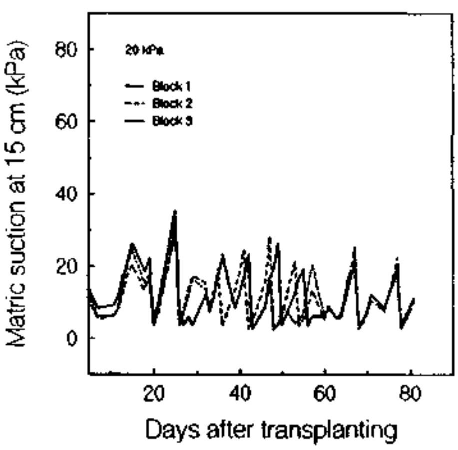
Where **T** was set at 20 kPa, the surface dried to a matric suction around 30 kPa during the first 15-30 days after transplanting, indicating irrigation frequency was insufficient to maintain the correct treatment regime (Figure 2). The deeper tensiometer in Block 1 also demonstrated drier conditions 45 cm below the ground surface, until an irrigation about 28 days after transplanting wet the profile to sufficient depth.

The treatment where irrigation commenced at a shallow tensiometer reading of 30 kPa was more correctly adhered to, although the soil was allowed to dry excessively around

70 days after transplanting, probably due to unexpectedly high evaporative demand. Note that the deeper tensiometers, while giving consistently low matric suction values for most of the period, also suggested substantial drying of the deeper soil profile from 60-75 days after transplanting (Figure 3).

In the 50 kPa treatment, the surface tensiometers followed the expected patterns, while the deeper tensiometers indicated substantial water extraction from the lower parts of the soil profile, commencing about 40 days after transplanting. Note that one of the deep tensiometers in this treatment ceased to function 48 days after transplanting (Figure 4).

Where **T** was 65 or 80 kPa, the shallow tensiometers were consistently high, except immediately after irrigations. The tensiometers installed 45 cm below the surface also showed substantial drying of the soil profile at that depth, commencing around 30 days after transplanting (Figures 5-6).



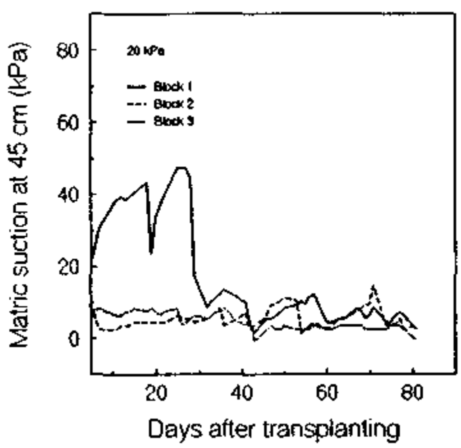


Figure 2. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where lettuce was irrigated when soil matric suction at 15 cm exceeded 20 kPa.

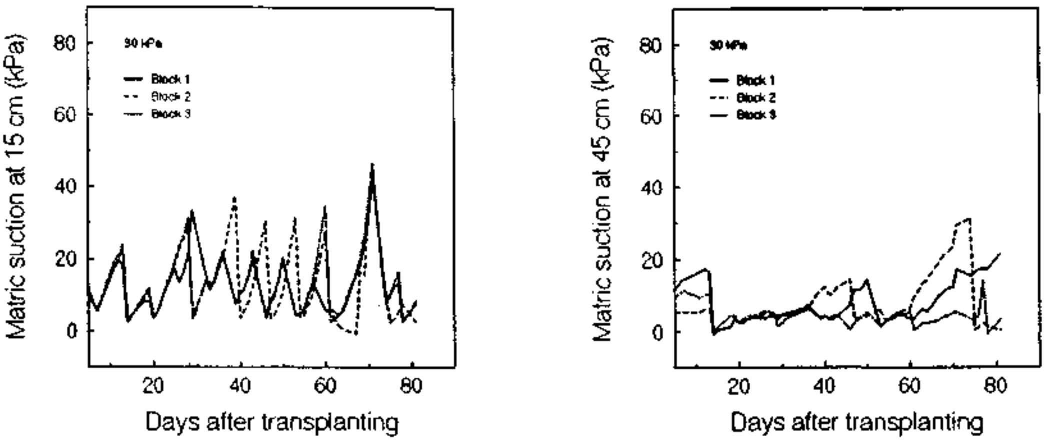


Figure 3. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where lettuce was irrigated when soil matric suction at 15 cm exceeded 30 kPa.

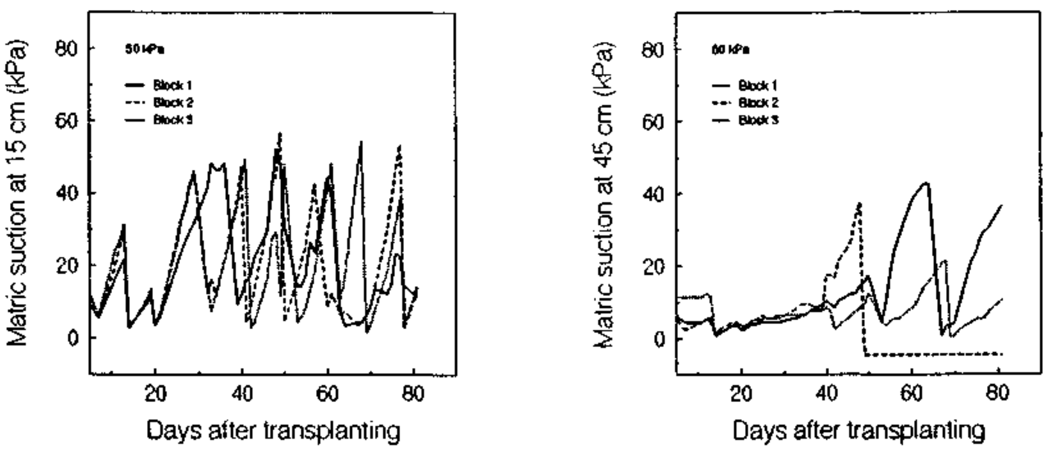


Figure 4. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where lettuce was irrigated when soil matric suction at 15 cm exceeded 50 kPa.

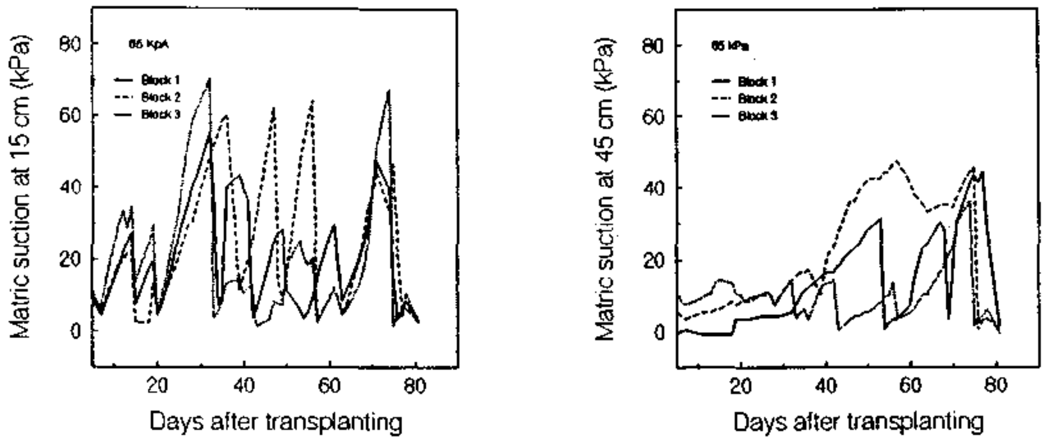


Figure 5. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where lettuce was irrigated when soil matric suction at 15 cm exceeded 65 kPa.

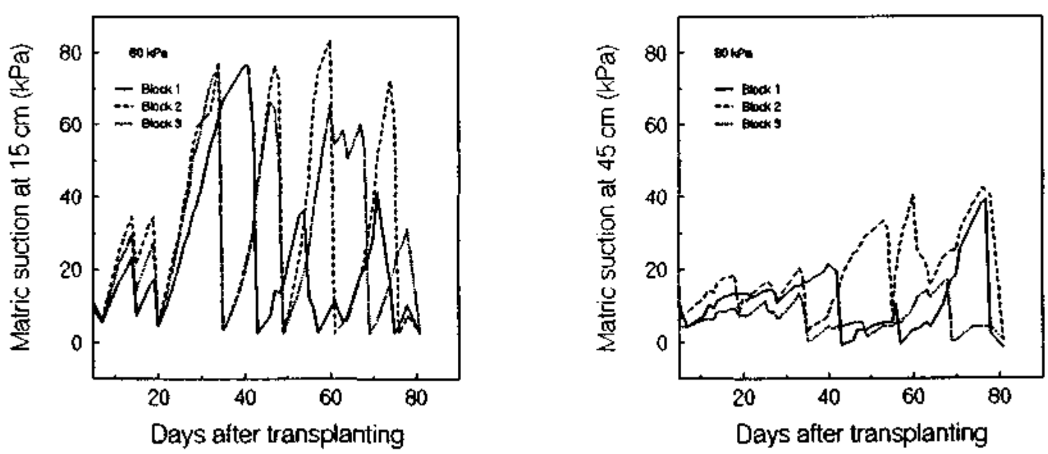


Figure 6. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where lettuce was irrigated when soil matric suction at 15 cm exceeded 80 kPa.

There were significantly ($P<0.01$) fewer irrigations as T was increased (Table 2). The wettest treatment received around 16 irrigations during the growing period, while the driest were irrigated 9 times. There were smaller differences in quantities of water applied at each irrigation (Table 3). During the first 30 days after transplanting, most irrigations were 15-20 mm, with no appreciable drainage losses. For the next 30 day interval 23-28 mm were applied at each watering, except in the 80 kPa treatment, where irrigations were about 35 mm at a time. Drainage losses were 22% where T was 20 or 80 kPa, and 14% for the other treatments. During the 20 days before harvesting 20-25 mm were applied at each irrigation, with greater losses due to drainage in the 20 and 30 kPa treatments, compared to the less frequently irrigated areas.

Table 2

Mean intervals (days) between irrigations for 5 watering regimes in winter grown lettuce.

Irrigation treatment	Growth period (days after transplanting)			Total number of irrigations
	0-30	31-60	61-81	
20 kPa	4.1 a	6.0 a	5.2 a	16.3 d
30 kPa	6.0 b	9.2 ab	5.8 a	12.0 c
50 kPa	6.5 b	13.3 c	6.4 a	10.3 b
65 kPa	7.5 c	11.7 bc	7.0 a	9.7 ab
80 kPa	7.5 c	15.0 c	6.4 a	9.3 a

Table 3

Mean irrigation quantities and drainage losses for 5 watering regimes in winter grown lettuce.

Irrigation treatment	Growth period (Days after transplanting)					
	0-30		31-60		61-81	
	Irrig. (mm)	Drain. (mm)	Irrig. (mm)	Drain. (mm)	Irrig. (mm)	Drain. (mm)
20 kPa	15.4 a	0.0 a	23.2 a	5.0 a	25.0 c	10.3 c
30 kPa	20.7 b	0.8 a	23.8 a	3.1 a	23.3 bc	7.4 bc
50 kPa	21.3 b	2.1 a	22.7 a	1.7 a	21.5 ab	4.0 ab
65 kPa	17.1 a	0.0 a	28.2 a	2.8 a	19.5 a	1.6 a
80 kPa	17.2 a	0.0 a	35.0 b	8.1 a	22.3 bc	3.3 ab

A summary of the total growing period water balance for each of the irrigation treatments (Figure 7) shows curvilinear relationships between the Critical Tensiometer Value (T kPa), Irrigation (I mm), Total Evapotranspiration (ET mm) and Total Drainage (D mm), where;

$\mathbf{I} = 454 - 7.67\ \mathbf{T} + 0.0584\ \mathbf{T}^2$ $r^2 = 0.90^{***}$ Equation (2)

$\mathbf{ET} = 256 - 2.33\ \mathbf{T} + 0.0117\ \mathbf{T}^2$ $r^2 = 0.80^{***}$ Equation (3)

$\mathbf{D} = 121 - 3.35\ \mathbf{T} + 0.0271\ \mathbf{T}^2$ $r^2 = 0.64^{**}$ Equation (4)

Although substantial proportions of the extra water applied to the 20 and 30 kPa treatments were lost through increased drainage (Figure 7), there was still a significant trend for greater evapotranspiration in these well-watered areas. Differences in cumulative evapotranspiration between the irrigation treatments became apparent as early as 15 days after transplanting, with most divergence occurring after 25 days (Figure 8). The lettuce did not achieve full canopy cover within the row until about 50 days after transplanting. At the same time, because of the 0.7 m inter-row spacing, there was still 35-40 cm of bare soil between the rows. It is likely that soil evaporation contributed to a substantial fraction of total evapotranspiration, particularly in more frequently irrigated treatments, where the soil surface was wet for longer periods.

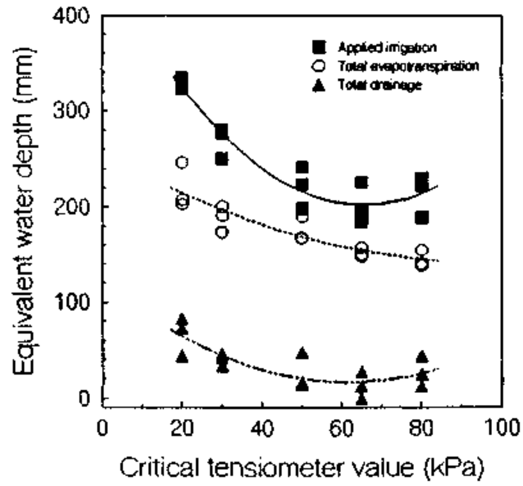


Figure 7. Changes in quantities of irrigation, total evapotranspiration and drainage losses as the Critical Tensiometer Value increased.

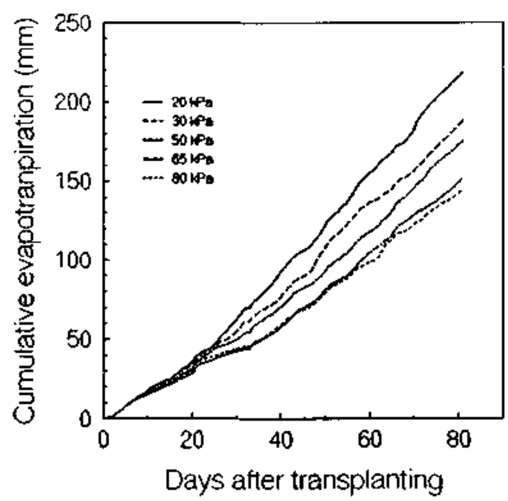


Figure 8. Reductions in cumulative evapotranspiration as the Critical Tensiometer Value increased.

Differences in the growth of the lettuce plants were not apparent until 40-45 days after transplanting, when plants on the more frequently irrigated plots were measurably smaller. The diameter of plants was a more sensitive and consistent measure of plant growth than was height (Figure 9). Differences in plant width between the irrigation treatments were maintained until the lettuce were harvested. Lettuce plants on plots with **T** less than 50 kPa were smaller than the plants that were watered less frequently.

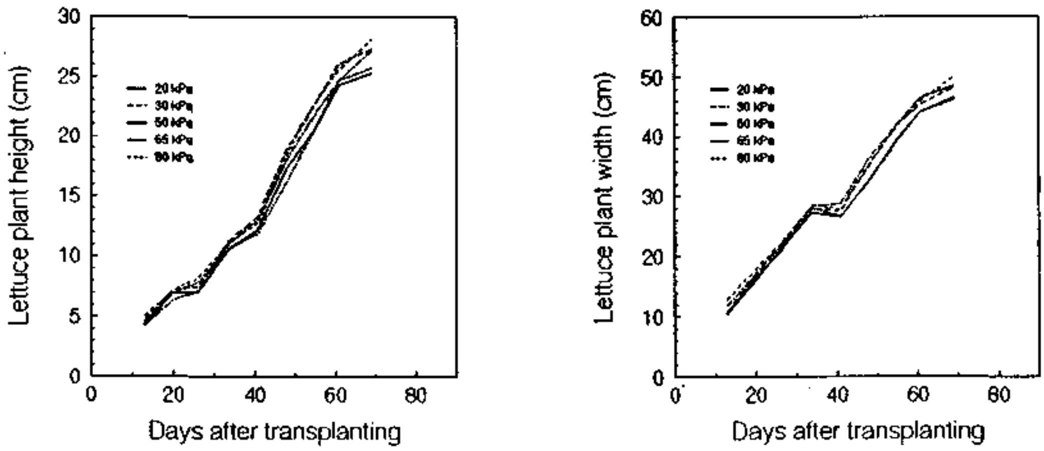


Figure 9. Increasing the Critical Tensiometer Value slightly increased the height and diameter of winter grown lettuce plants.

There was a severe incidence of Lettuce Necrotic Yellows Virus in this experiment, with around 35% of lettuce sufficiently affected as to be considered unmarketable. There did not appear to be any relationship between the incidence of this disease and the irrigation treatments. There were no significant relationships between the number of lettuce heads harvested (**L** '000/ha) and either **T** or **ET**. There was a trend for greater variation in head number under the drier irrigation regimes (Figure 10). There was also considerable variation in mean head size in this experiment, with non-significant trends for head weight (**W**) to increase as **T** increased or **ET** declined (Figure 11). As a consequence, overall lettuce yields were also very variable, with no significant relationships between yields (**Y**) and either **T** or **ET** (Figure 12).

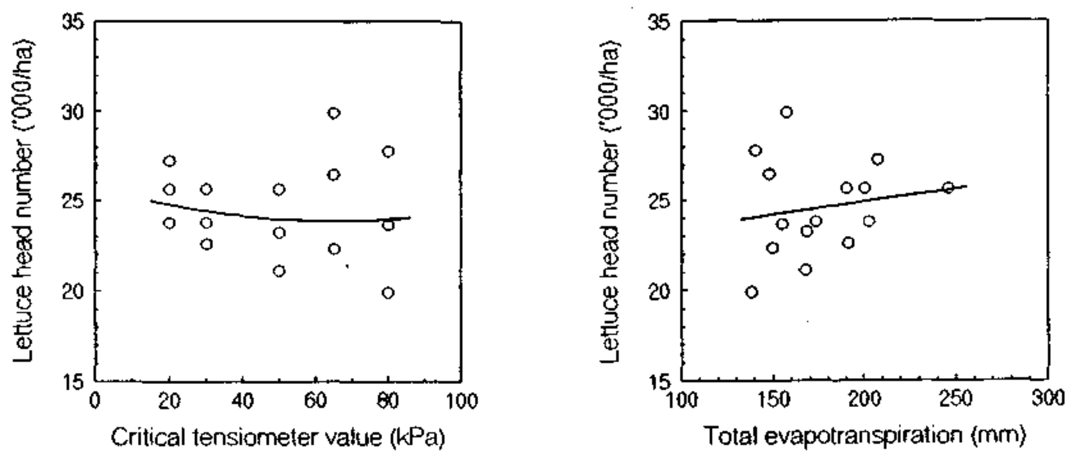


Figure 10. The number of marketable lettuce heads was not affected by altering either the Critical Tensiometer Value or the total evapotranspiration of winter grown lettuce.

$\mathbf{L} = 25.8 - 0.0578\ \mathbf{T} + 0.000437\ \mathbf{T}^2$ $\quad r^2 = 0.04^{ns}$ $\quad$ Equation (5)

$\mathbf{L} = 22.1 + 0.0142\ \mathbf{ET}$ $\quad r^2 = 0.03^{ns}$ $\quad$ Equation (6)

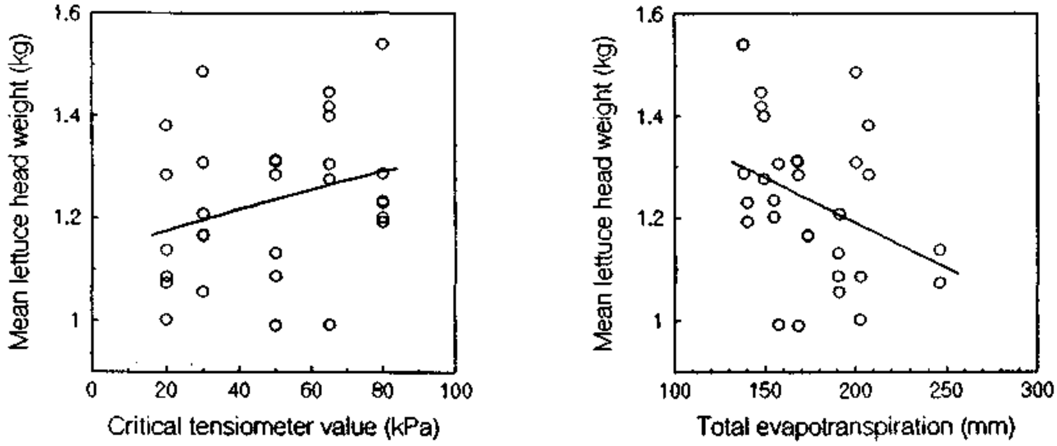


Figure 11. The mean weight of marketable lettuce heads was slightly reduced by reducing the Critical Tensiometer Value, or increasing the total evapotranspiration of winter grown lettuce.

$\mathbf{W = 1.13 + 0.00228\ T}$ $\quad r^2 = 0.09^{ns}$ $\quad$ Equation (7)

$\mathbf{W = 1.54 - 0.00176\ ET}$ $\quad r^2 = 0.76^{***}$ $\quad$ Equation (8)

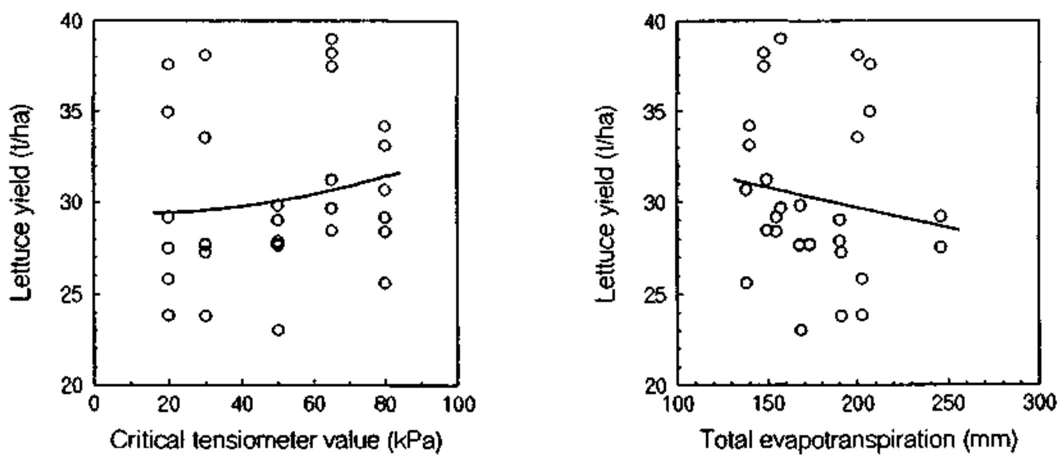


Figure 12. The total yield of marketable lettuce heads was not affected by altering either the Critical Tensiometer Value or the total evapotranspiration of winter grown lettuce.

$\mathbf{Y = 29.4 - 0.00674\ T + 0.000395\ T^2}$ $\quad r^2 = 0.03^{ns}$ $\quad$ Equation (9)

$\mathbf{Y = 34.1 - 0.0220\ ET}$ $\quad r^2 = 0.02^{ns}$ $\quad$ Equation (10)

5. Discussion and conclusions

The tensiometer system used in this experiment proved useful for scheduling irrigation. It was easy to install and use, gave accurate, reliable readings, required little maintenance and was relatively cheap. The neutron probe needed intensive calibration to give accurate readings in the surface soil, where most evaporation and plant water use occurred. The neutron probe provided useful information for deriving daily water balances, however the intense nature of our monitoring would be neither appropriate nor possible for most farmers or consultants.

One problem with the tensiometer system was determining the correct quantities (as opposed to frequencies) of irrigation to apply to avoid excessive losses through drainage beyond the root zone. Unlike the neutron probe, tensiometers do not give immediate estimates of soil water deficits within the root zone, so the amount of irrigation applied relies to some extent on previous experience with the particular soil type/crop combination. In most instances we would be hoping to lose about 10% of the applied irrigation as drainage, rather than 20% as occurred in the 20 kPa irrigation treatment.

There were obvious production problems in this experiment, that may have substantially affected the outcome. In hindsight, selection of *Oxley* for this experiment probably exacerbated the severity of the disease outbreak, as it appears to be more susceptible to Lettuce Necrotic Yellows than most cultivars. Apart from disease, the other agronomic factor impinging on the results may well have been nitrogen deficiency, particularly in the well watered treatments. Only 60 kg of N was applied prior to transplanting, with a sidedressing of another 60 kg 8 weeks later. The well watered treatments may have suffered from leaching of N below the active root zone during the initial 8 week period prior to the second fertiliser application.

The inter-row spacing for lettuce at Gatton Research Station is much wider than in commercial grower operations, mainly due to machinery limitations. As a consequence, full canopy cover is never achieved, which results in less efficient use of irrigation water, due to a greater proportion of soil evaporation compared to transpiration. This is exacerbated with increased frequency of irrigation, where the surface soil remains wetter for longer periods.

Given the above problems, we would be reluctant to derive specific Critical Tensiometer Values for lettuce from this experiment. From other research, and some grower experience, we would be looking at a T value of 20-30 kPa as optimum for lettuce. Under this criteria, irrigation would be applied every 4-5 days for the first 30 days after transplanting, reducing in frequency to every 5-6 days until harvest (due to the deeper rooting of the older lettuce plants). On the black earth soil types, it is probable that around 15 mm would be applied at each irrigation for the first 30 days, increasing to 20 mm per irrigation until harvest. Obviously any rainfall during the intervening period would reduce these requirements. Given this sequence, a total of 13-15 irrigations (around 250 mm) would be needed to obtain optimum lettuce yields and quality while minimising irrigation costs and drainage losses. The target evapotranspiration for the growing season appeared to be around 220 mm, although this would obviously depend on cultivar and growing conditions (both weather and agronomic). There is probably scope for reducing this requirement with closer plantings. A Critical Tensiometer Value of around 25 kPa is somewhat lower than overseas values for lettuce (40-60 kPa), emphasising the need for local research.

We intend to conduct further experiments investigating irrigation scheduling techniques and application methods for lettuce production. In these experiments we will be attempting closer plantings, and monitoring cultivar selection and nutrition more closely, in order to confirm our hypotheses from the experiment reported on here.

EXPERIMENT REPORT

1. Report **Final** **Date of Report:** 17-6-92

Initiation Date: 10-7-91 **Completion Date:** 14-11-91

Project Number: S8902

Project Title: Irrigation scheduling in vegetables

Experiment Number: S8902.06 **Officer Responsible:** Craig Henderson

Experiment Title: Irrigation scheduling for spring grown green beans.

2. Experiment Objectives

This experiment sought to determine the relationship between bean yield, tensiometer values and heat dissipation probe readings (from the CAMNET WATER MANAGEMENT SYSTEM). It also attempted to determine the efficiency of irrigation by quantifying the amounts of applied water draining beyond the root zone during the growing period.

3. Summary of Results

The experiment was conducted at Gatton Research Station, from October-November 1991. Green beans (cv. *Superstar*) were grown using standard agronomy, with 5 irrigation treatments replicated 3 times in a RCB design. Plots were 5.3 m wide and 10 m long, with a total experimental area of 0.075 ha. The five irrigation treatments involved commencing irrigation at different Critical Tensiometer Values (**T** kPa), using tensiometers installed 15 cm below ground level in each plot. The **T** values were 20, 35, 50, 70 and 90 kPa. Each plot was independently watered using a mini-sprinkler system that gave uniform application across the treatment beds, with no incursion into adjacent plots. An electronic water content monitoring system was also installed in selected plots, to compare its efficacy with tensiometer and neutron probe based systems.

There was a massive incidence of *Sclerotinia rolfsii* in the experimental area. The treatment beds were re-sown by hand 2 weeks after the initial sowing, however these were also affected by the disease. The experiment was abandoned in mid-November. The CAMNET soil water monitoring system operated relatively reliably, however there were some initial problems with data manipulation and probe calibration. The CAMNET probes did not respond to several irrigations, particularly when compared with the tensiometers installed in the same locations. This may have been due to slight differences in depths of installation, however it may also have been caused by restricted water flow into the probe body. We have programmed further experiments investigating irrigation scheduling techniques and application methods for green bean production, including the tensiometer and CAMNET scheduling systems, as well as sprinkler, trickle and subsurface irrigation systems.

EXPERIMENT REPORT

Irrigation scheduling for spring grown green beans

by C. Henderson and M. Webber
Department of Primary Industries
Gatton Research Station

Experiment No. S8902.06   10.10.91-14.11.91

1. Relevance to Industry

In many regions, including the Lockyer Valley, irrigation demands regularly exceed the reliable capacity of the water supply, resulting in scarcity or reliance on poorer quality water. In many vegetable enterprises irrigation is a significant proportion of overall production costs. Green beans generally require around 3 ML of irrigation per crop. Until recently, the frequency and amount of irrigation was relatively ad hoc, based on tradition and grower experience, combined with superficial observations of plant or soil conditions.

Some vegetable growers use tensiometers or neutron probes to monitor soil water status and schedule irrigations. Both methods have advantages and disadvantages, however tensiometers appear to have the best immediate potential for use in shallow rooted vegetables. Beans have deeper root systems than many other vegetables, however most water uptake still occurs in the upper 0.5 m of the soil profile. There are a number of new irrigation scheduling systems currently being developed, involving electronic capture, recording and display of soil water status on a virtually continuos basis.

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 overwatering, problems with leaching of nutrients and pesticides into groundwater (and beyond the zone of usefulness) are reduced, as well as a decrease in disease levels.

2. Objectives

This experiment sought to determine the relationship between bean yield, tensiometer values and heat dissipation probe readings (from the CAMNET WATER MANAGEMENT SYSTEM). It also attempted to determine the efficiency of irrigation by quantifying the amounts of applied water draining beyond the root zone during the growing period.

3. Materials and methods

The experiment was conducted on a black earth soil (*Ug5.15*) at Gatton Research Station (lat 27°33'S, long 152°20'E). The experimental design was a randomised complete block, with 5 irrigation treatments replicated 3 times. Each plot was 3 beds (2 rows of green beans per 1.7 m bed) wide and 10 m long.

The soil was prepared as per standard practice for green beans. Beans (cv. *Superstar*) were sown on the 10th October 1991, with 0.85 m between the rows and 0.05 m intra-row spacing. A total of 60 kg/ha of N as urea was broadcast immediately after planting. Initial weed control was achieved by spraying metolachlor at 2.2 kg/ha of active constituent over the experimental area immediately after planting. The herbicide and fertiliser were incorporated with 36 mm of irrigation.

Unfortunately there was a severe infection of *Sclerotium rolfsii* in the experimental area, which killed more than 80% of the emerging bean seed. The middle bed of each plot was re-sown by hand on the 22nd October 1991. A fungicide, tebuconazole, was applied as a soil drench at 0.25 kg/ha active constituent on the 22nd and 29th October 1991, to try and improve bean establishment.

For the first week after planting the whole area was irrigated with standard solid-set pipes and overhead sprinklers. After this first week, systems of mini-sprinklers were installed to individually water each plot. A schematic of the individual plot layout is given in Figure 1. Each plot consisted of 3 beds of green beans side by side. The central bed was the treatment area, while the two outside beds were buffer zones. Lines of mini-sprinklers was installed down the 2 outer edges of the treatment beds, with 2 m between each sprinkler within a line. The sprinklers in the 2 lines were offset by 1 m, to give a staggered pattern down the bed (Figure 1). Each sprinkler was mounted on a 1 m high stake, and had an output radius of about 2 m and volume of 70 L/hr at 130 kPa operating pressure. Using this system, the irrigation was relatively uniform across the treatment bed, with no drift into neighbouring treatment beds. The application rate was around 20 mm/hr over the treatment beds. An electronic timing system was used to commence irrigation at 2 am on the appropriate days, to avoid windy conditions often prevalent during daylight hours.

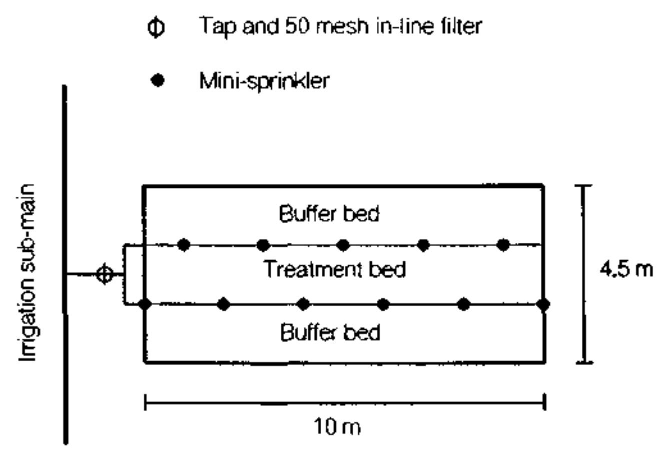


Figure 1. Mini-sprinkler system design for an individual plot in an experiment investigating irrigation scheduling in spring grown green beans.

Tensiometers were installed 15 cm and 45 cm below ground level in each treatment bed. *Loctronic* tensiometers were used, consisting of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum, while an electronic vacuum gauge attached to the syringe records the vacuum in the tensiometer air gap. Tensiometer readings were recorded daily, usually around 8 am. On the basis of the tensiometer readings, 5 separate irrigation treatments were scheduled:

1. Irrigation when the 15 cm tensiometer had 20 kPa soil water suction.
2. Irrigation when the 15 cm tensiometer had 35 kPa soil water suction.
3. Irrigation when the 15 cm tensiometer had 50 kPa soil water suction.
4. Irrigation when the 15 cm tensiometer had 70 kPa soil water suction.
5. Irrigation when the 15 cm tensiometer had 90 kPa soil water suction.

Each plot was irrigated according to its allocated treatment. Plots with the same irrigation treatment were occasionally watered on different days, due to differences in the time for the tensiometers to reach values necessary to trigger irrigation.

Aluminium neutron probe access tubes were installed to depths of 70 cm in each treatment bed, 5 cm inside a bean row and equidistant between 2 neighbouring plants. Neutron moisture meter readings were taken twice a week using a Campbell Pacific Nuclear Hydroprobe. A single reading was taken at 5 depth intervals, commencing 5 cm below the ground surface, incrementing by 10 cm. On each day that the neutron probe measurements were made, 5 standard counts was also conducted in a 200 L drum of water. Calibration equations for the neutron probe data were assumed to be the same as for other experiments at this site.

Weather data, including rainfall, Class A Pan evaporation, maximum and minimum temperatures were recorded daily. The equivalent depths of water applied at each irrigation were measured using rain gauges in each of the experimental plots. The water meter at the irrigation pump was calibrated with the rain gauges, as a further check on the amounts of water applied, particularly when the bushes overgrew the rain gauges.

Heat dissipation probes were installed in 2 replicates of treatments 2, 3 and 5, and 1 replicate of treatment 1, in equivalent positions to the 15 cm deep tensiometers. The probes were connected to the CAMNET system, which recorded soil moisture status and soil temperature for each of the probes on an hourly basis.

Even after re-planting, the disease problems in this experiment proved insurmountable. The experiment was abandoned on 14th November 1991.

4. Results

Rainfall during the growing period totalled 53.6 mm. Major events included 8 mm 1 day after planting (DAP), 10 mm 8 DAP and 35 mm around 22-25 DAP. The subsoil was relatively dry at planting time.

The calibration equations for the neutron probe took the following form;

$$V = a + b * FC \qquad \text{Equation (1)}$$

where
- V = volumetric water content (cm^3cm^{-3})
- FC = fractional neutron count (reading in soil divided by standard count in water)
- a and b are equation parameters

The parameter values and r^2 for the calibration equations for each of the blocks and depth intervals are given in Table 1.

Table 1

Parameters and goodness of fit for calibration equations relating volumetric soil water content to neutron probe readings.

Depth interval cm	Block 1			Block 2			Block 3		
	a	b	r^2	a	b	r^2	a	b	r^2
0-10	0.062	1.199	0.94	0.024	1.147	0.91	0.078	0.964	0.93
10-20	0.087	0.520	0.82	0.076	0.504	0.90	0.086	0.503	0.88
20-30	-0.125	0.829	0.73	-0.196	0.925	0.92	-0.122	0.831	0.96
30-40	-0.060	0.677	0.64	-0.062	0.705	0.73	-0.057	0.726	0.67
40-50	-0.032	0.600	0.46	-0.191	0.878	0.78	0.057	0.516	0.44

All r^2 values were highly significant ($P<0.01$), except for those less than 0.50, which were significant ($P<0.05$).

Using a simple spreadsheet, a daily water balance was calculated for each plot. Rainfall, irrigation, stored soil water, pan evaporation, evapotranspiration and drainage of soil water below 50 cm were determined from planting through to the conclusion of the experiment. Details of the calculations are available from the authors.

In all plots there were reductions in matric suctions at 15 cm soil depth 7-8 DAP and 14 DAP, due to rainfall and irrigation on those occasions (Figs. 2,4,6,8,9). On the latter date, application of 23 mm of irrigation, followed by 26 mm of rainfall resulted in substantial drainage losses from the soil profile (about 36 mm), indicated by the large drop in soil matric suction at 45 cm below ground level.

In the treatments scheduled for irrigation when the tensiometers reached 20 or 35 kPa, application of 23 mm of water at 22 DAP reduced matric suction in the shallow tensiometers, however there was no water drainage below 45 cm (shown by the lack of change in the deeper tensiometers Figs. 2,4). Application of 35 mm about 29 DAP did result in some drainage losses.

Interpretation of the results from the CAMNET system is more complex. Using Fig. 3 as an example; the line continuously fluctuating between values of 20-30 is a recording of soil temperature at the probe, 15 cm below the soil surface. The peaks and troughs indicate diurnal fluctuations and can be used to indicate the daily passage of time. Each peak in the temperature graph occurred around 2 pm on any given day. The numerals above the arrows near the top of the chart are an approximate indication of the number of days after planting (DAP), to enable comparison with the corresponding tensiometer values. Note that there was a system malfunction between 26-28 DAP; results for this time period should be ignored. The upper line on the chart indicates the degree of saturation, as estimated by the CAMNET system. The wavy nature of the moisture line is due to a slight error in the calibration formula.

Only 1 probe was placed in the 20 kPa irrigation treatment, however in all other treatments 2 probes were used, hence 2 charts per treatment. Probe readings commenced around 17 DAP and continued until the end of the experiment. In both the 20 and 35 kPa irrigation treatments, the probes indicated a relatively constant degree of saturation (around 70-80%) between 17-26 DAP (Figs. 3,5). They did not respond to the 23 mm irrigation at 22 DAP, in contrast to the shallow tensiometers in the same plots. Possibly the probes were installed slightly deeper than the tensiometers, just below the irrigation wetting front. As the matric suction during this period only fluctuated between 4-16 kPa, actual changes in soil water content were relatively small.

Similarly, only the 1st probe in the 35 kPa treatment responded to the 35 mm irrigation around 29 DAP, although all 3 probes in the 2 treatments showed increased soil saturation when 70 mm was applied 4 days later. Note that this final large irrigation was applied to check reaction of the probes to irrigation; it was not a scheduled watering in response to dry soil conditions.

For the first 22 DAP, the tensiometers and probes installed in plots scheduled for irrigation at 50 kPa behaved similarly to those previously discussed (Figs. 6,7). The wetting front from the 24 mm of water applied around 23 DAP did not initially reach the 15 cm deep tensiometers or probes, although unsaturated soil water movement did result in slight reductions in the former after about 2 days. As there were no further irrigations in this treatment, the shallower tensiometers continues to show increasing soil matric suction until the end of the experiment. (Note that the rapid reduction in the Block 2 tensiometer at the end of the experiment was due to tensiometer failure). The deeper tensiometers indicated there was little or no drainage below 45 cm after the initial saturation at 14 DAP. Although levels of saturation indicated by the heat dissipation probes toward the end of the experiment were 10-20% lower than initially recorded, the reductions were still not as substantial as expected, given the apparent changes in soil matric suction shown by tensiometers at the same depth.

As the 70 kPa treatment received the same irrigation regime as the 50 kPa plots, it is not surprising that the reaction of tensiometers in the former (Fig. 8) were similar to those shown in Fig. 6.

The tensiometer and probe responses for the plots scheduled for irrigation at a Critical Tensiometer Value (T) of 90 kPa were the same as all other treatments for the first 22 DAP (Figs. 9,10). Application of 30 mm of irrigation around 26 DAP reduced matric suction in the shallow tensiometers, but had no substantial effect on the deeper tensiometers, indicating little drainage loss (Fig. 9). Neither probes in the plots with **T** set at 90 kPa appeared to respond to this irrigation, although there may have been a slight increase in the saturation index (probably due to unsaturated flow Fig. 10).

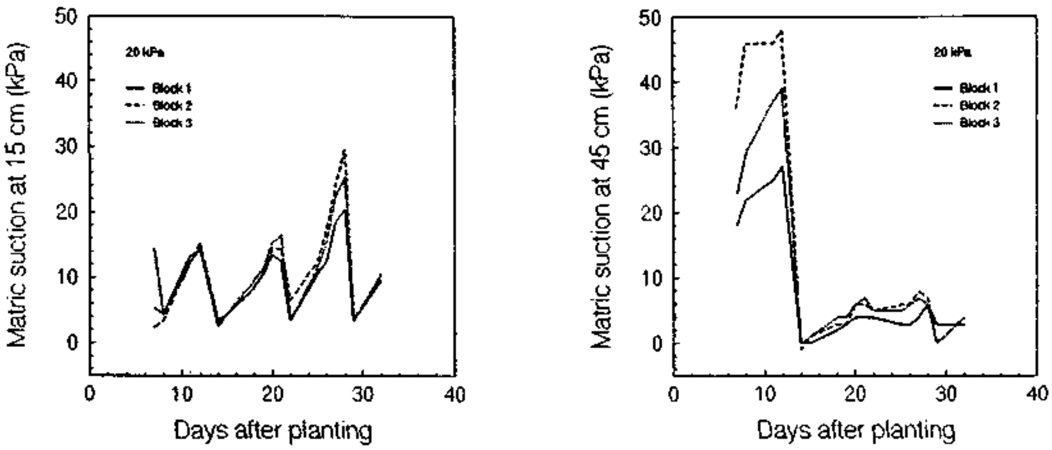


Figure 2. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where green beans were irrigated when soil matric suction at 15 cm exceeded 20 kPa.

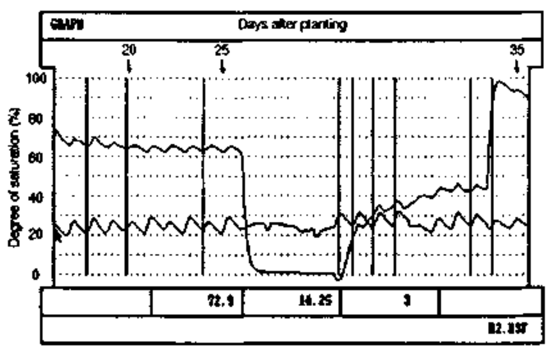


Figure 3. Fluctuations in the degree of soil saturation as measured by a heat dissipation probe 15 cm below ground level, where green beans were irrigated when soil matric suction at 15 cm exceeded 20 kPa.

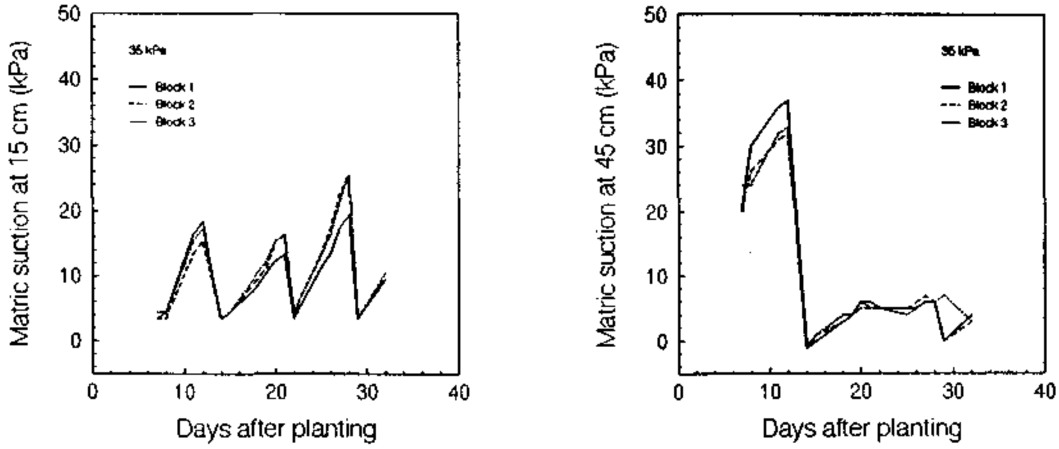


Figure 4. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where green beans were irrigated when soil matric suction at 15 cm exceeded 35 kPa.

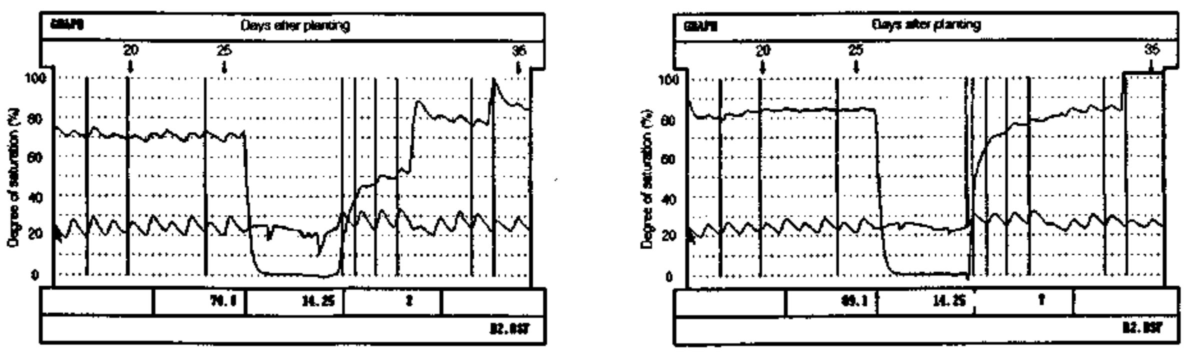


Figure 5. Fluctuations in the degree of soil saturation as measured by heat dissipation probes 15 cm below ground level, where green beans were irrigated when soil matric suction at 15 cm exceeded 35 kPa.

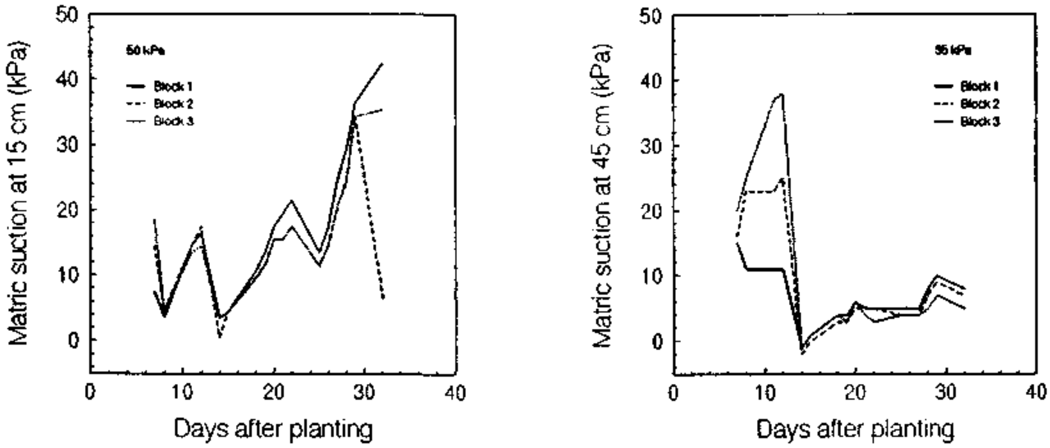


Figure 6. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where green beans were irrigated when soil matric suction at 15 cm exceeded 50 kPa.

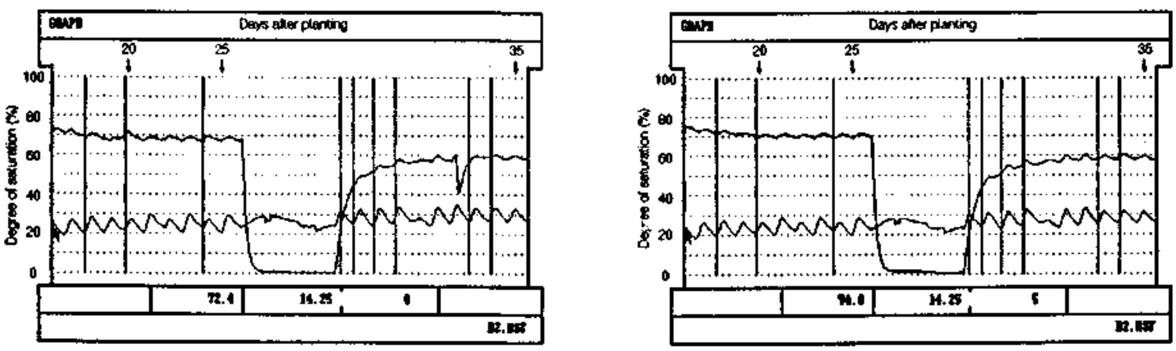


Figure 7. Fluctuations in the degree of soil saturation as measured by heat dissipation probes 15 cm below ground level, where green beans were irrigated when soil matric suction at 15 cm exceeded 50 kPa.

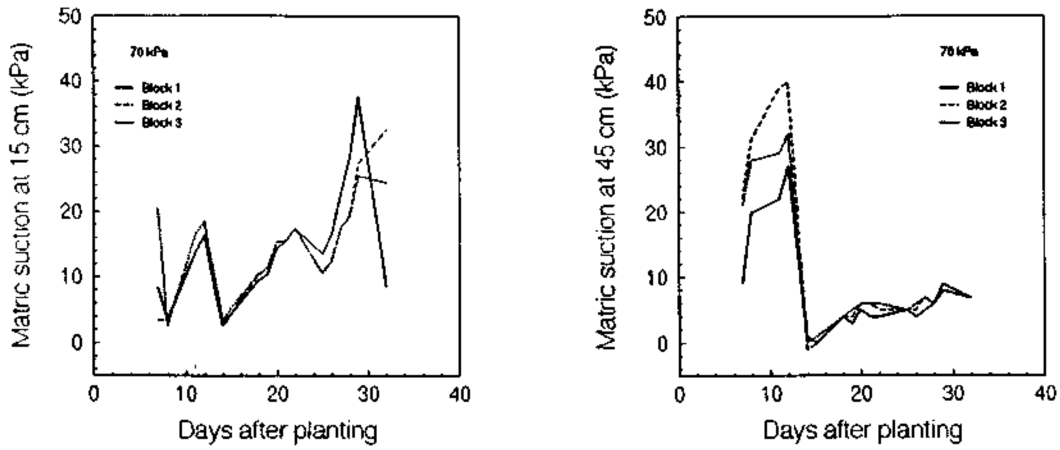


Figure 8. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where green beans were irrigated when soil matric suction at 15 cm exceeded 70 kPa.

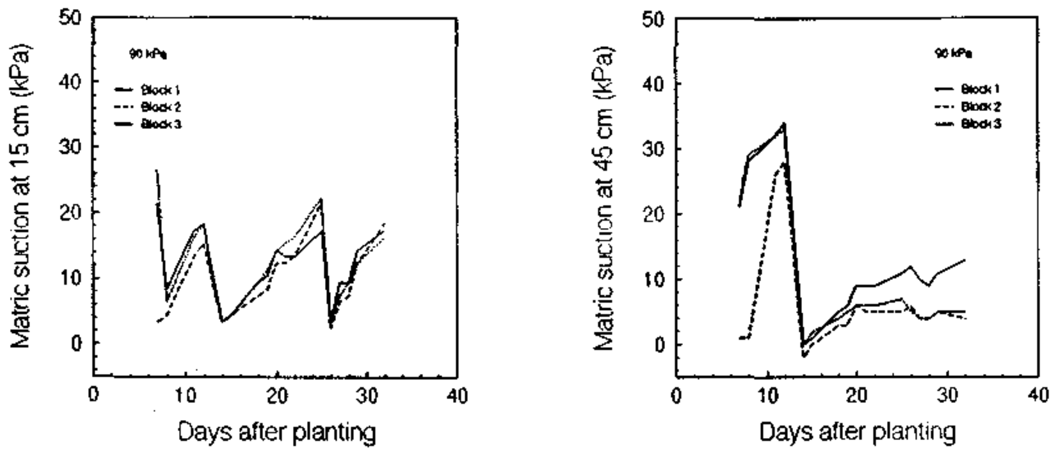


Figure 9. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where green beans were irrigated when soil matric suction at 15 cm exceeded 90 kPa.

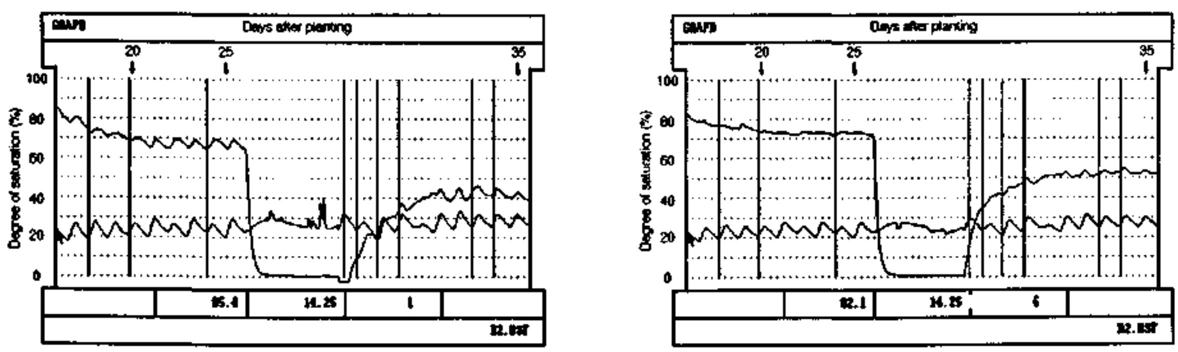


Figure 10. Fluctuations in the degree of soil saturation as measured by heat dissipation probes 15 cm below ground level, where green beans were irrigated when soil matric suction at 15 cm exceeded 90 kPa.

Because the plant growth in this experiment was disastrous, the amounts and quantities of irrigation applied do not reflect plant water requirements, but rather were initiated to test the different soil water monitoring systems. A summary of the water balance for each of the irrigation treatments over the duration of the experiment is shown in Fig. 11. There were curvilinear relationships between the Critical Tensiometer Value (**T** kPa), Irrigation (**I** mm) and Total Drainage (**D** mm), while there was no significant relationship between **T** and Total Evapotranspiration (ET mm).

$\mathbf{I} = 331^{***} - 5.49^{**}\ \mathbf{T} + 0.0345^{*}\ \mathbf{T}^2$ $\qquad r^2 = 0.80^{***}$ $\qquad$ Equation (2)

$\mathbf{ET} = 106$ $\qquad r^2 = 0.00^{ns}$ $\qquad$ Equation (3)

$\mathbf{D} = 156^{***} - 3.05^{**}\ \mathbf{T} + 0.0179^{*}\ \mathbf{T}^2$ $\qquad r^2 = 0.85^{***}$ $\qquad$ Equation (4)

The higher quantities of irrigation and drainage in the 20 and 35 kPa treatments were due to 2 extra irrigations at the end of the experiment, when testing the CAMNET probes. The only other significant drainage losses occurred about 15 DAP across the whole experiment, when about 25 mm of rainfall followed a similar quantity of irrigation. Given the similarity of irrigation regimes, and the lack of plant growth, it is not surprising that total ET was independent of treatment (about 45% of Pan Evaporation.

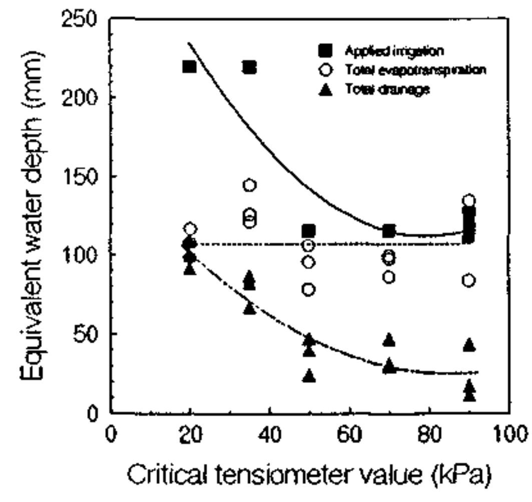


Figure 11. Changes in quantities of irrigation, total evapotranspiration and drainage losses as the Critical Tensiometer Value increased.

5. Discussion and conclusions

As there were no plant measurements conducted in this experiment, the only discussion concerns the relative performance of the tensiometers and CAMNET probes in assessing soil water status. As in previous research in this program, the tensiometer system was easy to install and use, gave accurate, reliable readings, required little maintenance and was relatively cheap. Given the deeper rooting habit of green beans compared to other vegetables, such as brassicas or lettuce, the deeper tensiometer should probably be installed at 60 cm, compared to the 45 cm depth used in this experiment. Similarly, neutron probe readings should be taken to 70 cm, rather than 50 cm below the soil surface.

A number of problems with the CAMNET system were readily apparent during the conduct of this investigation. Lack of memory capacity in our unit meant that at the desired 15 minute interval between probe readings, the system needed downloading onto computer every 1.5 days. In order to extend this downloading interval we increased the measurement period to 1 hour. We have since discovered that this can occasionally result in sub-optimal probe performance, particularly in rapidly changing soil temperature or moisture conditions. In order to bring the measurement interval back to a maximum of 0.5 hours, a substantially expanded memory in the CAMNET remote unit is probably required. The unit is also relatively susceptible to power spikes, meaning that effective surge suppressors are required. In this particular experiment, a lack of flexibility in the software, particularly in terms of data handling and calibration adjustment were also significant difficulties. It is anticipated that continued dialogue with the manufacturers and developers of the system will overcome many of these concerns.

We are still not confident in the response of the probes to changing soil water conditions, particularly where soil water content (or potential) changes slowly due to unsaturated flow. In this experiment, there were several instances where we were relatively certain that substantial increases in soil water content (and corresponding reductions in soil water potential) had occurred, yet were not indicated by the CAMNET system. The structure of the probe relies on water moving into the probe body under a potential gradient. Possibly the external material of the probe body is too restrictive to water flow under unsaturated soil conditions. We are aware that the probes are still undergoing refinement and modification, and intend investigating probe behaviour in future research.

We have programmed further experiments investigating irrigation scheduling techniques and application methods for green bean production, including the tensiometer and CAMNET scheduling systems, as well as sprinkler, trickle and subsurface irrigation systems.

EXPERIMENT REPORT

Report **Final** **Date of Report:** 19-11-93

Initiation Date: 24-10-91 **Completion Date:** 14-1-92

Project Number: S8902

Project Title: Irrigation scheduling in vegetables

Experiment Number: S8902.07 **Officer Responsible:** Craig Henderson

Experiment Title: Irrigation scheduling for summer sweet corn.

Experiment Objectives

This experiment sought to determine the relationship between sweet corn yield, tensiometer values and heat dissipation probe readings. It also attempted to determine the efficiency of irrigation by quantifying the amounts of applied water draining beyond the root zone during the growing period.

Summary of Results

The experiment was conducted at Gatton Research Station, from October 1991 - January 1992. Sweet corn (cv. *Kulara II*) were grown using standard agronomy, with 5 irrigation treatments replicated 3 times in a RCB design. Plots were 3.0 m wide and 10 m long, with a total experimental area of 0.05 ha. The five irrigation treatments involved commencing irrigation at different Critical Tensiometer Values (**T** kPa), using tensiometers installed 15 cm below ground level in each plot. The T values were 20 kPa, 35 kPa, 50 kPa, 70 kPa and 90 kPa. All irrigation after the first 10 days was applied using surface drip tape. Scheduling with tensiometers reduced drainage losses due to irrigation to <5% of application, however drainage associated with excess rainfall was substantial (about 180 mm). Due to substantial rainfall during the growing period, there were no significant effects of irrigation regime on cob yields (about 14 t/ha). There was a significant trend for lower yields on plots with lower total evapotranspiration. The optimum **T** value for irrigation scheduling appeared to be 50-60 kPa. The heat dissipation probe system had numerous problems during this experiment; conclusive evaluation on the basis of data collected was not possible.

EXPERIMENT REPORT

Irrigation scheduling for summer sweet corn

by C. Henderson and M. Webber
Department of Primary Industries
Gatton Research Station

Experiment No. S8902.07 28.10.91-14.1.92

1. Relevance to Industry

In many regions, including the Lockyer Valley, irrigation demands regularly exceed the reliable capacity of the water supply, resulting in scarcity or reliance on poorer quality water. Sweet corn is a major user of irrigation water from October through April in southern Queensland. With the introduction of new, better adapted cultivars, there is potential for major expansion of the sweet corn industry for both the fresh and processing markets. Many producers budget on applying around 4-6 ML/ha of irrigation to a sweet corn crop. Until recently, the frequency and amount of irrigation was relatively ad hoc, based on tradition and grower experience, combined with superficial observations of plant or soil conditions.

Some sweet corn growers interstate and overseas use tensiometers or neutron probes to monitor soil water status and schedule irrigations. Both methods have advantages and disadvantages, however tensiometers appear to have the best immediate potential for use in southern Queensland. There are a number of new irrigation scheduling systems currently being developed, involving electronic data capture, recording and real-time display of soil water status on a virtually continuous basis. Most water uptake in sweet corn occurs in the upper 0.3-0.5 m of the soil profile.

Matching irrigation to crop requirements maximises production by minimising plant water stress, nutrient deficiencies and some diseases, as well as preventing build up of salinity problems. By preventing overwatering, problems with leaching of nutrients and pesticides into groundwater (and beyond the zone of usefulness) are reduced, as well as a decrease in disease levels.

2. Objectives

This experiment sought to determine the relationship between sweet corn yield, tensiometer values and heat dissipation probe readings (from the CAMNET WATER MANAGEMENT SYSTEM), under various irrigation regimes. It also attempted to determine the efficiency of scheduling systems, by quantifying the amounts of applied water draining beyond the root zone during the sweet corn growing period.

3. Materials and methods

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

The soil was prepared as per standard practice for sweet corn. Cv. *Kulara II* were sown on the 28 October 1991, with 1.00 m between the rows and 0.17 m intra-row spacing. A basal application of 60 kgN/ha as urea was applied immediately after sowing and incorporated with the initial irrigation of 39 mm. A side dressing of 60 kgN/ha as urea was applied through trickle irrigation on 18 December 1991. A tank-mix containing 1 kg/ha of urea and 1 kg/ha of zinc sulphate was sprayed over the crop on 2 occasions; 4 December and 19 December 1992. Weeds were managed by spraying 2.16 kg/ha of metolachlor immediately after planting, prior to the initial irrigation. Occasional hand-hoeing also took place as other weeds emerged. Insects were controlled with regular applications of insecticides, including chlorpyrifos, methomyl, endosulfan and dimethoate.

The initial irrigations utilised standard solid-set pipes and overhead sprinklers over the whole experimental area, for the first 10 days after planting (DAP). For all other irrigations, systems of drip tape were used to individually water each plot. A schematic of plot layout is shown in Fig. 1. Each plot consisted of 3 rows of sweet corn side by side. The central row was the treatment area, while the two outside rows were buffer zones. The drip tapes were positioned immediately adjacent to the sweet corn rows. The tape used was 'T-Tape Row Crop' with drip emitters every 20 cm, and an output of about 7.3 $Lm^{-1}hr^{-1}$ at an operating pressure of 70 kPa. This corresponded to an application rate of approximately 9 mm/hr on a total area basis.

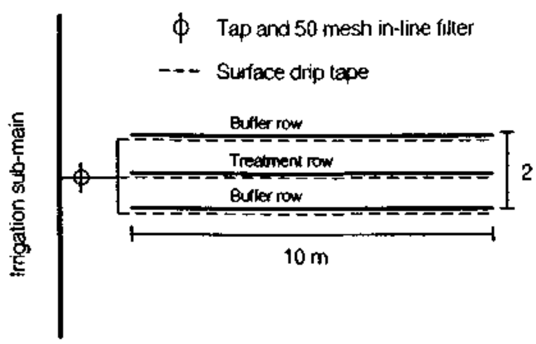


Figure 1. Surface drip tape system design for an individual plot in an experiment investigating irrigation scheduling in summer sweet corn.

Tensiometers were installed 15 cm and 60 cm below ground level in each treatment row. *Loctronic* tensiometers were used, consisting of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum, while an electronic vacuum gauge attached to the syringe records the vacuum in the tensiometer air gap. Tensiometer readings were recorded daily, usually around 9 am.

Critical Tensiometer Values (T) were used to trigger irrigations in this experiment. Irrigation was applied when readings for the tensiometers installed 15 cm below the ground surface were greater than the **T** individually set for each treatment. Five irrigation treatments were investigated, involving scheduling regimes based on tensiometer readings:

1. Irrigated at a shallow tensiometer value of 20 kPa.

2. Irrigated at a shallow tensiometer value of 35 kPa.

3. Irrigated at a shallow tensiometer value of 50 kPa.

4. Irrigated at a shallow tensiometer value of 70 kPa.

5. Irrigated at a shallow tensiometer value of 90 kPa.

Each plot was irrigated according to its allocated treatment. Plots with the same irrigation treatment were occasionally watered on different days, due to differences in the time for the tensiometers to reach values necessary to trigger irrigation.

Aluminium neutron probe access tubes were installed to depths of 80 cm in each treatment bed, 10 cm on the opposite side of the sweet corn row to the drip tape and equidistant between 2 neighbouring plants. Neutron moisture meter readings were taken twice a week using a Campbell Pacific Nuclear Hydroprobe. A single reading was taken at 5 depth intervals, commencing 5 cm below the ground surface, incrementing by 10 cm. On each day that the neutron probe measurements were made, 5 standard counts was also conducted in a 200 L drum of water. Calibration equations for the neutron probe data were assumed to be the same as for previous experiments at this site.

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

Heat dissipation probes were installed at 15 cm below ground level in Blocks 1 and 3, for Treatments 1, 2, 3 and 5. The probes were connected to the CAMNET system, which recorded soil moisture status and soil temperature for each of the probes on a half-hourly basis.

The heights of the sweet corn plants were measured 25, 32, 39 and 46 DAP. Five plants were randomly selected and assessed in each plot. Sweet corn cobs were harvested by hand from the treatment rows on 14 January 1992, 78 days after planting. The number of marketable heads per row were counted, harvested and weighed.

4. Results

A total of 364 mm of rain fell during the growing period. There was a prolonged wet period from 30-47 DAP, with further substantial rain around 65 and 72 DAP (Fig. 2). This rainfall adversely affected treatment differentiation in the experiment.

Using a simple spreadsheet, a daily water balance was calculated for each plot. Rainfall, irrigation, stored soil water, pan evaporation, evapotranspiration and drainage of soil water below 50 cm were determined from planting through to harvest. Details of the calculations are available from the authors.

The version of the CAMNET software used during this experiment was not amenable to graphical presentation in written reports. To overcome this difficulty, we manually transferred the soil water data for each of the probes into our normal graphics program. Although the probes were recording every 30 minutes, we only used the 9 am values for each day, as to manually transfer the complete data set would have been too time consuming. Using data collected at 9 am also enabled direct comparison with corresponding tensiometer values.

Due to pump failure, we were unable to irrigate between 38 and 51 DAP. Fortunately, there was substantial rainfall during this period. During this interval, the shallow tensiometers in all treatments reached values above 50 kPa on 3-4 separate days.

Except when the irrigation pump was inoperable, the shallow tensiometers fluctuations during the growing period for the 20 kPa treatment were 0-30 kPa, for the 35 kPa trwatment 0-40 kPa, 50 kPa treatment 0-40 kPa, 70 kPa treatment 0-50 kPa and for the 90 kPa treatment 0-70 kPa (Figs. 2-6). Between 15 and 31 DAP (prior to the prolonged wet period), the 20 and 35 kPa treatments were irrigated on 3 occasions, while the other 3 treatments were irrigated twice. Average irrigations were 18 mm. From 50 DAP until harvest, the 20 kPa treatment was irrigated on 7 occasions (average 17 mm), the 35 and 50 kPa treatments 6 times (18 and 15 mm respectively), the 70 kPa treatment 5 times (12 mm) and the 90 kPa treatment 4 times (14 mm).

The deep tensiometers in the 20 kPa treatment ranged from 0 kPa after heavy rainfall to a maximum of 10 kPa immediately prior to irrigation. Deep tensiometers in the other treatments tended to fluctuate between 0 and 15 kPa for the first 50 DAP. From then until harvest, the deep tensiometers in these latter treatments tended to oscillate between 15 and 40 kPa, except after the rain around 65 DAP, when they declined to about 5 kPa (Figs. 2-6).

The graphics for the CAMNET system show average values for the 2 probes in each treatment. Unfortunately, there were many problems with operating the system in this experiment. The remote data logger was destroyed by a power surge associated with a proximate lightening strike about 31 DAP. A new remote was installed 39 DAP, however software problems (which erased data from the remote prior to down-loading) caused data losses for the intervals 45-48 DAP and 51-66 DAP. The CAMNET probe in the 35 kPa plot in Block 1 ceased functioning 30 DAP, while the probe in the same treatment in Block 3 stopped working 44 DAP. The responses of probes to wetting and drying conditions were highly variable and inconsistent between plots. Only after very heavy rainfall would all probes register wet soil conditions (Figs. 2-6).

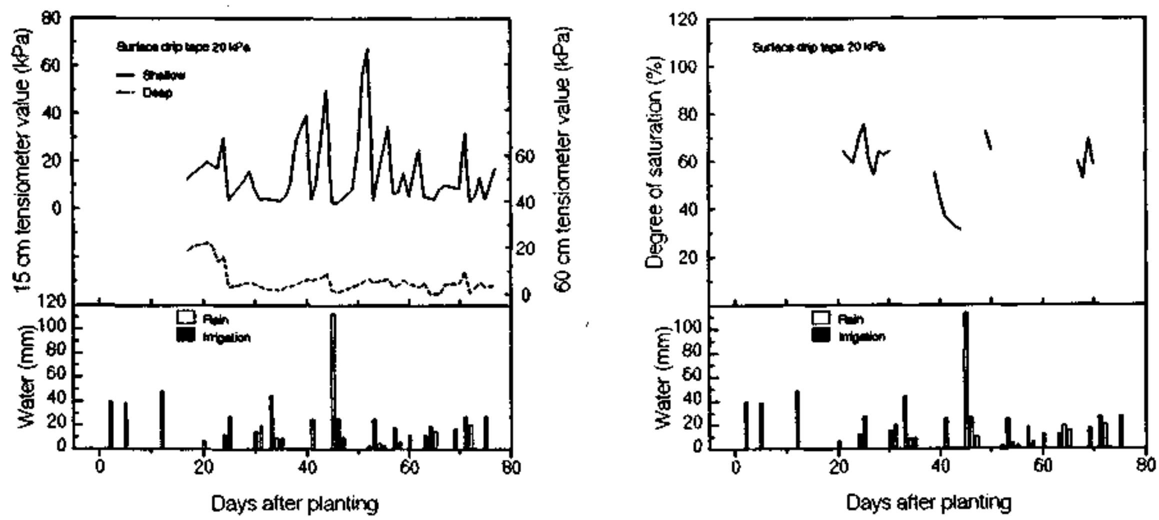


Figure 2. Fluctuations in soil matric suction at 15 and 60 cm below ground level, and heat dissipation probe values at 15 cm below ground level, where sweet corn were irrigated using surface drip tape, when soil matric suction at 15 cm exceeded 20 kPa during the growing period.

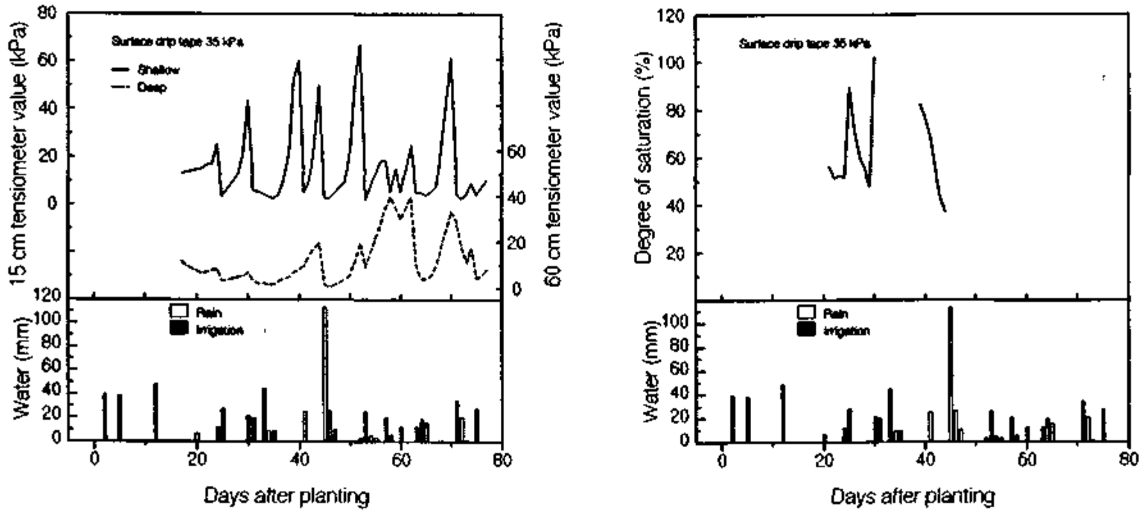


Figure 3. Fluctuations in soil matric suction at 15 and 60 cm below ground level, and heat dissipation probe values at 15 cm below ground level, where sweet corn were irrigated using surface drip tape, when soil matric suction at 15 cm exceeded 35 kPa during the growing period.

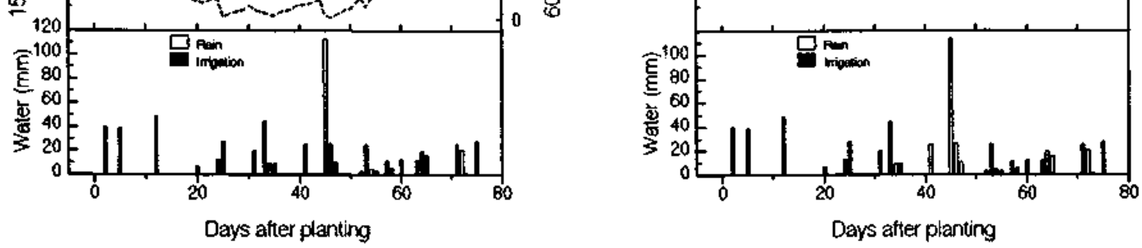


Figure 4. Fluctuations in soil matric suction at 15 and 60 cm below ground level, and heat dissipation probe values at 15 cm below ground level, where sweet corn were irrigated using surface drip tape, when soil matric suction at 15 cm exceeded 50 kPa during the growing period.

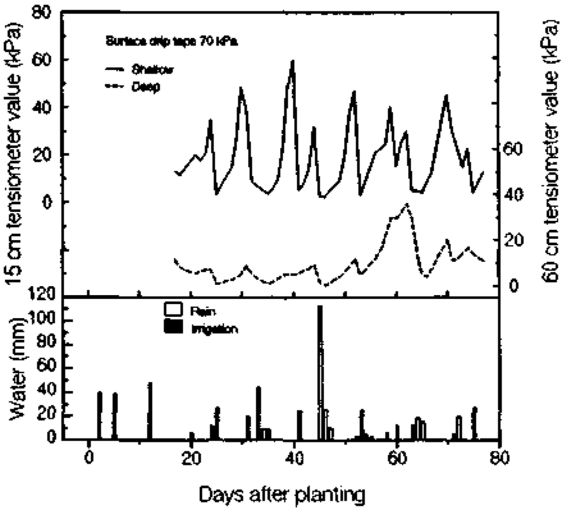


Figure 5. Fluctuations in soil matric suction at 15 and 60 cm below ground level, where sweet corn were irrigated using surface drip tape, when soil matric suction at 15 cm exceeded 70 kPa during the growing period.

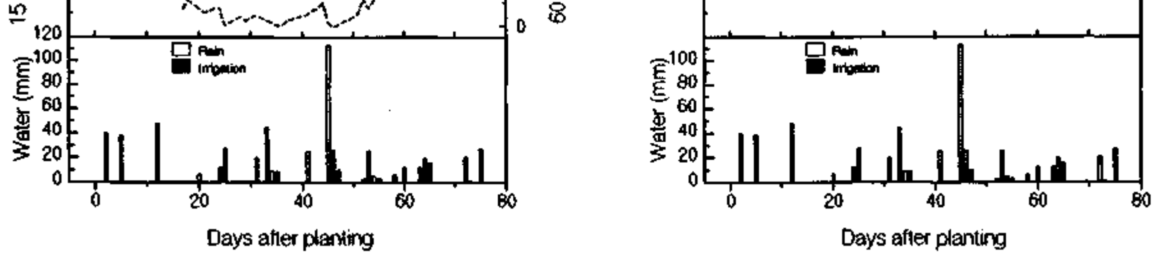


Figure 6. Fluctuations in soil matric suction at 15 and 60 cm below ground level, and heat dissipation probe values at 15 cm below ground level, where sweet corn were irrigated using surface drip tape, when soil matric suction at 15 cm exceeded 90 kPa during the growing period.

The calculated water balances indicate substantial through-drainage during the life of this sweet corn crop (Fig. 7). There were 2 components to this drainage, associated with (i) excess irrigation and (ii) excess rainfall. All drainage due to excess irrigation (about 65 mm) occurred at the first 3 irrigations, using standard irrigation pipes and commercial practices. This was prior to commencing the scheduling program and different irrigation treatments.

Over 70% of drainage was due to rainfall in excess of the soil water holding reserve at the time. There was significantly less total drainage in the 70 and 90 kPa treatments, when compared with the more frequently irrigated sweet corn. In these former plots, drier soil conditions between irrigations created a greater capacity to absorb rainfall before runoff or drainage occurred.

The water balances also indicated that the 70 and 90 kPa treatments had significantly lower total evapotranspiration (ET) than the more frequently irrigated sweet corn (Fig. 7). These differences came about during the final 3 weeks prior to cob harvesting (Fig. 8).

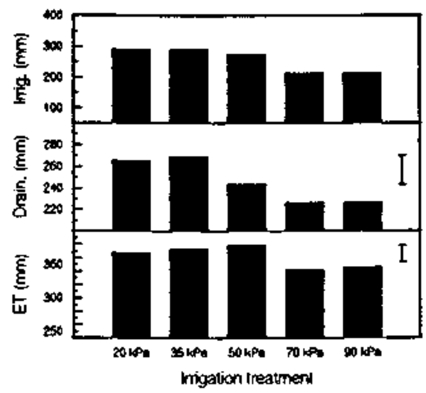


Figure 7. Changes in quantities of irrigation, total evapotranspiration and drainage losses under 5 irrigation regimes. Bars indicate the 5% L.S.D.

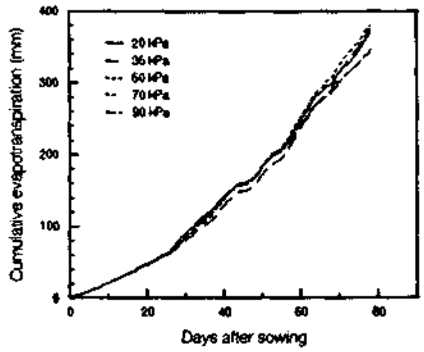


Figure 8. Cumulative evapotranspiration under 5 irrigation regimes.

There were no significant effects of irrigation treatment on heights of sweet corn plants at 25 DAP (mean 49 cm), 32 DAP (86 cm), 39 DAP (118 cm) nor 46 DAP (158 cm). This was expected, given the lack of irrigation treatment differentiation during the first 7 weeks after planting.

Yield differences between irrigation treatments were small (< 2 t/ha) and generally not significant. Any differences were associated with variation in cob numbers, not individual cob weights (Fig. 9). Interestingly, data from individual plots showed a significant ($P<0.01$) linear relationship between estimated total ET and cob yield (Y), as shown in Fig. 9;

$$Y = -5.04 + 0.0528\ ET \qquad R^2 = 0.49$$

Maximum yield was attained at an ET value of about 370 mm.

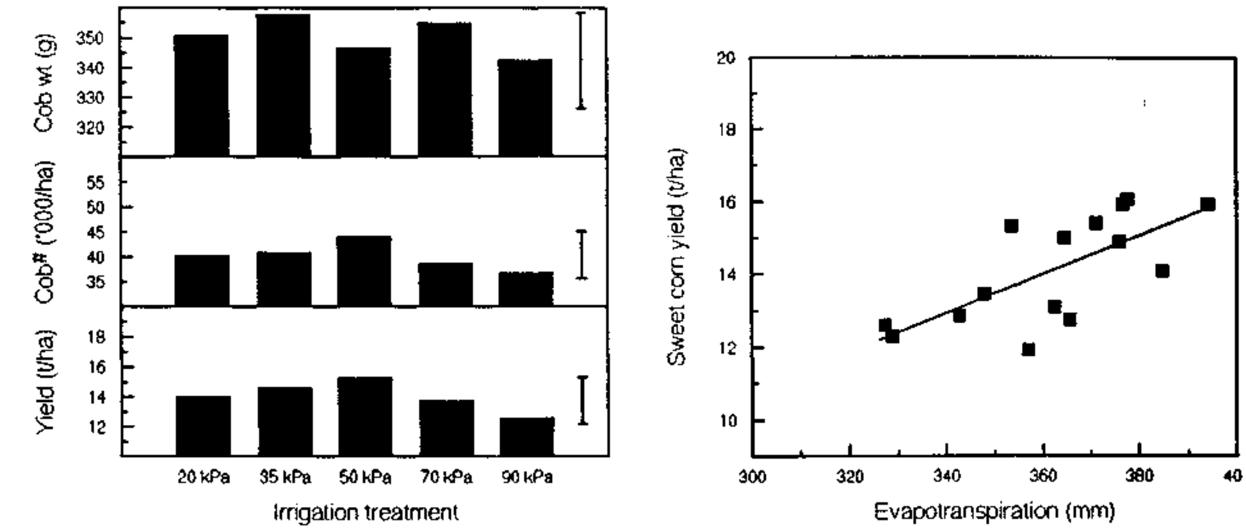


Figure 9. Sweet corn yield parameters were not significantly affected by altering Critical Tensiometer Values, however yield was significantly increased at higher ET totals.

5. Discussion and conclusions

As in previous experiments, the tensiometer system was easy to install and use, gave accurate, reliable readings, required little maintenance and was relatively cheap. Although most water uptake from the sweet corn occurred in the upper 50 cm of the soil profile, there still appeared to be some root activity below that depth.

Because of the limited amount of time that the CAMNET system was actually functioning, thorough evaluation of the system from data generated in this experiment was not possible. However, the following points were apparent. The CAMNET probes used in this experiment were unreliable, suffering intermittent electronic failure, as well as leakage of the sand matrix through a small hole at the bottom of the probe. Probe readings were also highly variable between plots. Due to the nature of the probe design and construction materials, I believe there was a problem with flow of water into the probe from unsaturated soil. Unsaturated flow conditions frequently occur when drip irrigation systems are used; where water is moving out (or upward) from point sources. The effective responses to rainfall, in contrast to slow responses to drip irrigation used in this experiment, tend to confirm this hypothesis. Calibration of the CAMNET probes seemed to shift over time. After heavy irrigation or rainfall, several probes would still not register 100% saturation.

Destruction of the remote data logger due to a power surge emphasised the need for electronic protection. There were frequent problems in communication between the lap-top micro-computer and the remote data logger. This seemed to be due to a glitch in the controlling software. To overcome this problem required re-setting of the whole system on each occasion. This re-setting caused any data logged after the previous down-loading to be lost. The operating software did not label the time axis with meaningful values (e.g. date or days), making interpretation of data very difficult. The software was neither flexible nor compatible with other programs. Of particular concern was the lack of graphic or data editing facilities. This could be overcome by enabling input/output in standard text and graphic formats. There are also several incorrect interpretations within the operating software, including assumptions that probes measure soil water content, and that an ET rate (mm/day) can be derived directly from probe readings.

Once we commenced managing irrigation with our scheduling systems (utilising watering regimes suggested by our previous research), virtually no drainage could be attributed directly to over-irrigation. The bulk of deep drainage was due to rainfall in excess of the storage capacity of the soil profile.

Because of the substantial rainfall during this experiment, conclusions on the irrigation requirements on sweet corn were difficult to derive. It is likely that deficit irrigation during the vegetative phase may encourage activity of deeper roots, as well as provide a more effective reserve for capturing rainfall and reducing deep drainage.

Initial indications are that a Critical Tensiometer Value for maximum production of summer sweet corn is probably 50-60 kPa pre-silking, dropping to 50 kPa during the pollination and cob development phases. On black earth soil types under trickle, this involves irrigation about every 4 days, applying 10 mm per irrigation for the first 7 weeks after planting, increasing to 15 mm per irrigation until harvest. Under overhead irrigation, the frequency would be reduced and the total depths increased. The target evapotranspiration for sweet corn would probably be around 340-370 mm, with a total irrigation requirement of about 3.5-4 ML/ha, allowing for inefficiencies and drainage losses. Obviously any rainfall during the intervening period would reduce these requirements, although there may still be a need to irrigate for other purposes, such as fertiliser or pesticide incorporation. The regime would also be affected by cultivar and agronomic practices.

We intend repeating irrigation management experiments on sweet corn, to try and obtain more definitive data on water requirements and critical scheduling values.

EXPERIMENT REPORT

1. **Report** **Final** **Date of Report:** 01-07-92

Initiation Date: 10-7-91 **Completion Date:** 15-05-92

Project Number: S8902

Project Title: Irrigation scheduling in vegetables

Experiment Number: S8902.08 **Officer Responsible:** Craig Henderson

Experiment Title: Irrigation scheduling for autumn grown green beans.

2. Experiment Objectives

This experiment sought to determine the relationship between bean yield, tensiometer values and heat dissipation probe readings (from the CAMNET WATER MANAGEMENT SYSTEM). It also attempted to determine the efficiency of irrigation by quantifying the amounts of applied water draining beyond the root zone during the growing period.

3. Summary of Results

The experiment was conducted at Gatton Research Station, from March-May 1992. Green beans (cv. *Labrador*) were grown using standard agronomy, with 5 irrigation treatments replicated 3 times in a RCB design. Plots were 5.3 m wide and 10 m long, with a total experimental area of 0.075 ha. The five irrigation treatments involved commencing irrigation at different Critical Tensiometer Values (**T** kPa), using tensiometers installed 15 cm below ground level in each plot. The **T** values were; 70 kPa before budding and 80 kPa after budding; 70/40 kPa; and 40/40 kPa. The 40/40 kPa treatment was further divided into application with overhead sprinklers, conventional drip tape, or subsurface drip tubing. The CAMNET soil water monitoring system operated relatively reliably, however, as in a previous experiment, the CAMNET probes did not respond to several irrigations, particularly when compared with the tensiometers installed in the same locations. There is some evidence that there is inhibited flow of water into the initial versions of the probe under unsaturated conditions. Frequent rain during the growing period reduced contrasts between the irrigation treatments. Scheduling with tensiometers reduced drainage losses due to irrigation to 5-10% of application, however drainage associated with excess rainfall was substantial (70-90 mm). There was a slight yield reduction (circa 1.1 t/ha) in beans watered at a pre-budding **T** value of 70 kPa, compared to 40 kPa, with yields of around 11.5 t/ha in the better treatments. Bean yields on areas watered with either drip system were equivalent to the treatment irrigated with overhead sprinklers. We have programmed further experiments investigating irrigation scheduling techniques and application methods for green bean production.

EXPERIMENT REPORT

Irrigation scheduling for autumn grown green beans

by C. Henderson and M. Webber
Department of Primary Industries
Gatton Research Station

Experiment No. S8902.08 6.3.92-15.5.92

1. Relevance to Industry

In many regions, including the Lockyer Valley, irrigation demands regularly exceed the reliable capacity of the water supply, resulting in scarcity or reliance on poorer quality water. In many vegetable enterprises irrigation is a significant proportion of overall production costs. Green beans generally require around 3 ML of irrigation per crop. Until recently, the frequency and amount of irrigation was relatively ad hoc, based on tradition and grower experience, combined with superficial observations of plant or soil conditions.

Some vegetable growers use tensiometers or neutron probes to monitor soil water status and schedule irrigations. Both methods have advantages and disadvantages, however tensiometers appear to have the best immediate potential for use in shallow rooted vegetables. Beans have deeper root systems than many other vegetables, however most water uptake still occurs in the upper 0.5 m of the soil profile. There are a number of new irrigation scheduling systems currently being developed, involving electronic data capture, recording and real-time display of soil water status on a virtually continuous basis.

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 overwatering, problems with leaching of nutrients and pesticides into groundwater (and beyond the zone of usefulness) are reduced, as well as a decrease in disease levels.

2. Objectives

This experiment sought to determine the relationship between bean yield, tensiometer values and heat dissipation probe readings (from the CAMNET WATER MANAGEMENT SYSTEM), under various irrigation systems and regimes. It also attempted to determine the efficiency of these scheduling and application systems by quantifying the amounts of applied water draining beyond the root zone during the bean growing period.

3. Materials and methods

The experiment was conducted on a black earth soil (*Ug5.15*) at Gatton Research Station (lat 27°33'S, long 152°20'E). The experimental design was a randomised complete block, with 5 irrigation treatments replicated 3 times. Each plot was 3 beds (2 rows of green beans per 1.7 m bed) wide and 10 m long.

The soil was prepared as per standard practice for green beans. Beans (cv. *Labrador*) were sown on the 11th March 1992, with 0.85 m between the rows and 0.05 m intra-row spacing. A total of 60 kg/ha of N as urea was broadcast immediately before planting. Weed control was achieved by spraying metolachlor at 2.52 kg/ha of active constituent over the experimental area 1 day after planting. The herbicide and fertiliser were incorporated with 36 mm irrigation immediately after the herbicide application. Insects were controlled with regular applications of insecticides, including dimethoate, methomyl and endosulfan. A single application of mancozeb was sprayed on the 1st May 1992 to prevent bean rust.

The initial post-planting irrigation utilised standard solid-set pipes and overhead sprinklers over the whole experimental area. After this first irrigation, systems of mini-sprinklers, drip tape or subsurface drip tubing were installed to individually water each plot. Schematics of plot layouts are shown in Figs. 1 and 2. Each plot consisted of 3 beds of green beans side by side. The central bed was the treatment area, while the two outside beds were buffer zones.

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

The plots watered with surface drip tape had 2 rows of tape in each treatment bed, positioned immediately adjacent to the bean rows. In addition, another single row of tape was positioned beside the closest bean row in each of the buffer beds, as shown in Fig. 2. The tape used was 'T-Tape Row Crop' with drip emitters every 20 cm, and an output of about 7.3 $Lm^{-1}hr^{-1}$ at an operating pressure of 70 kPa. This corresponded to an application rate of approximately 8.5 mm/hr on a total area basis.

The beds watered with the subsurface system had the 'AGRI-GRO' continuous drip tubing positioned directly under the 2 bean rows in the treatment beds, as well as the 2 adjacent bean rows in the buffer beds (Fig. 2). It was intended to bury the tubing 20 cm below the ground surface, however when the tube was installed using a pipe-laying ripper, it appeared that the actual depth was 25-30 cm. The tube was installed on the 6th March 1992, with the whole experimental area cultivated and harrowed after installation, to remove tractor marks. The tubing had an initial output of around 5.3 $Lm^{-1}hr^{-1}$ at an operating pressure of 70 kPa. This corresponded to an application rate of approximately 6.3 mm/hr on a total area basis.

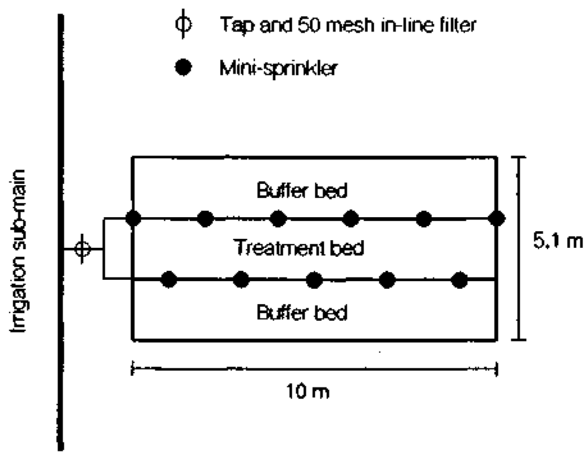


Figure 1. Mini-sprinkler system design for an individual plot in an experiment investigating irrigation scheduling in autumn grown green beans.

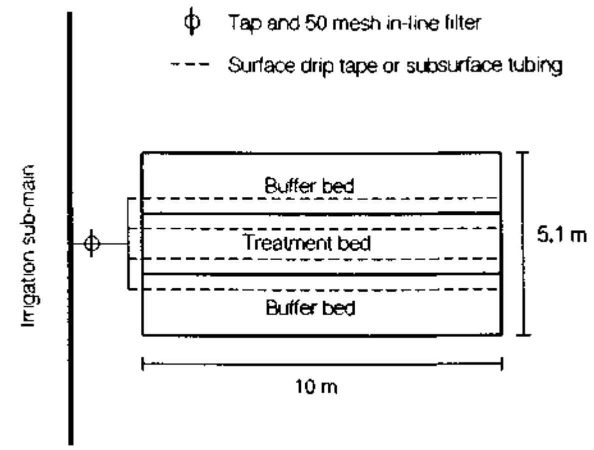


Figure 2. Surface and subsurface drip system designs for an individual plot in an experiment investigating irrigation scheduling in autumn grown green beans.

Tensiometers were installed 15 cm and 60 cm below ground level in each treatment bed. *Loctronic* tensiometers were used, consisting of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum, while an electronic vacuum gauge attached to the syringe records the vacuum in the tensiometer air gap. Tensiometer readings were recorded daily, usually around 9 am.

Critical Tensiometer Values (T) were used to trigger irrigations in this experiment. Irrigation was applied when readings for the tensiometers installed 15 cm below the ground surface were greater than the **T** individually set for each treatment. In this experiment 2 **T** were allocated; one for the period prior to budding, with a second for the period from budding to bean harvest. A treatment designated '70/80 kPa' had a **T** of 70 kPa pre-budding and 80 kPa post-budding. The objective was to examine the effects of different water stress periods on vegetative and reproductive performance.

Five irrigation treatments were investigated, involving 3 application methods, combined with 3 scheduling regimes based on tensiometer readings:

1. Irrigated using mini-sprinklers, scheduled at **T** 70/80 kPa (**SPR 70/80**).
2. Irrigated using mini-sprinklers, scheduled at **T** 70/40 kPa (**SPR 70/40**).
3. Irrigated using mini-sprinklers, scheduled at **T** 40/40 kPa (**SPR 40/40**).
4. Irrigated using surface drip tape, scheduled at **T** 40/40 kPa (**SUR 40/40**).
5. Irrigated using subsurface drip tube, scheduled at **T** 40/40 kPa (**SUB 40/40**).

Each plot was irrigated according to its allocated treatment. Plots with the same irrigation treatment were occasionally watered on different days, due to differences in the time for the tensiometers to reach values necessary to trigger irrigation.

Aluminium neutron probe access tubes were installed to depths of 100 cm in each treatment bed, 5 cm inside a bean row and equidistant between 2 neighbouring plants. Neutron moisture meter readings were taken twice a week using a Campbell Pacific Nuclear Hydroprobe. A single reading was taken at 8 depth intervals, commencing 5 cm below the ground surface, incrementing by 10 cm. On each day that the neutron probe measurements were made, 5 standard counts was also conducted in a 200 L drum of water. Calibration equations for the neutron probe data were assumed to be the same as for previous experiments at this site.

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

Heat dissipation probes were installed at 15 cm below ground level in Blocks 1 and 2, for Treatments 1, 3 and 5. In addition, probes were installed 60 cm below ground level in the first replicate of Treatments 3 and 5. The probes were connected to the CAMNET system, which recorded soil moisture status and soil temperature for each of the probes on a half-hourly basis.

The heights of the bean plants were measured 22, 33, 36 and 58 days after planting (DAP). Five plants were randomly selected and assessed in each plot. Green beans were hand harvested from the central 5 m of the 2 rows in the treatment beds on the 15th May 1992, 65 DAP. The fresh weights of beans harvested from each plot were recorded. A rating of the severity of lodging was also determined for each plot, ranging from a value of 1 for no lodging, to a maximum of 5 for plants lying on the ground and beans unharvestable.

4. Results

There was frequent rainfall during the growing period (Table 1), somewhat interfering with the experiment.

Table 1. Rainfall during the growing period for autumn grown green beans.

Weeks after sowing	Rainfall (mm)
1	62.2
2	21.6
3	1.7
4	32.7
5	3.8
6	2.4
7	18.8
8	0
9	19.4
TOTAL	162.60

The calibration equations for the neutron probe took the following form;

$$\mathbf{V} = a + b * \mathbf{FC} \qquad \text{Equation (1)}$$

where
V = volumetric water content (cm^3cm^{-3})
FC = fractional neutron count (reading in soil divided by standard count in water)
a and b are equation parameters

The parameter values and r^2 for the calibration equations for each of the blocks and depth intervals are given in Table 2. The equations for depths > 50 cm were assumed to be the same as for the 40-50 cm depth interval.

Table 2. Parameters and goodness of fit for calibration equations relating volumetric soil water content to neutron probe readings.

Depth interval cm	Block 1			Block 2			Block 3		
	a	b	r^2	a	b	r^2	a	b	r^2
0-10	0.062	1.199	0.94	0.024	1.147	0.91	0.078	0.964	0.93
10-20	0.087	0.520	0.82	0.076	0.504	0.90	0.086	0.503	0.88
20-30	-0.125	0.829	0.73	-0.196	0.925	0.92	-0.122	0.831	0.96
30-40	-0.060	0.677	0.64	-0.062	0.705	0.73	-0.057	0.726	0.67
40-50	-0.032	0.600	0.46	-0.191	0.878	0.78	0.057	0.516	0.44

All r^2 values were highly significant ($P<0.01$), except for those less than 0.50, which were significant ($P<0.05$).

Using a simple spreadsheet, a daily water balance was calculated for each plot. Rainfall, irrigation, stored soil water, pan evaporation, evapotranspiration and drainage of soil water below 80 cm were determined from planting through to harvest. Details of the calculations are available from the authors.

Because of rainfall events, the shallow tensiometers in Treatment 1 only recorded peak matric suctions of 50-60 kPa for the first 50 DAP, except for Block 3, where the tensiometer did reach 70 kPa on one occasion (Fig. 3). During the week prior to harvesting the shallow tensiometer did indicate soil suctions greater than 60 kPa for about 7 days. Only the declines in tensiometer values at 37 and 62 DAP were associated with irrigation. Although several reductions in matric suction (to around 0 kPa) for the tensiometers installed at 60 cm indicate a number of drainage events, only the dip at 37 DAP was associated with excess irrigation (Fig. 3). The large reduction at 63 DAP was due to 20 mm of rainfall following irrigation.

The version of the CAMNET software used during this experiment (since superseded) for recording and displaying data was not amenable to graphical presentation in written reports. To overcome this difficulty, we manually transferred the soil water content data for each of the probes into our normal graphics program. Although the probes were recording every 30 minutes, we only used the 9 am values for each day, as to manually transfer the complete data set would have been too time consuming. Using data collected at 9 am also enabled direct comparison with corresponding tensiometer values.

The values for the CAMNET probes installed at 15 cm in Treatment 1 mirrored tensiometers installed in the same locations, i.e. as soil matric suction increased the saturation index indicated by the probes declined (Figs. 3,4). Although the probes indicated surface saturation after the 2 irrigation events 37 and 62 DAP, following rainfall 26 DAP the probe in Block 1 did not indicate saturated conditions, unlike the corresponding tensiometer. Neither probe showed saturation 48 DAP, following another rainfall event.

Apart from probe malfunction, either the probes were installed slightly deeper than the tensiometers (beyond the rainfall wetting front), or there were some restrictions to water flow into the probes. The former explanation is unlikely for the event 26 DAP, as the deep tensiometers also registered saturation on that occasion.

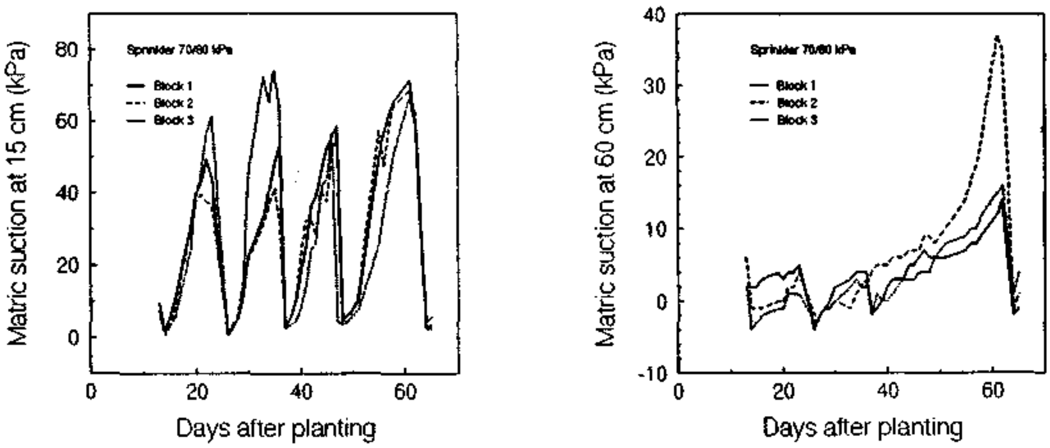


Figure 3. Fluctuations in soil matric suction at 15 and 60 cm below ground level, where green beans were irrigated using mini-sprinklers, when soil matric suction at 15 cm exceeded 70 kPa prior to budding or 80 kPa after budding.

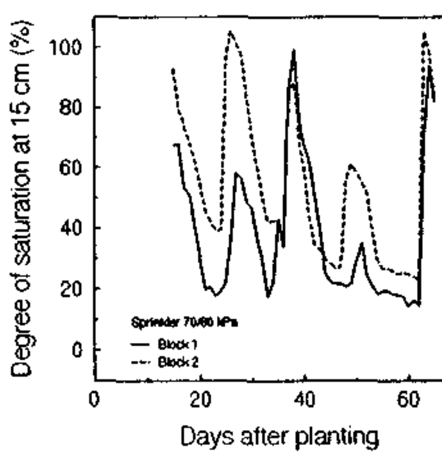


Figure 4. Fluctuations in the degree of soil saturation as measured by heat dissipation probes 15 cm below ground level, where green beans were irrigated using mini-sprinklers, when soil matric suction at 15 cm exceeded 70 kPa prior to budding or 80 kPa after budding.

Tensiometers in Treatment 2, with **T** at 70 kPa before and 40 kPa after budding, produced similar cycles in matric suction to Treatment 1 during the pre-budding period, i.e. up to 35 DAP (Fig. 5). From then until harvesting, soil matric suction only reached **T** on 2 occasions (43 and 58 DAP), triggering irrigation. Other declines in matric suction were obviously due to rainfall. The tensiometers installed at 60 cm indicated continuously wet conditions during the whole of the growing period, with several drainage events following either irrigation or rainfall (Fig. 5).

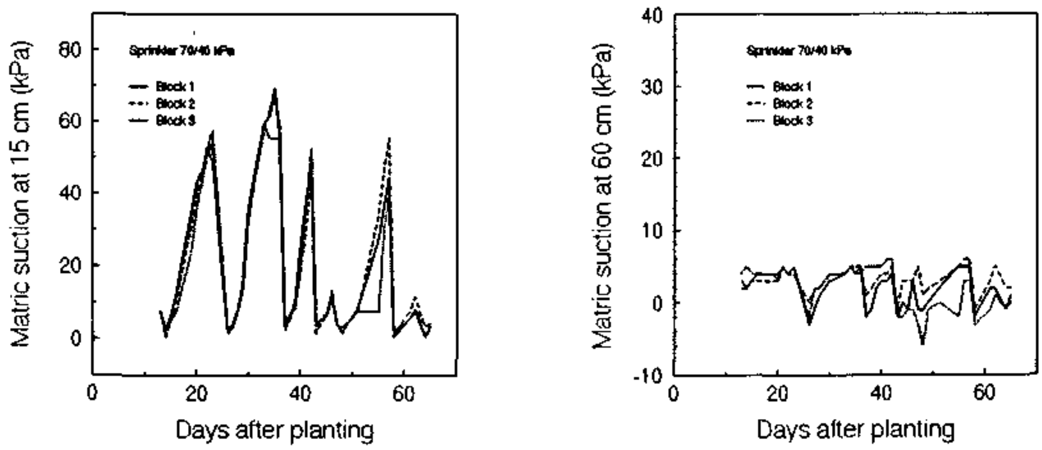


Figure 5. Fluctuations in soil matric suction at 15 and 60 cm below ground level, where green beans were irrigated using mini-sprinklers, when soil matric suction at 15 cm exceeded 70 kPa prior to budding or 40 kPa after budding.

Shallow tensiometers in Treatment 3 fluctuated regularly between saturation and a matric suction of 30-40 kPa throughout the growing period (Fig. 6). This was not because of a large increase in irrigation frequency (Treatment 3 received the same number of irrigations as Treatment 2), but because different irrigation timings meant the surface soil remained wetter for longer periods, resulting in deeper penetration of the intermittent rainfall wetting fronts. Apart from excess irrigation at 58 DAP, most deep drainage was associated with rainfall events, indicated by low matric suctions in the deeper tensiometers (Fig. 6).

During the pre-budding period, the data from the CAMNET probes installed at 15 cm in Treatment 3 reflected the corresponding shallow tensiometers (Fig. 7). From budding until the irrigation at 58 DAP, the CAMNET probes showed a steady decline in soil saturation. Although there were minor spikes in the readings from the CAMNET probes, the changes were certainly less substantial than the tensiometer values (Figs. 6,7). After the irrigation at 58 DAP, the shallow CAMNET probes again correlated well with changes in soil matric suction.

The changes in soil saturation from the CAMNET probe installed at 60 cm could be correlated to increasing soil suction in the corresponding deep tensiometer for the first 58 DAP. Following irrigation on that particular day, the deep tensiometer registered saturated soil conditions, however CAMNET probe only showed a slight increase in soil saturation (Fig. 7).

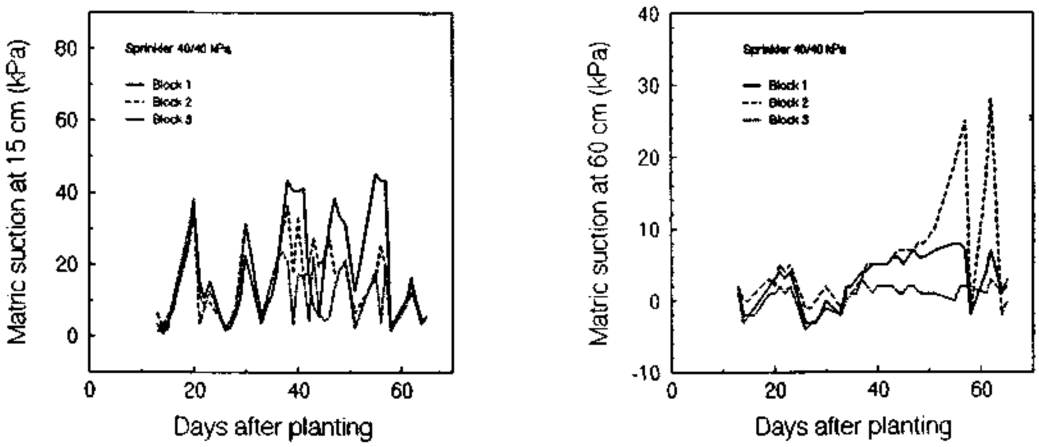


Figure 6. Fluctuations in soil matric suction at 15 and 60 cm below ground level, where green beans were irrigated using mini-sprinklers, when soil matric suction at 15 cm exceeded 40 kPa during the growing period.

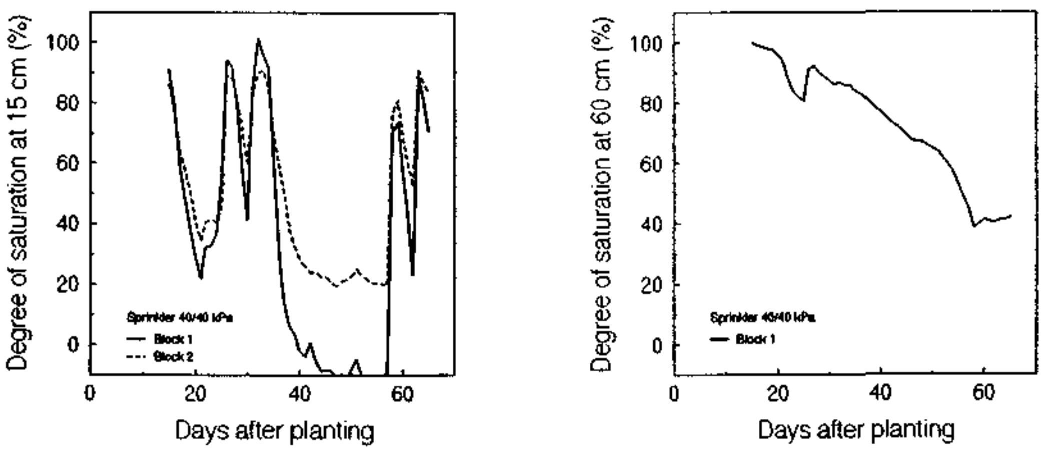


Figure 7. Fluctuations in the degree of soil saturation as measured by heat dissipation probes 15 cm below ground level, where green beans were irrigated using mini-sprinklers, when soil matric suction at 15 cm exceeded 40 kPa during the growing period.

The treatment irrigated using surface drip tape was watered twice as frequently as the sprinkler treatment with the same **T** settings. The fluctuations in soil matric suctions from the shallow tensiometers reflect this more rapid wetting/drying cycle (Fig. 8). Increases in matric suction in the shallow tensiometers were more rapid in the plots irrigated with drip tape compared to sprinklers. This was primarily because water was moving away from the tensiometer into drier soil not initially wet by the drip zone of the tape, i.e. the inter-row area. This was in addition to normal plant uptake and soil evaporative losses. Although the deeper tensiometers indicated saturated soil conditions on numerous occasions, most of this was attributable to rainfall, rather than excess irrigation (Fig. 8).

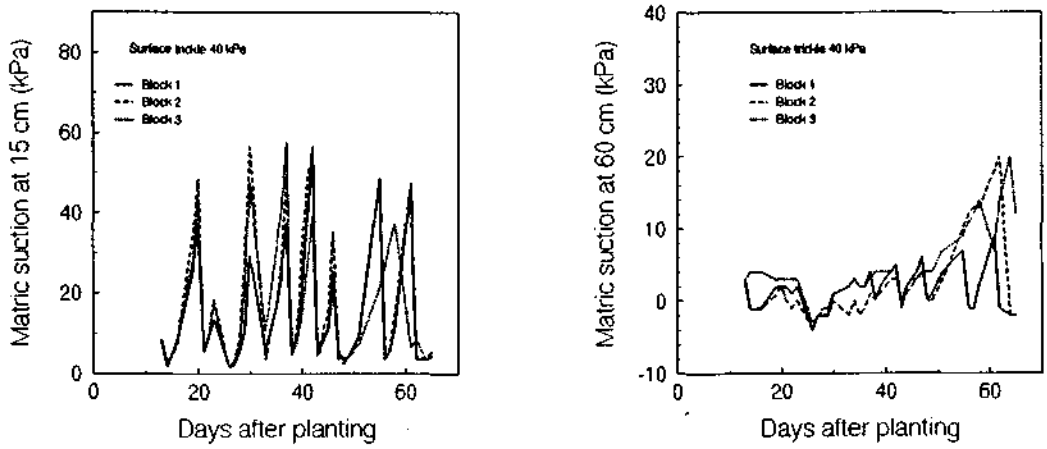


Figure 8. Fluctuations in soil matric suction at 15 and 60 cm below ground level, where green beans were irrigated using surface drip tape, when soil matric suction at 15 cm exceeded 40 kPa during the growing period.

The treatment irrigated with the subsurface tubing was the most frequently irrigated of all the treatments (it also had the least quantity applied at any one irrigation). The shallow tensiometer cycled rapidly between about 5 and 50 kPa (Fig. 9). The upper value is greater than the indicated T for this treatment because the matric suction tended to climb rapidly in 24 hr (frequently up to 15 kPa per day). Because of the nature of this irrigation system, irrigation water moving from the drip tubing to the shallow tensiometer (and shallow probe) transferred as unsaturated flow. Thus the shallow tensiometers seldom indicated saturated conditions after irrigation. The exceptions were after heavy rains (e.g. 26, 48 and 63 DAP). Interestingly, there was a general trend for slightly increased matric suction in the deep tensiometers installed under this treatment, indicating little drainage loss from this irrigation system (Fig. 9).

As in other treatments, the shallow CAMNET probes in Treatment 5 did not appear to be quite as sensitive to changes in soil matric suction as the corresponding tensiometers (Fig. 10). Although the shallow probes responded as expected to the heavy rainfall 26 DAP, follow up rainfall and irrigation did not cause the probes to indicate saturation, and often only resulted in 2-5% changes in probe readings (Fig. 10). The deep CAMNET probe showed a general trend for reducing soil wetness at 60 cm, punctuated by very small increases following rainfall or irrigation. There was no indication of completely saturated soil condition from 26 DAP until the beans were harvested (Fig. 10).

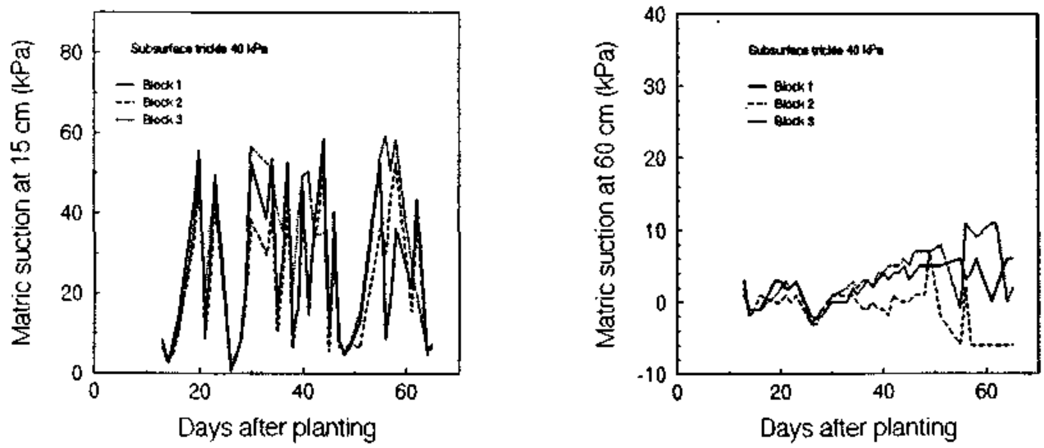


Figure 9. Fluctuations in soil matric suction at 15 and 60 cm below ground level, where green beans were irrigated using subsurface drip tube, when soil matric suction at 15 cm exceeded 40 kPa during the growing period.

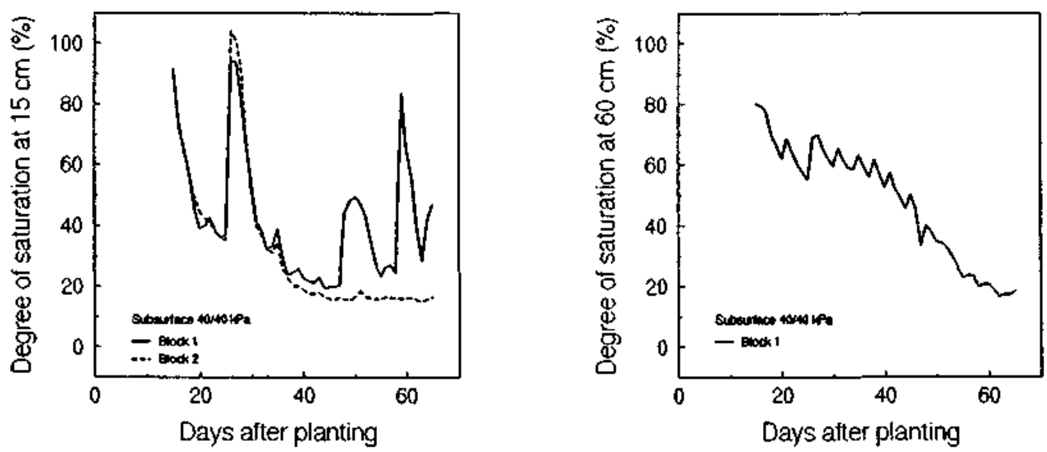


Figure 10. Fluctuations in the degree of soil saturation as measured by heat dissipation probes 15 cm below ground level, where green beans were irrigated using subsurface drip tube, when soil matric suction at 15 cm exceeded 40 kPa during the growing period.

The sprinkler irrigated treatments in this experiment only received 3-4 waterings during the growing period, compared to 12-19 irrigations for similar treatments at an equivalent time in 1991. Both drip irrigated treatments were irrigated significantly more frequently, particularly during the middle phases of the growing period, when there was less rainfall (Table 3). Irrigation during the first 30 DAP consisted of the initial post-sowing application of 36 mm, with the 40 kPa treatments receiving a further 10-15 mm about 3 weeks later. From 31 DAP until harvesting, the sprinkler irrigated treatments received 20-25 mm per irrigation, while the surface and subsurface drip treatments received 16 and 11 mm per irrigation respectively (Table 4). **Note that the irrigation and drainage values shown in Table 4 are averages per irrigation, not totals for the period.** Drainage values shown in Table 4 were mainly due to rainfall, not associated with any particular irrigation.

Table 3. Mean intervals (days) between irrigations for 5 watering regimes in autumn grown green beans. values in the same column followed by the same letter were not significantly different ($P<0.05$).

Irrigation treatment	Growth period (days after planting)			Total number of irrigations
	0-30	31-50	51-65	
SPR 70/80	30.0 b	20.0 d	15.0 b	3.0 a
SPR 70/40	30.0 b	10.0 c	15.0 b	4.0 b
SPR 40/40	15.0 a	20.0 d	15.0 b	4.0 b
SUR 40/40	15.0 a	6.7 b	10.0 a	6.7 c
SUB 40/40	15.0 a	3.8 a	12.5 ab	8.7 d

Table 4. Mean irrigation quantities and drainage losses for 5 watering regimes in autumn grown green beans.

Irrigation treatment	Growth period (Days after planting) 0-30		31-50		51-65	
	Irrig. (mm)	Drain. (mm)	Irrig. (mm)	Drain. (mm)	Irrig. (mm)	Drain. (mm)
SPR 70/80	36.0 d	59.0 b	29.0 e	5.4 a	19.0 c	0.6 a
SPR 70/40	36.0 d	58.1 b	24.0 d	11.6 a	26.0 d	11.1 b
SPR 40/40	25.2 b	32.7 a	21.7 c	10.6 a	26.0 d	0.0 a
SUR 40/40	26.5 c	32.8 a	16.0 b	5.6 a	15.3 b	3.1 ab
SUB 40/40	24.0 a	30.8 a	11.1 a	6.2 a	11.0 a	0.0 a

A summary of the total growing period water balance for each of the irrigation treatments (Fig. 11) shows the drip irrigated treatments received significantly ($P<0.01$) more irrigation than the sprinkler treatment irrigated at the same **T**, although the difference was only 20-25 mm. The drip treatments also had slightly higher amounts of deep drainage, again around 20 mm. It should be noted that of the 75-90 mm of total drainage in these 3 treatments, only 5-10 mm was directly due to excess irrigation. All 3 treatments irrigated at a **T** of 40 kPa had very similar levels of total evapotranspiration (circa 170 mm).

Treatment 2, with a **T** regime of 70/40 kPa, received 10 mm more irrigation than Treatment 3, and an increased total drainage of the same magnitude. The increased drainage was mainly due to one excessive irrigation 37 DAP. Even so, the amount of drainage that could be directly associated with over-irrigation was only 18 mm for the whole growing season. As would be expected, Treatment 1 (**T** 70/80 kPa) had the lowest levels of irrigation and total drainage of any of the irrigation treatments (Fig. 11). Both treatments with an initial **T** of 70 kPa had significantly ($P<0.01$) lower total evapotranspiration (**ET**) than the other 3 treatments. Observing the cumulative evapotranspiration of all 5 treatments (Fig. 12), most of the differences in ET rates occur between 15 and 40 DAP. There may have been lower rates of soil evaporation in the treatments with **T** at 70 kPa during this period, due to drier conditions at the soil surface. However, at least some of the difference may have been due to less vigorous plant growth resulting in reduced transpiration. From 40 DAP until harvest, there appeared to be very little difference in evapotranspiration between any of the 5 treatments, as shown by the parallel nature of the lines (Fig. 12).

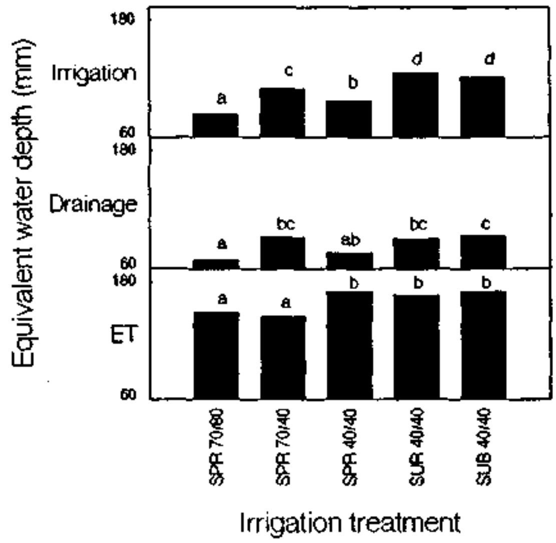


Figure 11. Changes in quantities of irrigation, total evapotranspiration and drainage losses under 5 irrigation regimes. Bars labelled with the same letter were not significantly different (P<0.05).

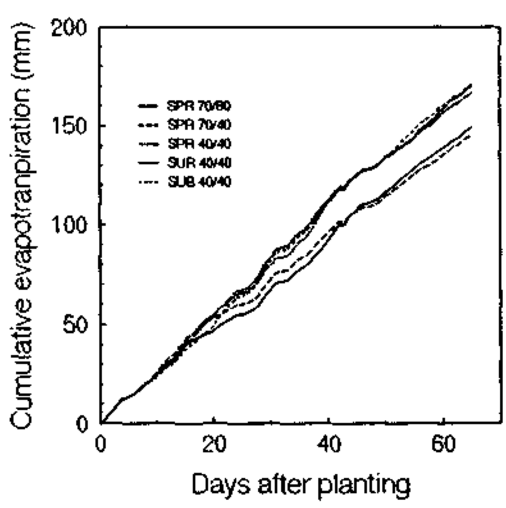


Figure 12. Reductions in cumulative evapotranspiration as the Critical Tensiometer Value increased.

Whilst there may have been a slight trend for increased growth of the bean plants watered using drip irrigation between 35 and 40 DAP, any differences in height were not substantial, and certainly not evident during the final few weeks prior to harvesting (Fig. 13).

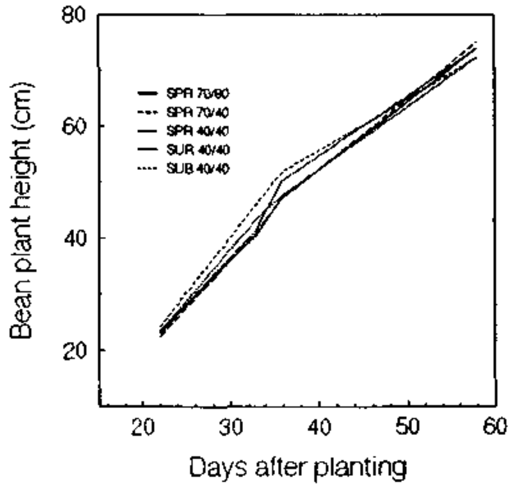


Figure 13. Irrigation application and scheduling systems have little effect on the heights of autumn grown green beans plants.

Yields ranged from 9-12 t/ha in this experiment, at least 2-3 times grower averages (Fig. 14). There was a non-significant trend for a 1.1 t/ha increase in bean yields for treatments with **T** set at 40 kpa during the pre-budding phase, compared with treatments with an initial **T** of 70 kPa. Within the treatments with a consistent **T** of 40 kPa throughout the growing period, there were no significant differences in yields between the 3 irrigation application systems. There was a significant ($P<0.1$) trend for bean yields (**Y**) to increase with **ET**, although there was substantial variability about the trend (Fig. 14). There was no effect of irrigation treatment on the lodging rating (**L**) in the beans, nor was there any significant relationship between **ET** and lodging. The overall mean lodging rating of 2.1 would not cause problems with mechanical harvesting, except in very wet conditions.

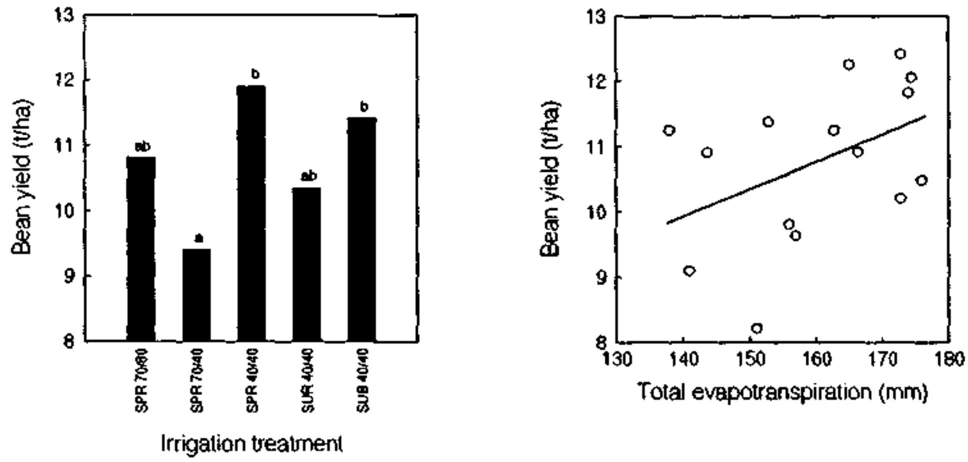


Figure 14. The yield of autumn grown green beans was slightly affected by the Critical Tensiometer Value used pre-budding, with a significant trend for increased yields as total evapotranspiration during the growing season rose.

$$Y = 4.11 + 0.0416\ ET \qquad r^2 = 0.20^{+} \qquad \text{Equation (2)}$$

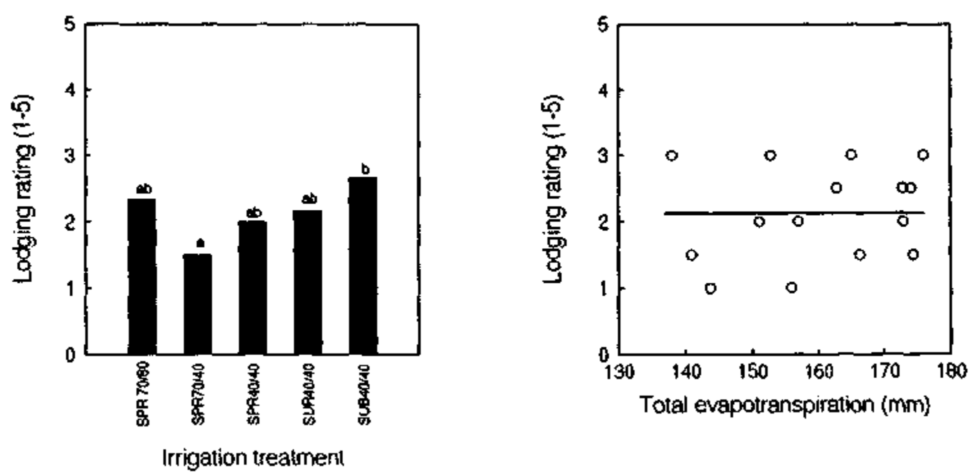


Figure 15. Irrigation method, scheduling regime and total evapotranspiration had no effect on the lodging rating of autumn grown green beans.

$$L = 2.133 \qquad r^2 = 0.00^{ns} \qquad \text{Equation (8)}$$

5. Discussion and conclusions

As in previous experiments, the tensiometer system was easy to install and use, gave accurate, reliable readings, required little maintenance and was relatively cheap. The deeper tensiometer was installed at 60 cm and neutron probe readings taken to 80 cm below the soil surface as previously suggested. There was little uptake of water from the lower parts of the soil profile in this instance.

As discussed in a previous report, we are still not confident in the response of the initial version of the CAMNET probes to increases in soil water content due to unsaturated flow. Whilst some of the failure to indicate saturation in certain circumstances may have been caused by shifts in calibration, there is evidence that unsaturated flow into the probes is inhibited to some degree. This hypothesis is further strengthened by observations that the probes were least responsive in the subsurface irrigation treatment, where unsaturated water flow was most important. Apart from intermittent failure of several CAMNET probes during the growing period, generally the system as a whole performed relatively well. A new probe design has just been released, in addition to new calibration software, both of which should overcome some of the current problems. In addition, the system developers intend supplying text and screen editors that will enable manipulation of raw data files and graphical output, both of which are highly desirable features. This new technology, as well as the performance of the probes in unsaturated soil conditions, will be investigated in future experiments.

Utilising watering regimes suggested by our previous research, in this experiment there was little drainage from any of the treatments that could be attributed directly to over-irrigation (only 5-10% of total drainage losses). The 70-90 mm of drainage were almost entirely due to rainfall in excess of the storage capacity of the soil profile. Unfortunately, the rainfall during this experiment adversely affected contrasts between the various irrigation treatments, particularly where a range of **T** values were investigated. Soil matric suctions at 15 cm below the ground surface were greater than 50 kPa for only 12 and 8 days for Treatments 1 and 2 respectively. This certainly reduced the likelihood of differences in bean growth and yield occurring.

Although there was a trend for lower yields in treatments irrigated at a pre-budding **T** of 70 kPa, such a slight yield reduction may be acceptable if irrigation costs could be substantially decreased, or less vegetative bean plants develop as a consequence of reduced water use. There may also be an advantage from greater soil water deficits increasing the reserve for storing rainfall. The effectiveness of such a strategy would depend on the timing, frequency and amounts of rainfall during the growing period, in relation to the imposed irrigation regime. As an example, a less frequently watered crop may still have more drainage losses compared to a more frequently watered crop if rainfall in the former immediately followed irrigation (as happened in this experiment). Unfortunately, the frequency of rainfall during the pre-budding phase did not enable the potential yield losses from an increased early deficit strategy to be fully investigated.

Due to the extensive rainfall, mean evaporative demand during the growing period (around 3.5 mm of pan evaporation per day) was only 75% of that recorded in a similar experiment conducted in 1991. As a consequence, total evapotranspiration of the highest yielding treatments in 1992 was 170 mm, about 30 mm less than the corresponding treatments in 1991. This difference was almost entirely due to lower ET rates during the first 40 days after planting, suggesting a substantial component of soil evaporation.

Results from experiments to date suggest that a Critical Tensiometer Value for maximum production of autumn grown green beans is probably around 40 kPa, possibly even 50 kPa during the early vegetative phase. Under this criteria, irrigation would be applied every 6-7 days during the growing period, with 17-20 mm for the first 7 weeks after planting, increasing to 20-23 mm per irrigation for the final 3 weeks. Given this sequence, a total of about 11 irrigations (220 mm) would be needed to obtain optimum green beans yields and quality while minimising irrigation costs and drainage losses. This regime applies to overhead application systems. Similar overall quantities would probably be required for drip irrigation systems, supplied in smaller amounts on a more frequent basis. Obviously any rainfall during the intervening period would reduce these requirements, although there may still be a need to irrigate for other purposes, such as fertiliser or pesticide incorporation. The target evapotranspiration for the growing season is probably around 170 mm in cool, moist conditions, increasing to 210 mm in warm, dry growing periods. These values would also be affected by cultivar and agronomic practices.

Although increased irrigation frequency may enhance risks of fertiliser (and pesticide) leaching, disease outbreaks and crop lodging, we have not encountered these problems to date. Careful attention to crop nutrition and pest management, as well as precise monitoring of the amounts of water applied at each irrigation, is required. There may be a case for selecting cultivars with a stronger bush habit, to reduce lodging losses.

In this experiment, method of application had little impact on the overall water balance, and no effect on the performance of the beans. The drip irrigated treatments received marginally more irrigation (supplied as less water more frequently) than the corresponding sprinkler irrigated treatment. They also had slightly higher drainage losses, entirely associated with the timing of rainfall with respect to irrigation, rather than excessive irrigation per se. The AGRI-GRO tubing was equally as effective at supplying irrigation water to the beans as the conventional drip tape or the overhead sprinklers. There is some indication of a decline in leak rate of the AGRI-GRO tubing over time, however over the 65 day growing period of the beans this did not affect plant performance. Installation and retrieval of the pipe was labour and time-intensive; a permanent installation would be needed if the product was to be cost effective. Permanent installation would mean require several changes to current vegetable production systems, probably including permanent bed / minimum tillage approaches.

We intend to conduct further experiments investigating irrigation scheduling techniques and application methods for green bean production. The format and design of these experiments have yet to be finalised, depending on experimental results for other crops.

EXPERIMENT REPORT

1. **Report** **Final** **Date of Report:** 13-10-92

Initiation Date: 10-7-91 **Completion Date:** 04-06-92

Project Number: S8902

Project Title: Irrigation scheduling in vegetables

Experiment Number: S8902.09 **Officer Responsible:** Craig Henderson

Experiment Title: Irrigation scheduling for autumn grown lettuce.

2. Experiment Objectives

This experiment sought to determine the relationship between lettuce yield and tensiometer values. It also attempted to determine the efficiency of irrigation by quantifying the amounts of applied water draining beyond the root zone during the growing period.

3. Summary of Results

The experiment was conducted at Gatton Research Station, from April-June 1992. Lettuce (cv. *Yatesdale*) were grown using standard agronomy, with 5 irrigation treatments replicated 3 times in a RCB design. Plots were 4.5 m wide and 10 m long, with a total experimental area of 0.065 ha. The five irrigation treatments involved commencing irrigation at different Critical Tensiometer Values (**T** kPa), using tensiometers installed 15 cm below ground level in each plot. The **T** values were; 40 kPa; 20 kPa; and 15 kPa. The 20 kPa treatment was further divided into application with overhead sprinklers, conventional drip tape, or subsurface drip tubing. Rain during the growing period reduced contrasts between the irrigation treatments. Scheduling with tensiometers reduced drainage losses due to irrigation to 5-10% of application, however drainage associated with excess rainfall was substantial (40-50 mm). The subsurface drip irrigated treatments received marginally more irrigation (supplied as less water more frequently) than the corresponding sprinkler irrigated treatment. They also had slightly higher drainage losses. There is some indication of a decline in leak rate of the AGRI-GRO tubing over time. There were no significant effects of irrigation method or frequency on the number of lettuce heads harvested (around 38 000/ha = 95% cut out), nor the mean weight of the harvested heads (1.07 kg), however the overall yield of the subsurface irrigated lettuce was significantly (10%) less than the mean of the other 4 treatments (37.7 t/ha vs. 41.5 t/ha). There were no significant relationships between any of the lettuce yield parameters and total evapotranspiration.

EXPERIMENT REPORT

Irrigation scheduling for autumn grown lettuce

by C. Henderson and M. Webber
Department of Primary Industries
Gatton Research Station

Experiment No. S8902.09 10.4.92-4.6.92

1. Relevance to Industry

In many regions, including the Lockyer Valley, irrigation demands regularly exceed the reliable capacity of the water supply, resulting in scarcity or reliance on poorer quality water. In many vegetable enterprises irrigation is a significant proportion of overall production costs. Shallow rooted vegetables are substantial users of water; for example brassicas and lettuce require 2-4 ML per hectare per crop. Until recently, the frequency and amount of irrigation was relatively ad hoc, based on tradition and grower experience, combined with superficial observations of plant or soil conditions.

Some vegetable growers use tensiometers or neutron probes to monitor soil water status and schedule irrigations. Both methods have advantages and disadvantages, however tensiometers appear to have the best immediate potential for use in shallow rooted vegetables. Most water uptake in lettuce occurs in the upper 0.3-0.5 m of the soil profile.

Matching irrigation to crop requirements maximises production by minimising plant water stress, nutrient deficiencies and some diseases, as well as preventing build up of salinity problems. By preventing overwatering, problems with leaching of nutrients and pesticides into groundwater (and beyond the zone of usefulness) are reduced, as well as a decrease in disease levels.

2. Objectives

This experiment sought to determine the relationship between lettuce yield and tensiometer values, under various irrigation systems and regimes. It also attempted to determine the efficiency of these scheduling and application systems by quantifying the amounts of applied water draining beyond the root zone during the lettuce growing period.

3. Materials and methods

The experiment was conducted on a black earth soil (*Ug5.15*) at Gatton Research Station (lat 27°33'S, long 152°20'E). The experimental design was a randomised complete block, with 5 irrigation treatments replicated 3 times. Each plot was 3 beds (2 rows of lettuce per 1.5 m bed) wide and 10 m long.

The soil was prepared as per standard practice for lettuce. Cv. *Yatesdale* were transplanted into beds on the 10th April 1992, with 0.67 m between the rows and 0.33 m intra-row spacing. A total of 400 kg/ha of compound fertiliser (52 kg N, 9 kg P, 53 kg K, 75 kg S) was applied immediately before planting. Calcium nitrate was sprayed at 0.8 kg/ha over the experiment on the 27th May 1992. The area was hand-hoed every 3 weeks for weed control. A single application of 1.76 kg/ha of mancozeb was sprayed on the 1st May 1992. Insects were controlled with regular applications of insecticides, including methomyl, endosulfan and dimethoate.

The initial post-planting irrigations utilised standard solid-set pipes and overhead sprinklers over the whole experimental area, for the first 2 weeks after transplanting. From then until harvest, systems of mini-sprinklers, drip tape or subsurface drip tubing were used to individually water each plot. Schematics of plot layouts are shown in Figs. 1 and 2. Each plot consisted of 3 beds of lettuce side by side. The central bed was the treatment area, while the two outside beds were buffer zones.

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

The plots watered with surface drip tape had 2 rows of tape in each treatment bed, positioned immediately adjacent to the lettuce rows. In addition, another single row of tape was positioned beside the closest lettuce row in each of the buffer beds, as shown in Fig. 2. The tape used was 'T-Tape Row Crop' with drip emitters every 20 cm, and an output of about 7.3 $Lm^{-1}hr^{-1}$ at an operating pressure of 70 kPa. This corresponded to an application rate of approximately 9 mm/hr on a total area basis.

The beds watered with the subsurface system had the 'AGRI-GRO' continuous drip tubing positioned directly under the 2 lettuce rows in the treatment beds, as well as the 2 adjacent lettuce rows in the buffer beds (Fig. 2). The tube was installed using small trench digger, at a depth of about 20 cm. The tube was installed on the 9th April 1992, with the whole experimental area cultivated and harrowed after installation. The tubing had an initial output of around 5.4 $Lm^{-1}hr^{-1}$ at an operating pressure of 90 kPa. This corresponded to an application rate of approximately 7 mm/hr on a total area basis.

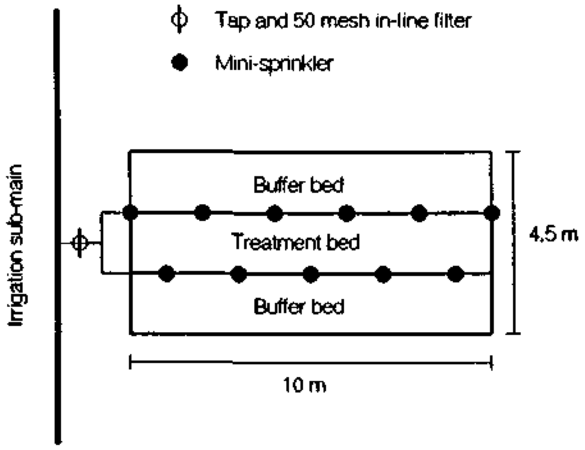


Figure 1. Mini-sprinkler system design for an individual plot in an experiment investigating irrigation scheduling in autumn grown lettuce.

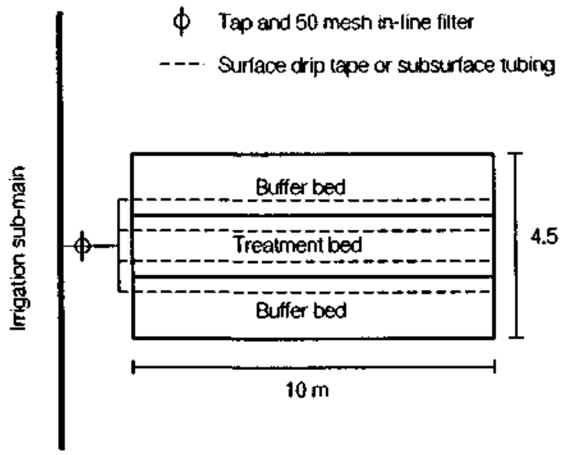


Figure 2. Surface and subsurface drip system designs for an individual plot in an experiment investigating irrigation scheduling in autumn grown lettuce.

Tensiometers were installed 15 cm and 45 cm below ground level in each treatment bed. *Loctronic* tensiometers were used, consisting of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum, while an electronic vacuum gauge attached to the syringe records the vacuum in the tensiometer air gap. Tensiometer readings were recorded daily, usually around 9 am.

Critical Tensiometer Values (T) were used to trigger irrigations in this experiment. Irrigation was applied when readings for the tensiometers installed 15 cm below the ground surface were greater than the **T** individually set for each treatment. Five irrigation treatments were investigated, involving 3 application methods, combined with 3 scheduling regimes based on tensiometer readings:

1. Irrigated using mini-sprinklers, scheduled at **T** 40 kPa (**SPR 40**).
2. Irrigated using mini-sprinklers, scheduled at **T** 20 kPa (**SPR 20**).
3. Irrigated using mini-sprinklers, scheduled at **T** 15 kPa (**SPR 15**).
4. Irrigated using surface drip tape, scheduled at **T** 20 kPa (**SUR 20**).
5. Irrigated using subsurface drip tube, scheduled at **T** 20 kPa (**SUB 20**).

Each plot was irrigated according to its allocated treatment. Plots with the same irrigation treatment were occasionally watered on different days, due to differences in the time for the tensiometers to reach values necessary to trigger irrigation.

Aluminium neutron probe access tubes were installed to depths of 80 cm in each treatment bed, 5 cm inside a lettuce row and equidistant between 2 neighbouring plants. Neutron moisture meter readings were taken twice a week using a Campbell Pacific Nuclear Hydroprobe. A single reading was taken at 5 depth intervals, commencing 5 cm below the ground surface, incrementing by 10 cm. On each day that the neutron probe measurements were made, 5 standard counts was also conducted in a 200 L drum of water. Calibration equations for the neutron probe data were assumed to be the same as for previous experiments at this site.

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

The widths of the lettuce plants were measured 28 days after transplanting (DAP). Five plants were randomly selected and assessed in each plot. Lettuce were harvested from the treatment beds on the 4th June 1992. For each plot the number of marketable heads were counted, and 2 samples containing 12 lettuce were weighed.

4. Results

There was frequent rainfall during the growing period (Table 1), somewhat interfering with the experiment.

Table 1. Rainfall during the growing period for autumn grown lettuce.

Weeks after sowing	Rainfall (mm)
1	3.8
2	2.4
3	18.8
4	0.8
5	18.6
6	47.6
7	0.0
8	0.8
TOTAL	92.80

The calibration equations for the neutron probe took the following form;

$$V = a + b * FC \qquad \text{Equation (1)}$$

where V = volumetric water content (cm^3cm^{-3})
FC = fractional neutron count (reading in soil divided by standard count in water)
a and b are equation parameters

The parameter values and r^2 for the calibration equations for each of the blocks and depth intervals are given in Table 2.

Table 2. Parameters and goodness of fit for calibration equations relating volumetric soil water content to neutron probe readings.

Depth interval cm	Block 1			Block 2			Block 3		
	a	b	r^2	a	b	r^2	a	b	r^2
0-10	0.062	1.199	0.94	0.024	1.147	0.91	0.078	0.964	0.93
10-20	0.087	0.520	0.82	0.076	0.504	0.90	0.086	0.503	0.88
20-30	-0.125	0.829	0.73	-0.196	0.925	0.92	-0.122	0.831	0.96
30-40	-0.060	0.677	0.64	-0.062	0.705	0.73	-0.057	0.726	0.67
40-50	-0.032	0.600	0.46	-0.191	0.878	0.78	0.057	0.516	0.44

All r^2 values were highly significant ($P<0.01$), except for those less than 0.50, which were significant ($P<0.05$).

Using a simple spreadsheet, a daily water balance was calculated for each plot. Rainfall, irrigation, stored soil water, pan evaporation, evapotranspiration and drainage of soil water below 50 cm were determined from planting through to harvest. Details of the calculations are available from the authors.

For the first 3 weeks after transplanting, the shallow tensiometers in all the plots fluctuated between 2 and 20 kPa. During the next 14 days, the surface soils in all treatments gradually dried out, reaching matric suctions of about 40 kPa in Treatments 1 and 4, and 25-30 kPa in the other 3 treatments (Fig. 3-7). Several rainfall events between 33 and 43 DAP saturated the soil profile, as indicated by the low values for both the shallow and deeper tensiometers in all treatments. There was substantial through drainage associated with excess rainfall during this period.During the final 2 weeks prior to harvesting, the shallow tensiometers in the plots watered with sprinklers or surface drip tape fluctuated between 2 kPa and the respective **T** values of 40, 20, 15 and 20 kPa. Despite frequent watering during this final 2 weeks, the shallow tensiometers in the areas irrigated with the subsurface pipe continued to rise (Fig. 7).

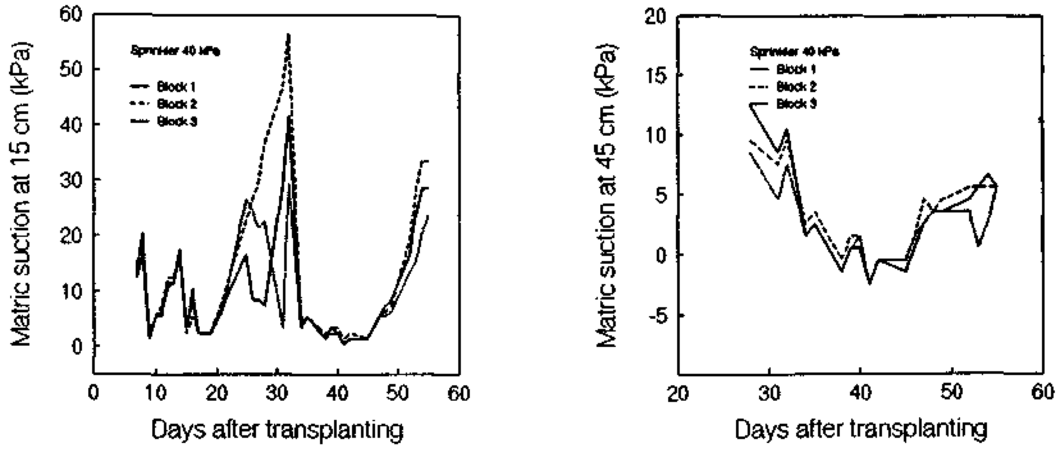


Figure 3. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where lettuce were irrigated using mini-sprinklers, when soil matric suction at 15 cm exceeded 40 kPa.

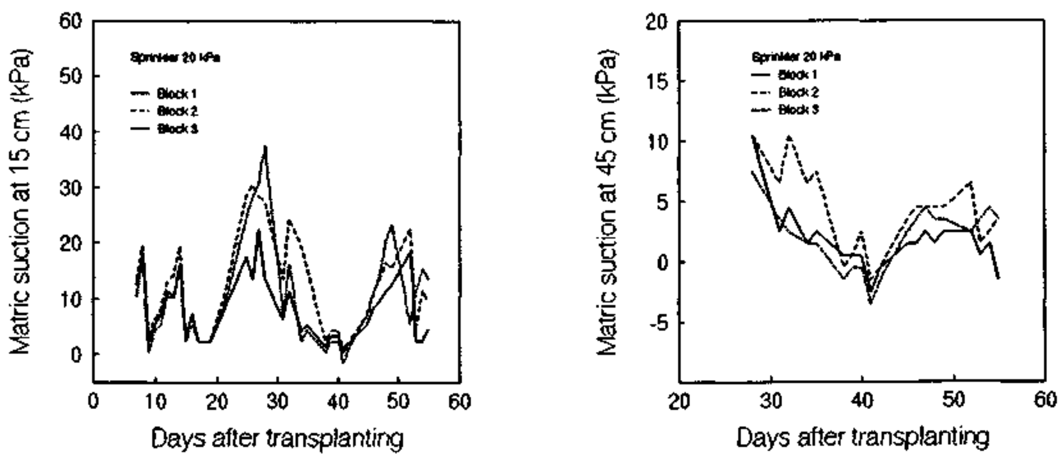


Figure 4. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where lettuce were irrigated using mini-sprinklers, when soil matric suction at 15 cm exceeded 20 kPa.

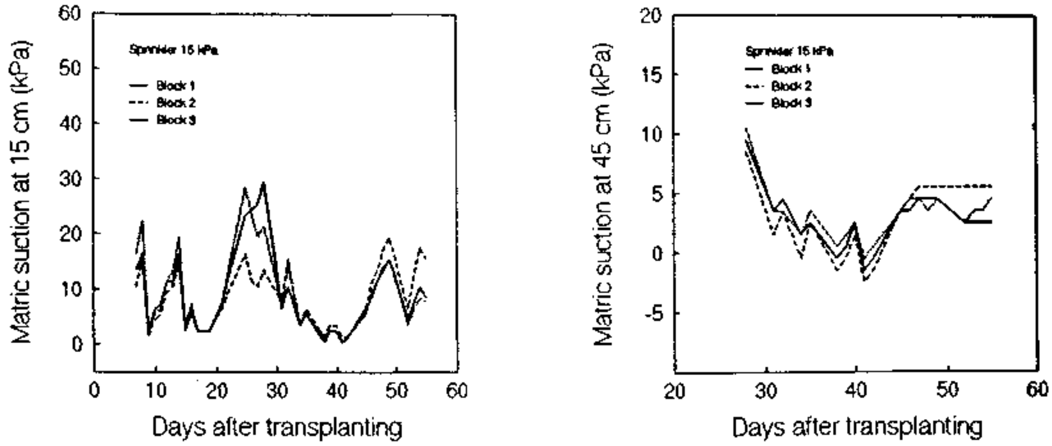


Figure 5. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where lettuce were irrigated using mini-sprinklers, when soil matric suction at 15 cm exceeded 15 kPa during the growing period.

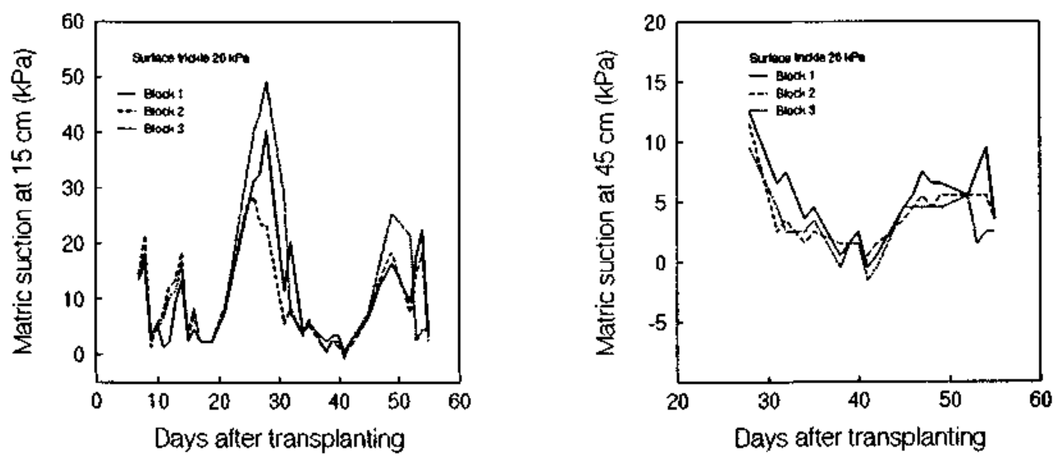


Figure 6. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where lettuce were irrigated using surface drip tape, when soil matric suction at 15 cm exceeded 20 kPa during the growing period.

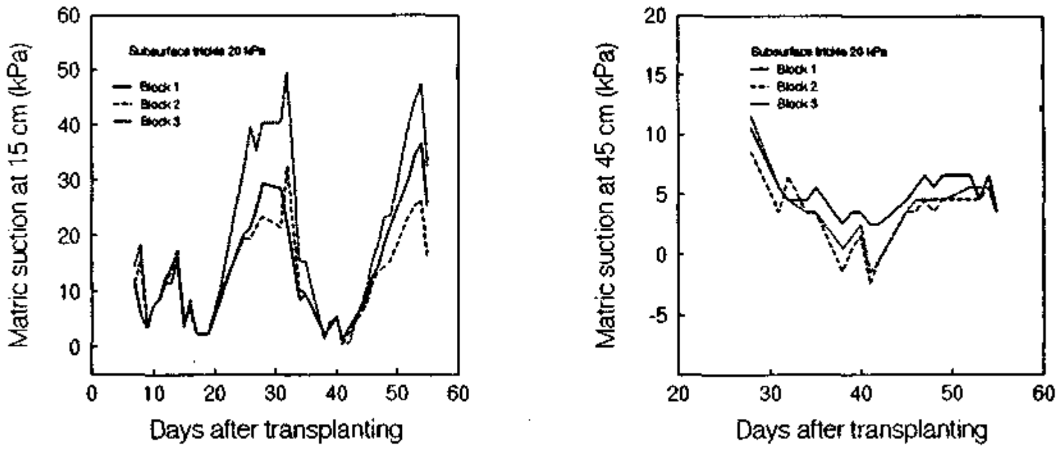


Figure 7. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where lettuce were irrigated using subsurface drip tube, when soil matric suction at 15 cm exceeded 20 kPa during the growing period.

Due to the episodic nature of the rainfall events, the sprinkler irrigated treatments in this experiment received 5 irrigations during the growing period (only 2 after 20 DAP). This compared to 12-19 irrigations for similar treatments in 1991. Both drip irrigated treatments were irrigated significantly more frequently (Table 3).

Irrigation for all lettuce during the first 20 DAP consisted of an initial post-transplanting application of 40 mm, followed by 40 mm and 25 mm (8 and 14 DAP respectively). Each of these irrigations was in excess of requirements, resulting in substantial drainage losses (circa 11 mm per irrigation). From 21 DAP until harvesting, the sprinkler irrigated treatments received 18-22 mm per irrigation, the surface drip treatment received 8-16 mm per irrigation, while the subsurface treatments were irrigated with 10 mm of water on average (Table 4). There were no significant drainage losses associated with excess irrigation in Treatments 2-4. Up to 25% of the final irrigation applied to the plots watered with T set at 40 kPa was lost as drainage, while an even greater proportion of drainage occurred in the subsurface irrigated plots during the 14 days prior to harvest (Table 4). **Note that the irrigation and drainage values shown in Table 4 are averages per irrigation, not totals for the period.**

Table 3. Mean intervals (days) between irrigations for 5 watering regimes in autumn grown lettuce. Values in the same column followed by the same letter were not significantly different ($P<0.05$).

Irrigation treatment	Growth period (days after transplanting)			Total number of irrigations
	0-20	21-40	41-55	
SPR 40	6.7 a	20.0 c	15.0 c	5.0 a
SPR 20	6.7 a	20.0 c	15.0 c	5.0 a
SPR 15	6.7 a	20.0 c	15.0 c	5.0 a
SUR 20	6.7 a	16.7 b	7.5 b	6.3 b
SUB 20	6.7 a	10.0 a	5.0 a	8.0 c

Table 4. Mean irrigation quantities and drainage losses (attributable to excess irrigation) for 5 watering regimes in autumn grown lettuce.

Irrigation treatment	Growth period (Days after planting)					
	0-20		21-40		41-55	
	Irrig. (mm)	Drain. (mm)	Irrig. (mm)	Drain. (mm)	Irrig. (mm)	Drain. (mm)
SPR 40	34.7 a	11.5 a	19.0 c	0.0 a	18.0 c	5.4 b
SPR 20	34.7 a	11.5 a	20.0 c	0.0 a	20.0 d	1.1 a
SPR 15	34.7 a	11.5 a	22.0 c	0.0 a	18.0 c	2.5 ab
SUR 20	34.7 a	11.5 a	15.7 b	1.7 a	8.3 a	0.6 a
SUB 20	34.7 a	11.5 a	10.5 a	0.0 a	10.3 b	4.5 b

A summary of the total growing period water balance for each of the irrigation treatments (Fig. 8) shows the subsurface drip irrigated treatment received significantly ($P<0.01$) more irrigation than the other treatments, although the difference was only 20 mm. This treatment also had the greatest quantity of deep drainage, around 20 mm more than the plots sprinkled at T of 20 kPa. In all treatments, approximately half the deep drainage was associated with over-irrigation (mainly during the first 20 DAP), while the remainder occurred after heavy rain. There were significant trends for the treatments irrigated with sprinklers at T of 20 kPa or less to have higher levels of total evapotranspiration (circa 120 mm) than where T was 40 kPa, or where drip systems were used (circa 110 mm). Most of these differences were due to different ET rates between 21 and 42 DAP (Fig. 9). From 42 DAP until harvest, there appeared to be very little difference in evapotranspiration between any of the 5 treatments, as shown by the parallel nature of the lines. Note that the total ET in this experiment was about 80 mm less than in a lettuce experiment conducted at a similar time of year in 1991, reflecting lower evaporative demand in the 1992 experiment.

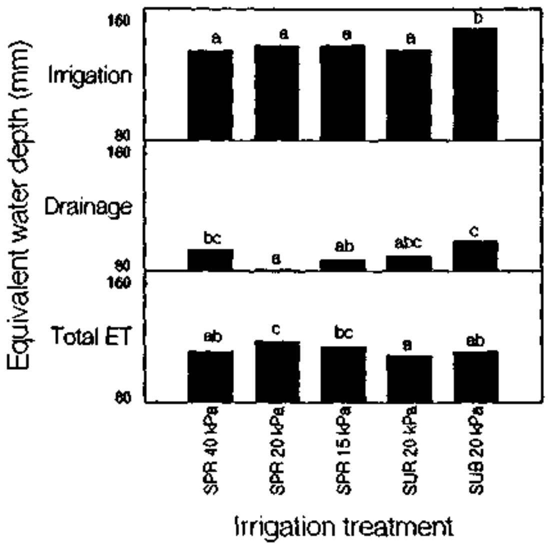


Figure 8. Changes in quantities of irrigation, total evapotranspiration and drainage losses under 5 irrigation regimes. Bars labelled with the same letter were not significantly different ($P<0.05$).

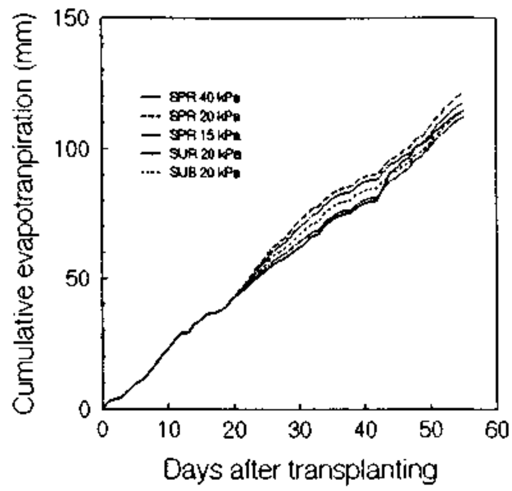


Figure 9. Reductions in cumulative evapotranspiration as the Critical Tensiometer Value increased.

Lettuce irrigated using drip systems were significantly narrower than the sprinkler irrigated lettuce (34.5 cm vs. 36.4 cm) at 28 DAP. Lettuce in the subsurface irrigation plots were around 1.2 cm smaller than the plants watered with the surface drip tape. There was also a slight trend for increasing lettuce width as **T** was reduced from 40 to 15 kPa.

There were no significant effects of irrigation method or frequency on the number of lettuce heads harvested (around 38 000/ha = 95% cut out), nor the mean weight of the harvested heads (1.07 kg), however the overall yield of the subsurface irrigated lettuce was significantly (10%) less than the mean of the other 4 treatments (37.7 t/ha vs. 41.5 t/ha). There were no significant relationships between any of the lettuce yield parameters and total evapotranspiration (Figs. 10-12).

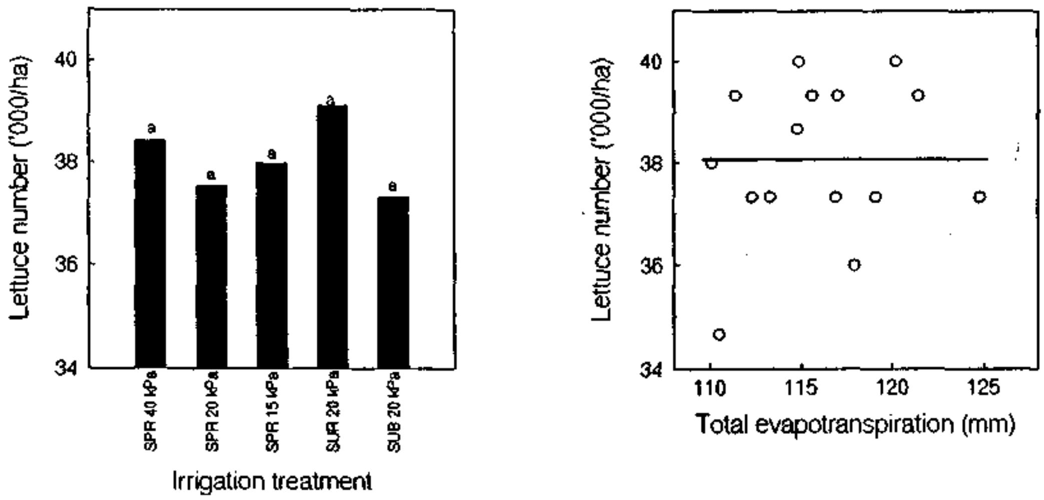


Figure 10. The number of marketable lettuce heads was unaffected by altering either the Critical Tensiometer Value, method of irrigation application, or the total evapotranspiration of autumn grown lettuce.

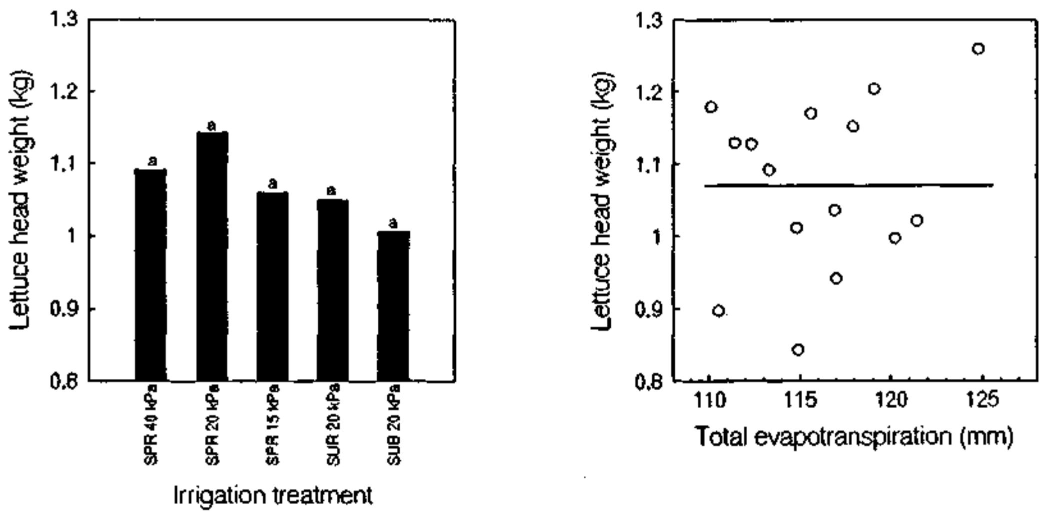


Figure 11. The mean weight of marketable lettuce heads was unaffected by altering either the Critical Tensiometer Value, method of irrigation application, or the total evapotranspiration of autumn grown lettuce.

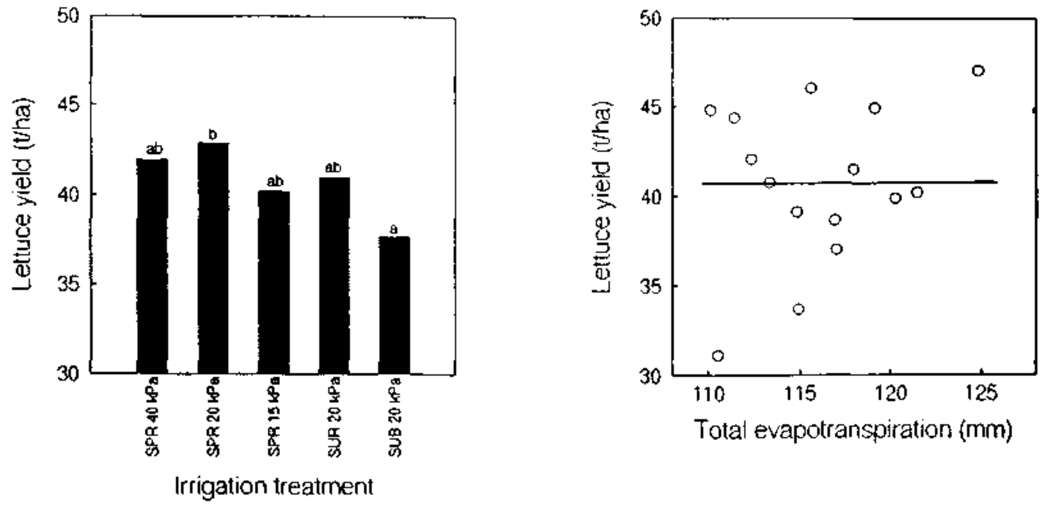


Figure 12. The total yield of marketable lettuce heads was slightly reduced by subsurface drip irrigation, however it was unaffected by altering either the Critical Tensiometer Value or the total evapotranspiration of autumn grown lettuce.

5. Discussion and conclusions

As in previous experiments, the tensiometer system was easy to install and use, gave accurate, reliable readings, required little maintenance and was relatively cheap.

During the 2 week period immediately after transplanting, when the experiment was irrigated using standard overhead sprinklers, problems with the irrigation pump control mechanism resulted in excess irrigation on at least 2 occasions. Once we commenced managing the irrigation with our control systems (utilising watering regimes suggested by our previous research), virtually no drainage could be attributed directly to over-irrigation. Most drainage losses occurred in the subsurface irrigated areas, due to the need to saturate zones around the drip pipes, in order to encourage upward water movement toward the lettuce root systems. The bulk of the deep drainage was due to rainfall in excess of the storage capacity of the soil profile.

Unfortunately, the rainfall during this experiment adversely affected contrasts between the various irrigation treatments, particularly where a range of **T** values were investigated. Soil matric suctions at 15 cm below the ground surface were greater than 20 kPa for only for only a few days in the sprinkler irrigated treatments, even when **T** was set at 40 kPa. Only in the subsurface drip irrigated treatment were there substantial intervals with surface soil matric suctions above 20 kPa. This certainly reduced the likelihood of differences in lettuce growth and yield occurring.

Results from experiments to date suggest that a Critical Tensiometer Value for maximum production of autumn grown lettuce is probably 15-20 kPa. On black earth soil types, this involves the following approximate irrigation sequences (given that no rainfall occurs). For early autumn crops, 13-15 mm every 2.5-3 days for the first 20 days, followed by 15-17 mm every 4-5 days as the lettuce root systems develop and evaporative demand declines. Normally the target evapotranspiration for lettuce is around 210-220 mm, however evaporative demand during this experiment (as indicated by an evaporation pan) was 25-30% lower than average, particularly during the first 30 DAP. In average seasons, the total irrigation requirement would be about 230-250 mm, allowing for inefficiencies and drainage losses. This regime applies to sprinkler irrigation. Similar overall quantities would probably be required for drip irrigation systems, supplied in smaller amounts on a more frequent basis. Obviously any rainfall during the intervening period would reduce these requirements, although there may still be a need to irrigate for other purposes, such as fertiliser or pesticide incorporation. The regime would also be affected by cultivar and agronomic practices.

In this experiment, method of application had little impact on the overall water balance or performance of the lettuce. The subsurface drip irrigated treatments received marginally more irrigation (supplied as less water more frequently) than the corresponding sprinkler irrigated treatment. They also had slightly higher drainage losses. There is some indication of a decline in leak rate of the AGRI-GRO tubing over time. Despite frequent irrigation, on several occasions during the latter stages of the lettuce growing period we were unable to reduce the matric suction in the surface of the soil using the subsurface drip tubing. Water did not appear to be moving readily from the saturated zone around the tube into the soil surrounding the tensiometer installations. This lack of wetting appeared to be confirmed by the trend for slightly lower lettuce yields in the areas irrigated using the subsurface tubing. Installation and retrieval of the pipe was labour and time-intensive; a permanent installation would be needed if the product was to be cost effective. Permanent installation would mean require several changes to current vegetable production systems, probably including permanent bed / minimum tillage approaches. The performance of the subsurface tubing will be further investigated under other crops in future experiments.

We are relatively confident that the irrigation regimes and scheduling systems developed over the past 2 years will maximise lettuce production and irrigation efficiency on farms in south-east Queensland. A future experiment will investigate the interactions between weed control technology, irrigation scheduling and varieties on larger farm scale plots.

EXPERIMENT REPORT

Report **Final** **Date of Report:** 28-10-93

Initiation Date: 2-6-92 **Completion Date:** 20-08-92

Project Number: S8902

Project Title: Irrigation scheduling in vegetables

Experiment Number: S8902.10 **Officer Responsible:** Craig Henderson

Experiment Title: Irrigation scheduling for winter grown broccoli.

Experiment Objectives

This experiment sought to determine the relationship between broccoli yield and tensiometer values. It also attempted to determine the efficiency of irrigation by quantifying the amounts of applied water draining beyond the root zone during the growing period.

Summary of Results

The experiment was conducted at Gatton Research Station, from June-August 1992. Broccoli (cv. *Greenbelt*) were grown using standard agronomy, with 5 irrigation treatments replicated 3 times in a RCB design. Plots were 4.5 m wide and 10 m long, with a total experimental area of 0.065 ha. The five irrigation treatments involved commencing irrigation at different Critical Tensiometer Values (T kPa), using tensiometers installed 15 cm below ground level in each plot. The T values were; 35 kPa; 60 kPa before budding and 35 kPa after budding; and 60 kPa. The 35 kPa treatment was further divided into application with overhead sprinklers, conventional drip tape, or sub-surface drip tubing. Rain during the growing period reduced contrasts between the irrigation treatments. Scheduling with tensiometers reduced drainage losses due to irrigation to <5% of application, however drainage associated with excess rainfall was substantial (about 60 mm). The subsurface drip irrigated treatments received 80 mm more irrigation than the corresponding sprinkler irrigated treatment. They also had correspondingly higher drainage losses. There is some indication of a decline in leak rate of the AGRI-GRO tubing over time. There were no significant effects of irrigation method or frequency on the number of broccoli heads harvested (around 39 000/ha = 95% cut out), mean weight and diameter of the harvested heads (187 g, 11 cm), overall yield (7.3 t/ha) or time to maturity. There were no significant relationships between any of the broccoli yield parameters and total evapotranspiration.

EXPERIMENT REPORT

Irrigation scheduling for winter grown broccoli

by C. Henderson and M. Webber
Department of Primary Industries
Gatton Research Station

Experiment No. S8902.10 2.6.92-20.8.92

1. Relevance to Industry

In many regions, including the Lockyer Valley, irrigation demands regularly exceed the reliable capacity of the water supply, resulting in scarcity or reliance on poorer quality water. In many vegetable enterprises irrigation is a significant proportion of overall production costs. Shallow rooted vegetables are substantial users of water; for example brassicas and lettuce require 2-4 ML per hectare per crop. Until recently, the frequency and amount of irrigation was relatively ad hoc, based on tradition and grower experience, combined with superficial observations of plant or soil conditions.

Some vegetable growers use tensiometers or neutron probes to monitor soil water status and schedule irrigations. Both methods have advantages and disadvantages, however tensiometers appear to have the best immediate potential for use in shallow rooted vegetables. Most water uptake in broccoli occurs in the upper 0.3-0.5 m of the soil profile.

Matching irrigation to crop requirements maximises production by minimising plant water stress, nutrient deficiencies and some diseases, as well as preventing build up of salinity problems. By preventing overwatering, problems with leaching of nutrients and pesticides into groundwater (and beyond the zone of usefulness) are reduced, as well as a decrease in disease levels.

2. Objectives

This experiment sought to determine the relationship between broccoli yield and tensiometer values, under various irrigation systems and regimes. It also attempted to determine the efficiency of these scheduling and application systems, by quantifying the amounts of applied water draining beyond the root zone during the broccoli growing period.

3. Materials and methods

The experiment was conducted on a black earth soil (*Ug5.15*) at Gatton Research Station (lat 27°33'S, long 152°20'E). The experimental design was a randomised complete block, with 5 irrigation treatments replicated 3 times. Each plot was 3 beds (2 rows of broccoli per 1.5 m bed) wide and 10 m long.

The soil was prepared as per standard practice for broccoli. Cv. *Greenbelt* were transplanted into beds on the 2 June 1992, with 0.67 m between the rows and 0.33 m intra-row spacing. A total of 400 kg/ha of compound fertiliser (52 kg N, 9 kg P, 53 kg K, 75 kg S) was applied immediately before planting. Sodium-molybdate (0.14 kg/ha) and SOLUBOR (0.15 kg/ha) were sprayed over the crop on 23 July 1992. A side dressing of 60 kgN/ha as urea was applied on 4 August 1992. Weeds were managed by spraying 3.84 kg/ha of propachlor immediately after transplanting, prior to the initial irrigation. Occasional hand-hoeing also took place as other weeds emerged. A single application of 1.76 kg/ha of mancozeb was sprayed on 11 June 1992. Insects were controlled with regular applications of insecticides, including chlorpyrifos, methomyl, endosulfan, fenvalerate, esfenvalerate, Bt, prothiofos, and mevinphos.

The initial irrigations utilised standard solid-set pipes and overhead sprinklers over the whole experimental area, for the first 2 weeks after transplanting. The side-dressing of urea was also incorporated with 18 mm of irrigation using this set-up. For all other irrigations, systems of mini-sprinklers, drip tape or sub-surface drip tubing were used to individually water each plot. Schematics of plot layouts are shown in Figs. 1 and 2. Each plot consisted of 3 beds of broccoli side by side. The central bed was the treatment area, while the two outside beds were buffer zones.

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

The plots watered with surface drip tape had 2 rows of tape in each treatment bed, positioned immediately adjacent to the broccoli rows. In addition, another single row of tape was positioned beside the closest broccoli row in each of the buffer beds, as shown in Fig. 2. The tape used was 'T-Tape Row Crop' with drip emitters every 20 cm, and an output of about 7.3 $Lm^{-1}hr^{-1}$ at an operating pressure of 70 kPa. This corresponded to an application rate of approximately 9 mm/hr on a total area basis.

The beds watered with the sub-surface system had the 'AGRI-GRO' continuous drip tubing positioned directly under the 2 broccoli rows in the treatment beds, as well as the 2 adjacent broccoli rows in the buffer beds (Fig. 2). The tube was installed using small trench digger, at a depth of about 20 cm. The tube was installed on 29 May 1992, with the whole experimental area cultivated and harrowed after installation. The tubing had an initial output of around 5.4 $Lm^{-1}hr^{-1}$ at an operating pressure of 90 kPa. This corresponded to an application rate of approximately 7 mm/hr on a total area basis.

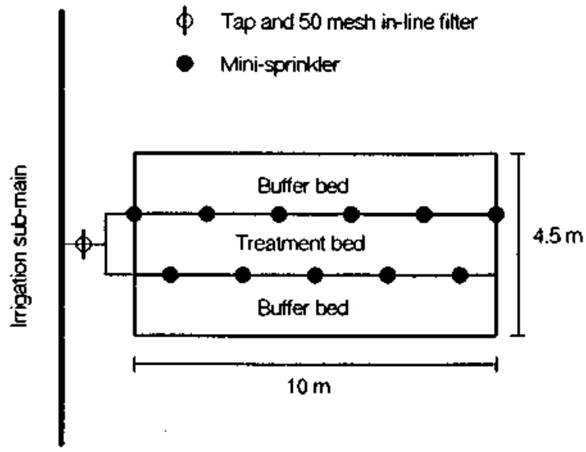


Figure 1. Mini-sprinkler system design for an individual plot in an experiment investigating irrigation scheduling in winter grown broccoli.

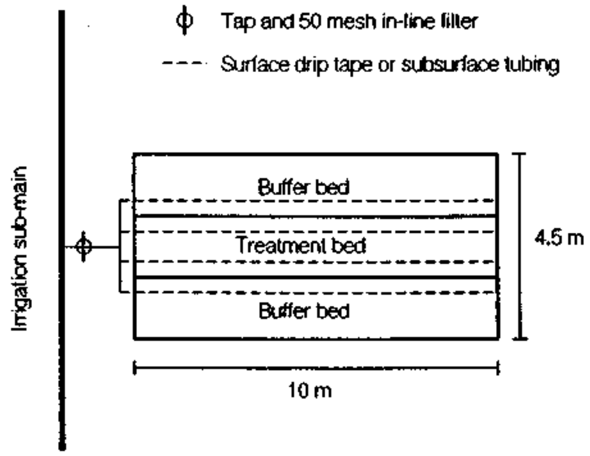


Figure 2. Surface and sub-surface drip system designs for an individual plot in an experiment investigating irrigation scheduling in winter grown broccoli.

Tensiometers were installed 15 cm and 45 cm below ground level in each treatment bed. *Loctronic* tensiometers were used, consisting of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum, while an electronic vacuum gauge attached to the syringe records the vacuum in the tensiometer air gap. Tensiometer readings were recorded daily, usually around 9 am.

Critical Tensiometer Values (T) were used to trigger irrigations in this experiment. Irrigation was applied when readings for the tensiometers installed 15 cm below the ground surface were greater than the **T** individually set for each treatment. Five irrigation treatments were investigated, involving 3 application methods, combined with 3 scheduling regimes based on tensiometer readings:

1. Irrigated using mini-sprinklers, scheduled at **T** 35 kPa both before and after the broccoli budded (**SPR 35/35**).

2. Irrigated using mini-sprinklers, scheduled at **T** 60 kPa before budding and **T** 35 kPa after budding (**SPR 60/35**).

3. Irrigated using mini-sprinklers, scheduled at **T** 60 kPa both before and after the broccoli budded (**SPR 60/60**).

4. Irrigated using surface drip tape, scheduled at **T** 35 kPa both before and after the broccoli budded (**SUR 35/35**).

5. Irrigated using sub-surface drip tube, scheduled at **T** 35 kPa both before and after the broccoli budded (**SUB 35/35**).

Each plot was irrigated according to its allocated treatment. Plots with the same irrigation treatment were occasionally watered on different days, due to differences in the time for the tensiometers to reach values necessary to trigger irrigation.

Aluminium neutron probe access tubes were installed to depths of 80 cm in each treatment bed, 5 cm inside a broccoli row and equidistant between 2 neighbouring plants. Neutron moisture meter readings were taken twice a week using a Campbell Pacific Nuclear Hydroprobe. A single reading was taken at 5 depth intervals, commencing 5 cm below the ground surface, incrementing by 10 cm. On each day that the neutron probe measurements were made, 5 standard counts was also conducted in a 200 L drum of water. Calibration equations for the neutron probe data were assumed to be the same as for previous experiments at this site.

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

The heights of the broccoli plants were measured 52 and 59 days after transplanting (DAP). Five plants were randomly selected and assessed in each plot. As they matured, broccoli heads were harvested from the treatment beds on 11 August, 13 August, 17 August and 20 August 1992. At each harvest, the number of marketable heads and their total weight were recorded, as well as the mean diameter of 10 harvested heads per plot.

4. Results

There was substantial rainfall 29 and 46 DAP (Fig. 3), which interfered with treatment differentiation in this experiment.

Using a simple spreadsheet, a daily water balance was calculated for each plot. Rainfall, irrigation, stored soil water, pan evaporation, evapotranspiration and drainage of soil water below 50 cm were determined from planting through to harvest. Details of the calculations are available from the authors.

In the most frequently irrigated sprinkler treatment, the shallow tensiometers fluctuated between 0 and 40 kPa for the entire growing period, except when irrigation ceased during the final week of harvesting (Fig. 3). Between 2 weeks after transplanting and buttoning (about 8 weeks after transplanting), this treatment only required 2 irrigations, each 16-20 mm. After buttoning, a further 5 irrigations were applied, each about 15-18 mm. The deep tensiometers indicated drainage occurred following both large rainfall events, as well as when 18 mm irrigation was used to incorporate the urea fertiliser at 64 DAP.

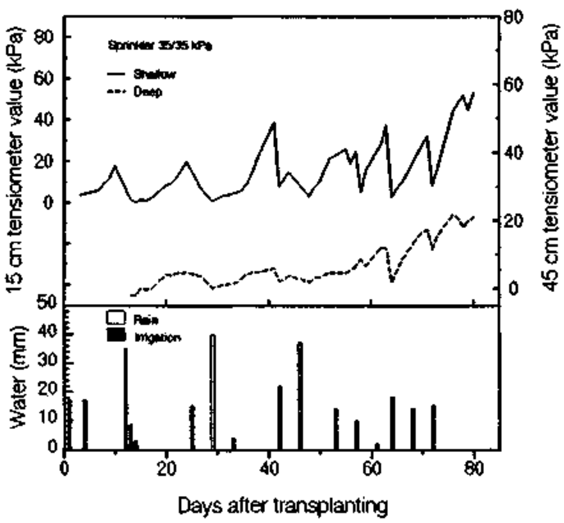


Figure 3. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where broccoli were irrigated using mini-sprinklers, when soil matric suction at 15 cm exceeded 35 kPa during the growing period.

Due to the rainfall, the less frequently irrigated sprinkler treatments only had a few days during the pre-buttoning period when the shallow tensiometers registered more than 40 kPa (Fig. 4 and 5), even though they only received one 16 mm irrigation between 2 and 8 weeks after transplanting. During the post-buttoning phase, the SPR60/35 treatment had a similar irrigation regime to the wetter treatment, receiving 5 irrigations each 12-16 mm. This caused the shallow tensiometers to remain less than 40 kPa for the rest of the growth period. In contrast, the driest sprinkler treatment was irrigated 3 times between buttoning and harvest, with the shallow tensiometers registering values of 50 kPa on 3 separate occasions. In both the latter treatments, the deep tensiometers indicated deep drainage only occurred following the 2 heavy rainfalls.

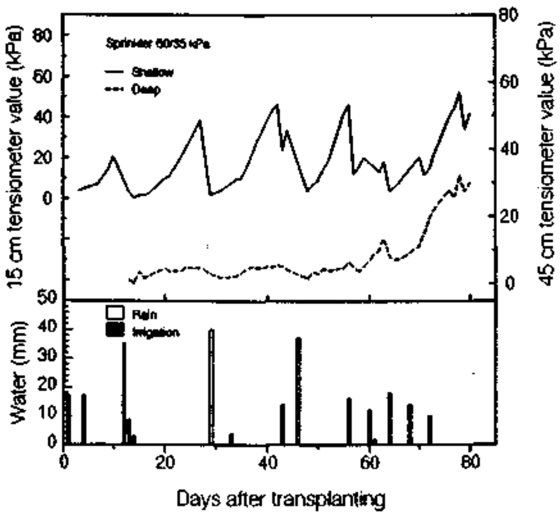


Figure 4. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where broccoli were irrigated using mini-sprinklers, when soil matric suction at 15 cm exceeded 60 kPa before buttoning and 35 kPa after buttoning.

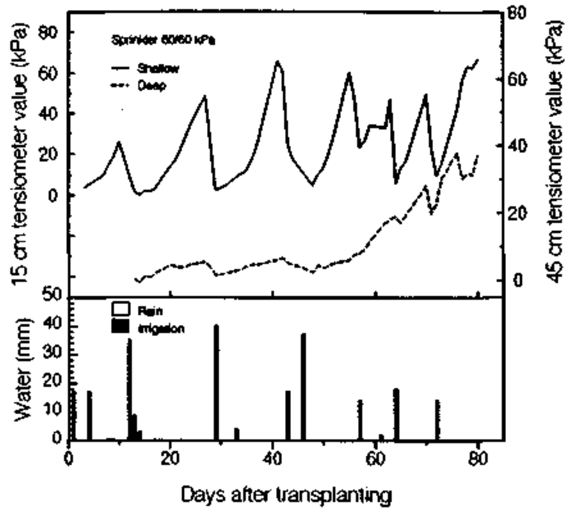


Figure 5. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where broccoli were irrigated using mini-sprinklers, when soil matric suction at 15 cm exceeded 60 kPa during the growing period.

The drip tape treatment received 2 more irrigations than the equivalent sprinkler treatment, with each irrigation about 8-10 mm. The shallow tensiometers fluctuated between 0 and 40 kPa for the entire growing period, except for the final week of harvesting (Fig. 6). As with the other treatments, the only indication of substantial deep drainage followed the heavy rainfall events.

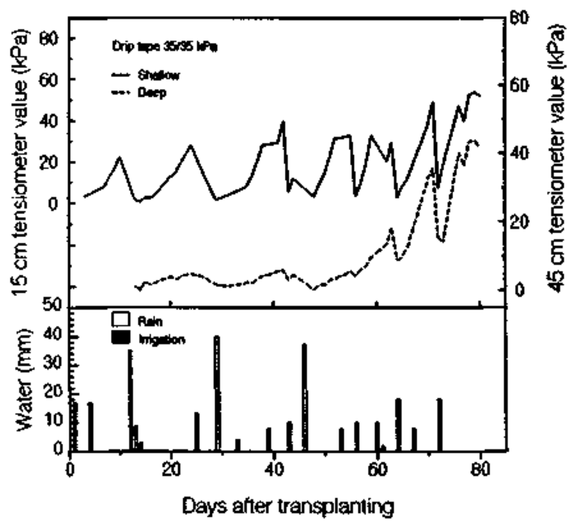


Figure 6. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where broccoli were irrigated using surface drip tape, when soil matric suction at 15 cm exceeded 35 kPa during the growing period.

During the pre-buttoning period, the shallow tensiometers in the sub-surface drip tube treatments fluctuated between 0 and 40 kPa. We noted that the irrigations with this system during this period seemed to have only minor impact on the shallow tensiometer values (Fig. 7). During the post-buttoning phase, matric suction in the shallow tensiometers continued to rise to between 40-70 kPa, despite numerous irrigations of 10-15 mm. In the pre-buttoning period, the deep tensiometer values stayed low, indicating that continuous slow deep drainage may have been occurring. After buttoning, the matric suctions of the deep tensiometers started to increase, suggesting substantial deep drainage was less likely.

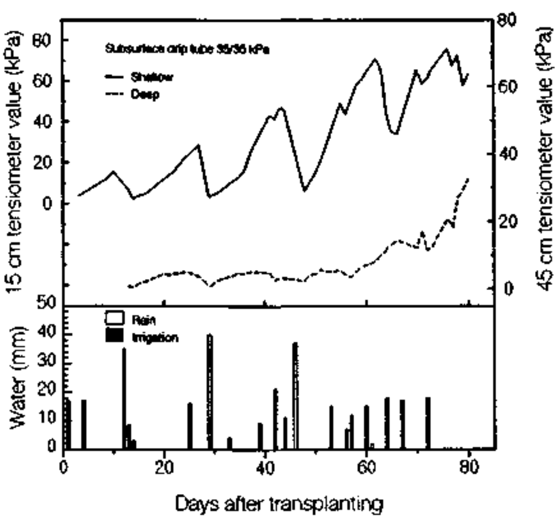


Figure 7. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where broccoli were irrigated using sub-surface drip tube, when soil matric suction at 15 cm exceeded 35 kPa during the growing period.

The most frequently irrigated sprinkler treatment received a total of 40 mm more water than the other 2 sprinkler treatments; also recording a total ET 30 mm greater than those treatments (Fig. 8). The irrigation received and total ET for the surface drip irrigated treatment were both about 10 mm less than for the most frequently irrigated sprinkler treatment. Deep drainage for these 4 treatments during the growing period was about 70 mm (Fig. 8); of this total only 10-15 mm was associated with excess irrigation. Most of the deep drainage was due to rainfall in excess of the soil water storage capacity in the root zone of the growing crop.

In attempting to maintain optimum moisture levels in the upper part of the broccoli root zone, the sub-surface drip tube treatment received about 70 mm more irrigation than the wettest sprinkler treatment (Fig. 8). Our measurements of water content and potentials during the growing season suggested that most of this extra water was being lost to deep drainage, rather than increasing crop water use or soil water levels in the root zone. Total ET for this treatment was equivalent to those for the wettest sprinkler and surface drip tape treatments.

Most of the differentiation in ET occurred in the 4 week period prior to budding (Fig. 9). From then until harvest, there was little consistent difference in ET rates between any of the 5 treatments, as shown by the parallel nature of the lines. Note that the total ET in this experiment was about 80 mm less than in a broccoli experiment conducted during Winter/Spring 1991, reflecting lower evaporative demand in the 1992 experiment (pan evaporation during the 1991 growing period was 361 mm; in 1992 it was 249 mm).

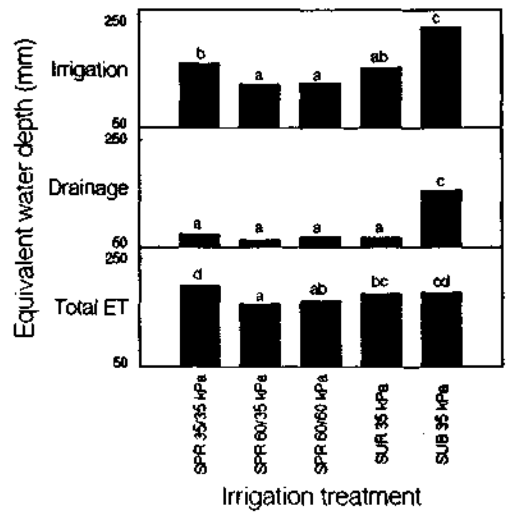


Figure 8. Changes in quantities of irrigation, total evapotranspiration and drainage losses under 5 irrigation regimes. Bars labelled with the same letter were not significantly different (P<0.05).

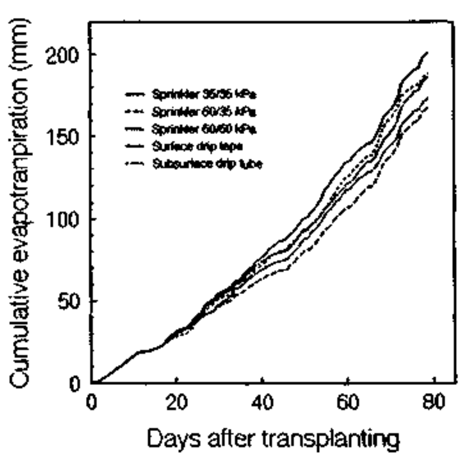


Figure 9. Cumulative evapotranspiration under 5 irrigation regimes.

There were no significant effects of irrigation treatment on broccoli height at 52 DAP (mean 39 cm) nor 59 DAP (mean 49 cm).

There were no significant effects of irrigation method or frequency on the number of broccoli heads harvested (around 39 000/ha = 96% cut out), nor the mean weight of the individual heads (187 g). Although total yield from the driest of the sprinkler irrigated treatments was significantly ($P<0.05$) greater than yields from the surface drip tape or the moderately irrigated sprinkler treatments, these differences were not consistent with results for the other 2 treatments, and were probably just a chance occurrence. Mean production for the experiment was 7.3 t/ha, a high yield expected under ideal growing conditions. There were no significant relationships between any of the broccoli yield parameters and total evapotranspiration (Figs. 10-12). Irrigation regime did not affect the time between transplanting and optimum broccoli head quality, nor the mean head diameter (about 11 cm).

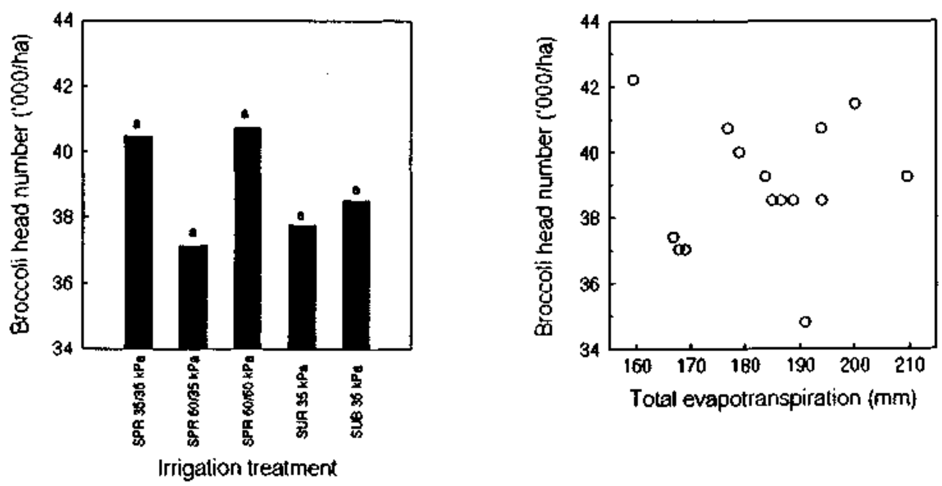


Figure 10. The number of marketable broccoli heads was unaffected by altering either the Critical Tensiometer Value, method of irrigation application, or the total evapotranspiration of autumn grown broccoli.

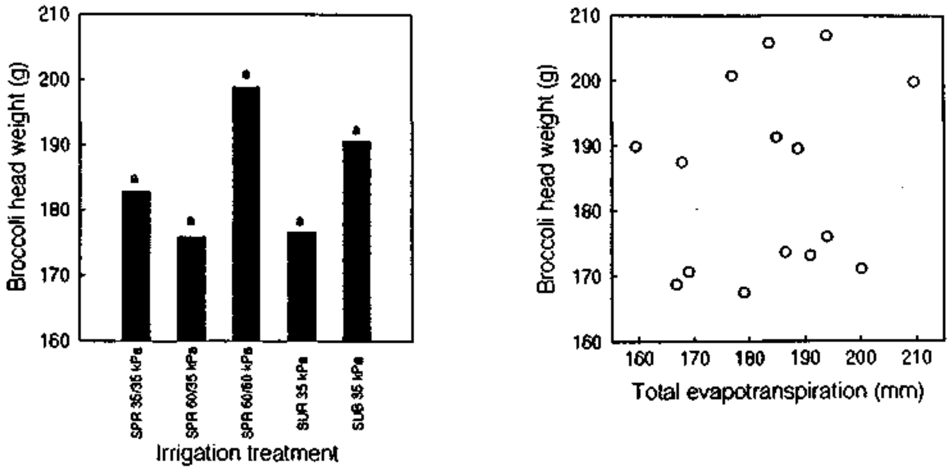


Figure 11. The mean weight of marketable broccoli heads was unaffected by altering either the Critical Tensiometer Value, method of irrigation application, or the total evapotranspiration of autumn grown broccoli.

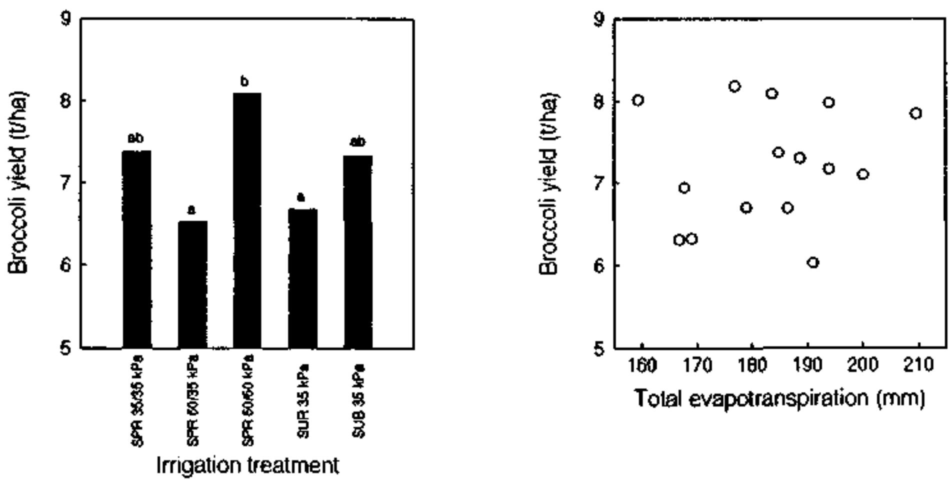


Figure 12. The total yield of marketable broccoli heads was slightly affected by irrigation regime, however it was not related to the total evapotranspiration of autumn grown broccoli.

5. Discussion and conclusions

As in previous experiments, the tensiometer system was easy to install and use, gave accurate, reliable readings, required little maintenance and was relatively cheap.

During the 2 week period immediately after transplanting, when the experiment was irrigated using standard overhead sprinklers, there was one excessive application where around 10-15 mm of drainage occurred. Once we commenced managing the irrigation with our control systems (utilising watering regimes suggested by our previous research), virtually no drainage could be attributed directly to over-irrigation, except in the sub-surface irrigation treatment. The bulk of the deep drainage was due to rainfall in excess of the storage capacity of the soil profile.

Unfortunately, the rainfall during this experiment adversely affected contrasts between the various irrigation treatments. In the sprinkler and surface drip tape treatments, soil matric suctions at 15 cm below the ground surface were greater than 50 kPa for only a few days, even in the least frequently irrigated regime. This certainly reduced the likelihood of differences in broccoli growth and yield occurring. In the sub-surface drip tube treatment, the shallow tensiometers were less than 50 kPa prior to buttoning, but consistently showed matric suctions higher than 60 kPa for most of the post-buttoning period. Yield values for this treatment indicate the broccoli was still able to take up sufficient water (from deeper in the root zone) to maximise production. I am still concerned that under high evaporative conditions (particularly when the crop root system is still developing) that yield reducing water stresses may still occur.

Results from experiments to date suggest that a Critical Tensiometer Value for maximum production of autumn grown broccoli is probably 35-50 kPa, with the lower value in conditions of high evaporative demand. On black earth soil types, this involves the following approximate irrigation sequences (given that no rainfall occurs). About 15-17 mm every 5-7 days for the first 7 weeks, increasing to 20 mm every 5 days as the broccoli root systems develop. Normally the target evapotranspiration for broccoli is probably about 230-280 mm for autumn and spring crops, and 180-220 mm for winter crops. In average seasons, the total irrigation requirement would be about 2.2-3 ML/ha, allowing for inefficiencies and drainage losses. This regime applies to sprinkler irrigation. Similar overall quantities would probably be required for drip irrigation systems, supplied in smaller amounts on a more frequent basis. Obviously any rainfall during the intervening period would reduce these requirements, although there may still be a need to irrigate for other purposes, such as fertiliser or pesticide incorporation. The regime would also be affected by cultivar and agronomic practices.

There appeared to be several problems with using the AGRI-GRO tubing to supply water to the broccoli in this experiment. Despite frequent irrigation, we were unable to reduce the matric suction in the surface of the soil during the latter stages of the broccoli growing period. When we compared the amounts of water we were applying through the tubing (using a water meter on the irrigation pump to record total flow) with the increase in soil water in the root zone of the crop, there were often large discrepancies. In general, for every 10 mm of irrigation we would only pick up 3-6 mm increase in soil water content. I discounted losses through fittings or large leaks in the tubing, as these usually leave obvious areas of saturated soil around the leaks. It seemed more likely that water was draining from saturated zones around the tubing to below the root zone. Water did not appear to be moving readily from the saturated zone around the tube into the soil surrounding the tensiometer installations. There was also an indication in a drop in leak rate of the tubing over time, suggesting pores within the tubing walls had become clogged. Installation and retrieval of the pipe was labour and time-intensive; after 2-3 such operations the tubing tended to become brittle and break up.

To be a viable alternative to other irrigation systems, the sub-surface drip tubing would need to address the following issues.

1. It must be cost competitive with standard retrievable drip systems.
2. A rapid method for installing the tubing at a consistent depth, without damaging the tubing and ensuring good contact with the surrounding soil is required.
3. The system must maintain a consistent leak rate for the life of the crop; this may mean an improved manufacturing process, combined with a periodic flushing technique for removing internal contaminants.

It may be that this product has most application where it is permanently installed; e.g. in perennial plantings or amenity horticulture situations. Permanent installation in vegetables would require several changes to current production systems, probably including permanent bed / minimum tillage approaches.

In this experiment, the surface drip tape gave similar overall water balance and broccoli performance results to the sprinkler methods.

We are relatively confident that the irrigation regimes and scheduling systems developed over the past 2 years will maximise broccoli production and irrigation efficiency on farms in south-east Queensland.

EXPERIMENT REPORT

Report **Final** **Date of Report:** 17-11-93

Initiation Date: 10-7-92 **Completion Date:** 19-10-92

Project Number: S8902

Project Title: Irrigation scheduling in vegetables

Experiment Number: S8902.11 **Officer Responsible:** Craig Henderson

Experiment Title: Irrigation scheduling for winter grown cabbage.

Experiment Objectives

This experiment sought to determine the relationship between cabbage yield and tensiometer values and heat dissipation probe readings. It also attempted to determine the efficiency of irrigation by quantifying the amounts of applied water draining beyond the root zone during the growing period.

Summary of Results

The experiment was conducted at Gatton Research Station, from July-October 1992. Cabbage (cv. *Galaxy*) were grown using standard agronomy, with 5 irrigation treatments replicated 3 times in a RCB design. Plots were 4.5 m wide and 10 m long, with a total experimental area of 0.065 ha. The five irrigation treatments involved commencing irrigation at different Critical Tensiometer Values (T kPa), using tensiometers installed 15 cm below ground level in each plot. The **T** values were; 35 kPa; 60 kPa before heading and 35 kPa after heading; and 60 kPa. The 35 kPa treatment was further divided into application with overhead sprinklers, conventional drip tape, or sub-surface drip tubing. Scheduling with tensiometers reduced drainage losses due to irrigation to <5% of application, however drainage associated with excess rainfall was substantial (about 40 mm). The sub-surface drip irrigated treatments had higher drainage losses than the other treatments. There is some indication of a decline in leak rate of the AGRI-GRO tubing over time. There were no significant effects of irrigation method or frequency on the number of cabbage harvested (around 19 000/ha = 96% cut out). The sub-surface drip treatment had significantly lighter heads (3.0 vs 3.5 kg) and lower yields (59 vs 70 t/ha) than the other treatments. There were significant curvi-linear relationships between total evapotranspiration and both mean head weight and total yield.

EXPERIMENT REPORT

Irrigation scheduling for winter grown cabbage

by C. Henderson and M. Webber
Department of Primary Industries
Gatton Research Station

Experiment No. S8902.11 10.7.92-19.10.92

1. Relevance to Industry

In many regions, including the Lockyer Valley, irrigation demands regularly exceed the reliable capacity of the water supply, resulting in scarcity or reliance on poorer quality water. In many vegetable enterprises irrigation is a significant proportion of overall production costs. Shallow rooted vegetables are substantial users of water; for example brassicas and lettuce require 2-4 ML per hectare per crop. Until recently, the frequency and amount of irrigation was relatively ad hoc, based on tradition and grower experience, combined with superficial observations of plant or soil conditions.

Some vegetable growers use tensiometers or neutron probes to monitor soil water status and schedule irrigations. Both methods have advantages and disadvantages, however tensiometers appear to have the best immediate potential for use in shallow rooted vegetables. Most water uptake in cabbage occurs in the upper 0.3-0.5 m of the soil profile. There are a number of new irrigation scheduling systems currently being developed, involving electronic data capture, recording and real-time display of soil water status on a virtually continuous basis.

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 overwatering, problems with leaching of nutrients and pesticides into groundwater (and beyond the zone of usefulness) are reduced, as well as a decrease in disease levels.

2. Objectives

This experiment sought to determine the relationship between cabbage yield, tensiometer values and heat dissipation probe readings (from the CAMNET WATER MANAGEMENT SYSTEM), under various irrigation systems and regimes. It also attempted to determine the efficiency of these scheduling and application systems, by quantifying the amounts of applied water draining beyond the root zone during the cabbage growing period.

3. Materials and methods

The experiment was conducted on a black earth soil (*Ug5.15*) at Gatton Research Station (lat 27°33'S, long 152°20'E). The experimental design was a randomised complete block, with 5 irrigation treatments replicated 3 times. Each plot was 3 beds (2 rows of cabbage per 1.5 m bed) wide and 10 m long.

The soil was prepared as per standard practice for cabbage. Cv. *Galaxy* were transplanted into beds on the 10 July 1992, with 0.67 m between the rows and 0.66 m intra-row spacing. A total of 400 kg/ha of compound fertiliser (52 kg N, 9 kg P, 53 kg K, 75 kg S) was applied immediately before planting. Sodium-molybdate (0.14 kg/ha) and SOLUBOR (0.15 kg/ha) were sprayed over the crop on 23 July, 26 August and 23 September 1992. A side dressing of 80 kgN/ha as urea was applied on 7 August 1992. Weeds were managed by spraying 3.84 kg/ha of propachlor immediately after transplanting, prior to the initial irrigation. Occasional hand-hoeing also took place as other weeds emerged. Insects were controlled with regular applications of insecticides, including chlorpyrifos, methomyl, endosulfan, fenvalerate, esfenvalerate, cypermethrin, deltamethrin, dimethoate, Bt, methamidophos, prothiofos, and mevinphos.

The initial irrigations utilised standard solid-set pipes and overhead sprinklers over the whole experimental area, for the first week after transplanting. The side-dressing of urea was also incorporated with 15 mm of irrigation using this set-up. For all other irrigations, systems of mini-sprinklers, drip tape or sub-surface drip tubing were used to individually water each plot. Schematics of plot layouts are shown in Figs. 1 and 2. Each plot consisted of 3 beds of cabbage side by side. The central bed was the treatment area, while the two outside beds were buffer zones.

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

The plots watered with surface drip tape had 2 rows of tape in each treatment bed, positioned immediately adjacent to the cabbage rows. In addition, another single row of tape was positioned beside the closest cabbage row in each of the buffer beds, as shown in Fig. 2. The tape used was 'T-Tape Row Crop' with drip emitters every 20 cm, and an output of about 7.3 $Lm^{-1}hr^{-1}$ at an operating pressure of 70 kPa. This corresponded to an application rate of approximately 9 mm/hr on a total area basis.

The beds watered with the sub-surface system had the 'AGRI-GRO' continuous drip tubing positioned directly under the 2 cabbage rows in the treatment beds, as well as the 2 adjacent cabbage rows in the buffer beds (Fig. 2). The tube was installed using small trench digger, at a depth of about 20 cm. The tube was installed on 9 July 1992, with the whole experimental area cultivated and harrowed after installation. The tubing had an initial output of around 5.4 $Lm^{-1}hr^{-1}$ at an operating pressure of 90 kPa. This corresponded to an application rate of approximately 7 mm/hr on a total area basis.

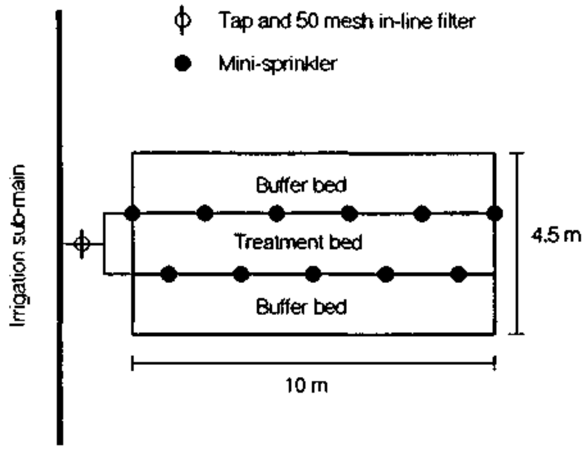


Figure 1. Mini-sprinkler system design for an individual plot in an experiment investigating irrigation scheduling in winter grown cabbage.

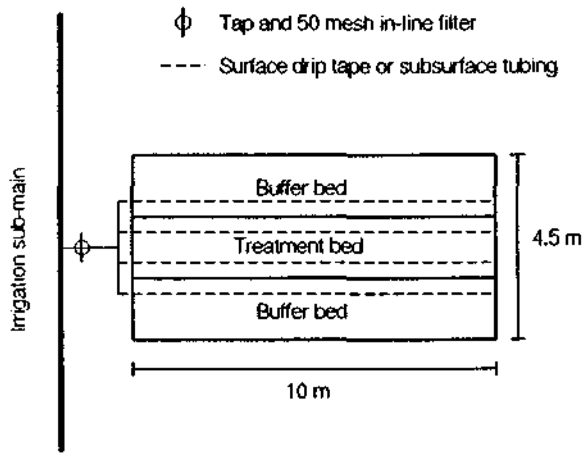


Figure 2. Surface and sub-surface drip system designs for an individual plot in an experiment investigating irrigation scheduling in winter grown cabbage.

Tensiometers were installed 15 cm and 45 cm below ground level in each treatment bed. *Loctronic* tensiometers were used, consisting of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum, while an electronic vacuum gauge attached to the syringe records the vacuum in the tensiometer air gap. Tensiometer readings were recorded daily, usually around 9 am.

Critical Tensiometer Values (T) were used to trigger irrigations in this experiment. Irrigation was applied when readings for the tensiometers installed 15 cm below the ground surface were greater than the T individually set for each treatment. Five irrigation treatments were investigated, involving 3 application methods, combined with 3 scheduling regimes based on tensiometer readings:

1. Irrigated using mini-sprinklers, scheduled at **T** 35 kPa both before and after the cabbage started to head (SPR35/35).

2. Irrigated using mini-sprinklers, scheduled at **T** 60 kPa before heading and **T** 35 kPa after heading (SPR60/35).

3. Irrigated using mini-sprinklers, scheduled at **T** 60 kPa both before and after the cabbage headed (**SPR60/60**).

4. Irrigated using surface drip tape, scheduled at **T** 35 kPa both before and after the cabbage headed (SUR35/35).

5. Irrigated using sub-surface drip tube, scheduled at **T** 35 kPa both before and after the cabbage headed (SUB35/35).

Each plot was irrigated according to its allocated treatment. Plots with the same irrigation treatment were occasionally watered on different days, due to differences in the time for the tensiometers to reach values necessary to trigger irrigation.

Aluminium neutron probe access tubes were installed to depths of 80 cm in each treatment bed, 5 cm inside a cabbage row and equidistant between 2 neighbouring plants. Neutron moisture meter readings were taken twice a week using a Campbell Pacific Nuclear Hydroprobe. A single reading was taken at 5 depth intervals, commencing 5 cm below the ground surface, incrementing by 10 cm. On each day that the neutron probe measurements were made, 5 standard counts was also conducted in a 200 L drum of water. Calibration equations for the neutron probe data were assumed to be the same as for previous experiments at this site.

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

Heat dissipation probes were installed at 15 cm below ground level in Blocks 1 and 2, for Treatments 1, 3, 4 and 5. The probes were connected to the CAMNET system, which recorded soil moisture status and soil temperature for each of the probes on a half-hourly basis.

The widths of the cabbage plants were measured 24, 32, 39, 46, 53 and 60 days after transplanting (DAT). Five plants were randomly selected and assessed in each plot. Cabbage heads were harvested from the treatment beds on 19 October 1992, 101 days after transplanting. The number of marketable heads per plot were counted, and 10 heads were randomly harvested and weighed.

4. Results

A total of 94 mm of rain fell during the growing period, with substantial events at 8 DAT, 51-56 DAT and 67 DAT (Fig. 3). This rainfall did not greatly interfere with differentiation between irrigation treatments.

Using a simple spreadsheet, a daily water balance was calculated for each plot. Rainfall, irrigation, stored soil water, pan evaporation, evapotranspiration and drainage of soil water below 50 cm were determined from planting through to harvest. Details of the calculations are available from the authors.

The latest version of the CAMNET software used during this experiment was still not amenable to graphical presentation in written reports. To overcome this difficulty, we manually transferred the soil water data for each of the probes into our normal graphics program. Although the probes were recording every 30 minutes, we only used the 9 am values for each day, as to manually transfer the complete data set would have been too time consuming. Using data collected at 9 am also enabled direct comparison with corresponding tensiometer values.

In the most frequently irrigated sprinkler treatment, the shallow tensiometers fluctuated between 0 and 35 kPa for the entire growing period (Fig. 3). During the vegetative development phase (from about 10-60 DAT), this treatment received 8 irrigations, averaging about 12 mm every 5 days. From 60 DAT until harvest the treatment was effectively irrigated 10 times (average 18 mm every 4 days). The deep tensiometers and water balance calculations indicated drainage occurred following the first rainfall event and the 2 irrigations around 20 DAT. The re may also have been deep drainage following the frequent heavy irrigations around 90 DAT. Note that matric suction in the deep tensiometers increased during the period between 60-85 DAT, as evaporative demand and crop water use rose markedly. Irrigation frequency and quantities were increased during this pre-harvest period, to meet the upsurge in water demand.

The graphics for the CAMNET system show average values for the 2 probes in each treatment. In the SPR35/35 treatment, the individual probe readings at any given time were seldom similar, except immediately after rain or heavy irrigation, when they would both register about 100%. The CAMNET probe in Block 2 was not functioning 19-41 DAT, and on several other occasions during the growing period; the values shown in those instances are for the Block 1 probe only (Fig. 3). Values for the probe in Block 1 were always much lower than for the corresponding probe in Block 2 (when the Block 2 probe was functioning). During the pre-heading phase, the average probe values would decline to 20-40% between irrigations, while from 60 DAT until harvest the minimum values were around 50-60% (Fig. 3).

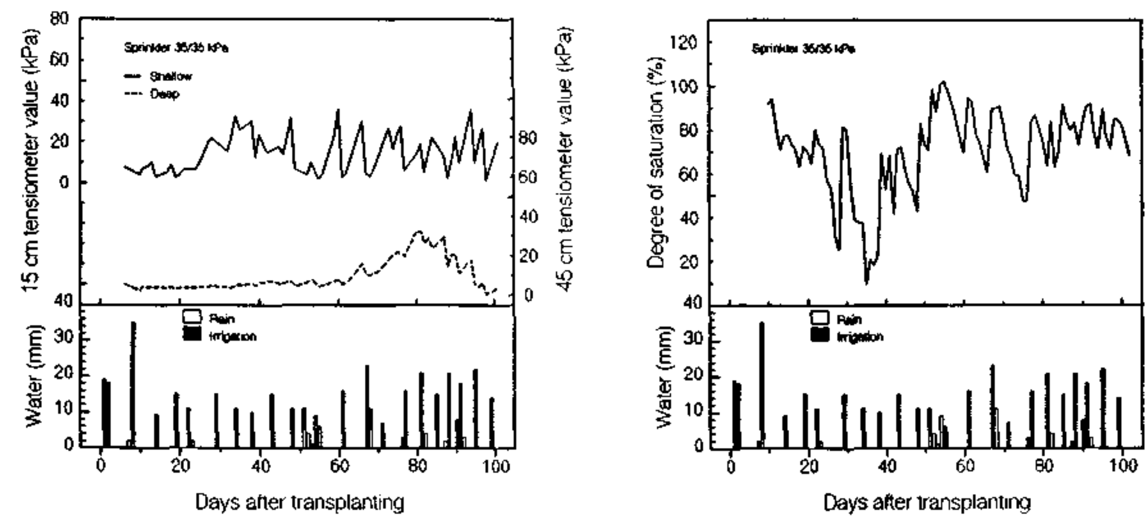


Figure 3. Fluctuations in soil matric suction at 15 and 45 cm below ground level, and heat dissipation probe values at 15 cm below ground level, where cabbage were irrigated using mini-sprinklers, when soil matric suction at 15 cm exceeded 35 kPa during the growing period.

The SPR60/35 shallow tensiometers fluctuated between 0 and 50 kPa before head development commenced and 0-35 kPa for the remainder of the growing period (apart from one instance where matric suction increased to 50 kPa), as shown in Fig. 4. During the vegetative development phase, this treatment received 7 irrigations (average 9 mm every 6 days). From 60 DAT until harvest the treatment was effectively irrigated 9 times (average 17 mm every 4-5 days). The tensiometer and water balance calculations suggested that irrigation quantities between 35-65 DAT were insufficient to refill the soil profile; a deficit irrigation strategy. Data indicates the only deep drainage in this treatment occurred after the initial heavy rainfall at 8 DAT. The fluctuating matric suctions in the deep tensiometers indicate substantial root/water uptake activity in this zone during the head development period.

In the driest sprinkler irrigated treatment, shallow tensiometer values were less than 40 kPa for the first 40 DAT (Fig. 5). For the remainder of the growing period, these tensiometers fluctuated between 0 and 50-60 kPa. After heading development commenced, the deep tensiometers fluctuated between 20 and 50 kPa. Our calculations suggest deep drainage only occurred following the initial 35 mm rainfall. This treatment was effectively irrigated on 4 occasions during the vegetative development phase (average 12 mm every 10 days). During the head development period the irrigation frequency and quantity increased to an average of 16 mm every 5-6 days. Similar to the previous treatment, there seemed to be substantial water uptake from deeper sections of the soil profile (in contrast to the most frequently sprinkler irrigated treatment).

The 2 CAMNET probes in the SPR60/60 irrigation treatment gave similar values during the first 60 DAT, after which the probe in Block 2 ceased to function. Values shown for 60 DAT until harvesting are for the probe in Block 1 only (Fig. 5). CAMNET probe values declined to 10-20% between irrigations. After irrigation they generally only increased to around 80%; only registering saturation at about 80 DAT (Fig. 5).

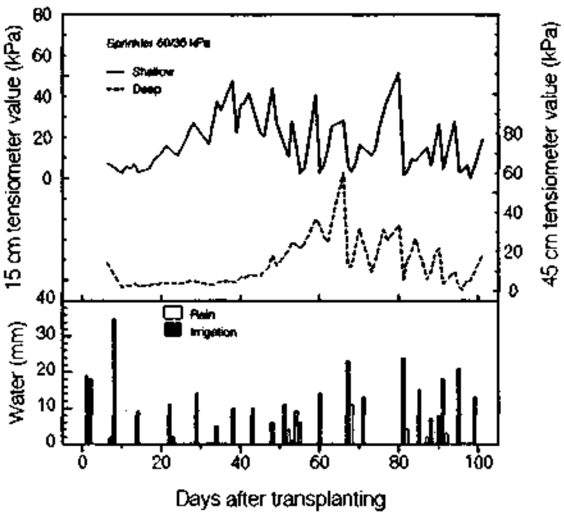


Figure 4. Fluctuations in soil matric suction at 15 and 45 cm below ground level, where cabbage were irrigated using mini-sprinklers, when soil matric suction at 15 cm exceeded 60 kPa before heading commenced and 35 kPa after heading.

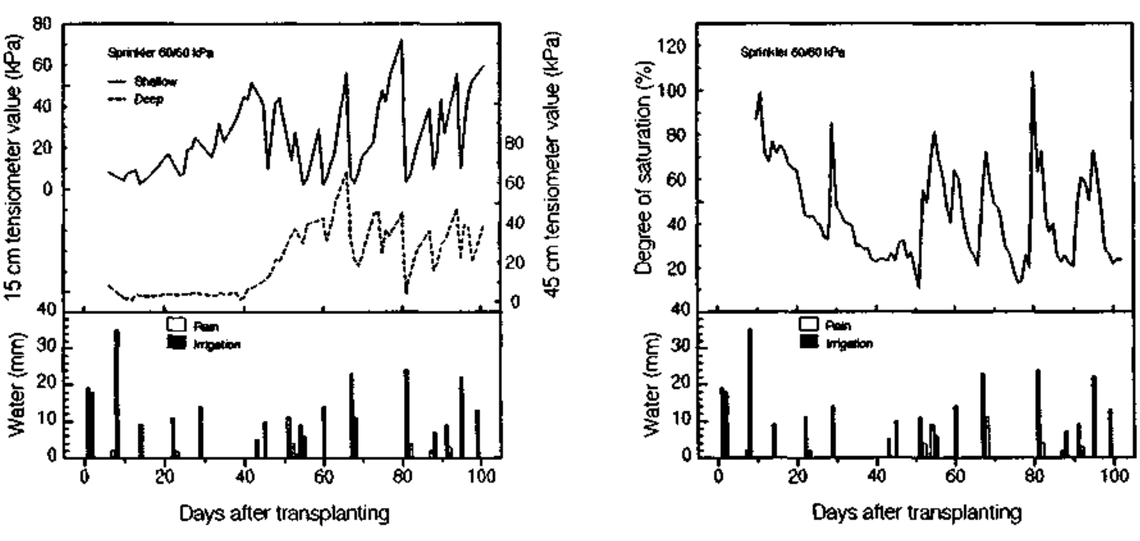


Figure 5. Fluctuations in soil matric suction at 15 and 45 cm below ground level, and heat dissipation probe values at 15 cm below ground level, where cabbage were irrigated using mini-sprinklers, when soil matric suction at 15 cm exceeded 60 kPa during the growing period.

Shallow tensiometers in the drip tape treatment fluctuated between 0-35 kPa and 0-40 kPa during the vegetative and head development periods respectively (Fig. 6). During the vegetative phase, this treatment was irrigated on 8 occasions (average 12 mm every 5 days), similar to the corresponding sprinkler treatment. As water demand during the head development stage increased, irrigation intensity increased to an average of 11 mm every 4 days. This was the same frequency as the SPR35/35 treatment, but with lower quantities at each irrigation. Water balance calculations suggest there was little deep drainage due to excessive irrigation, however deep tensiometers indicated moist subsoil conditions for most of the growing period. In such circumstances, deep drainage from rainfall or over-irrigation is much more likely, compared to irrigation regimes that invoke drier subsoil conditions.

Average values for CAMNET probes in cabbage irrigated with drip tape declined to 20-30% between irrigations. After irrigation, average values generally only increased to 60-70% (Fig. 6). This can be contrasted with the increase to about 100% following rain at 51-54 DAT. In particular, values for the probe in Block 2 often only increased by 15-20% after a 10-15 mm irrigation.

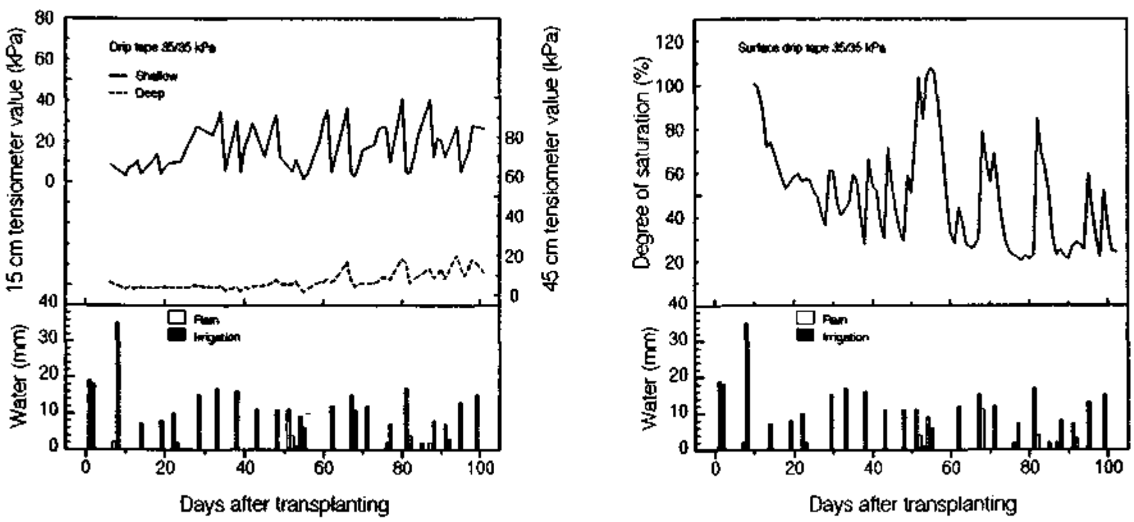


Figure 6. Fluctuations in soil matric suction at 15 and 45 cm below ground level, and heat dissipation probe values at 15 cm below ground level, where cabbage were irrigated using surface drip tape, when soil matric suction at 15 cm exceeded 35 kPa during the growing period.

During the vegetative period, the shallow tensiometers in the sub-surface drip tube treatments fluctuated between 20 and 40 kPa. At no stage did irrigation applied with this system reduce soil matric suction to less than 18 kPa (Fig. 7), even though there was an average of 14 mm applied every 4-5 days. In contrast, the 4 days of rain toward the end of the vegetative period did reduce matric suctions in both the shallow and deep tensiometers to < 5 kPa. During the head development phase, the shallow tensiometers were generally between 30 and 60 kPa, only declining to below 30 kPa on 2 occasions (Fig. 7). Similarly, the deep tensiometers were also around 20 kPa for most of this time. This was despite 11 irrigations, averaging 14 mm every 3-4 days. Water budget calculations suggest that around 30% of the irrigation applied using this system was not being used by the plants, or stored in the surface soil. Presumably it was therefore being lost via preferential deep drainage.

Values for CAMNET probes installed in this treatment rapidly declined to around 20% at about 25 DAT (Fig. 7). Probe values remained at about 20% for the remainder of the growing period, except; (i) after irrigation with overhead sprinklers to incorporate the urea fertiliser at 29 DAT and (ii) after 4 days of rain some 3 weeks later. Results for both the CAMNET probes and the shallow tensiometers suggest poor lateral and upward movement of water from the sub-surface drip tube into the surrounding soil.

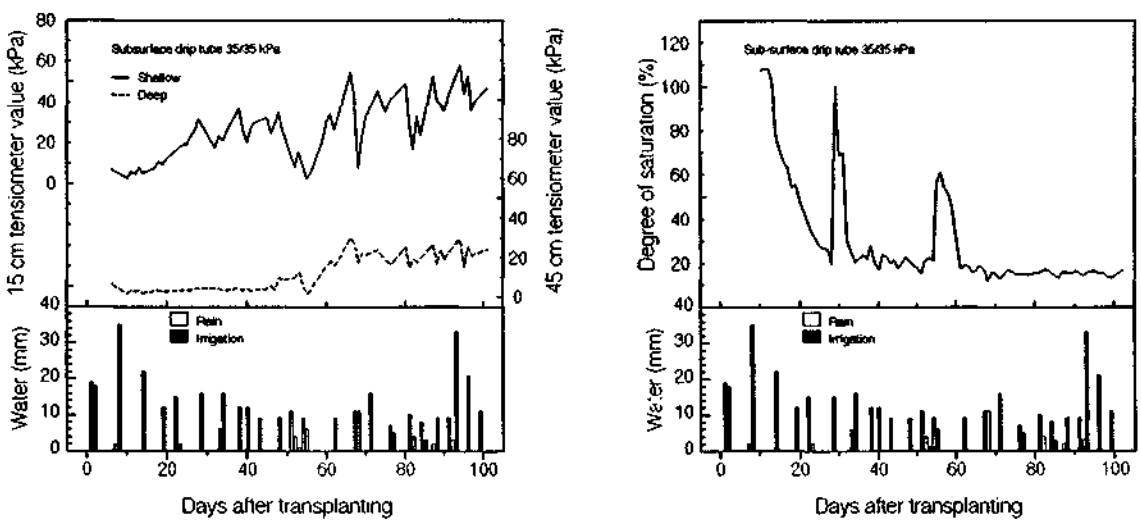


Figure 7. Fluctuations in soil matric suction at 15 and 45 cm below ground level, and heat dissipation probe values at 15 cm below ground level, where cabbage were irrigated using sub-surface drip tube, when soil matric suction at 15 cm exceeded 35 kPa during the growing period.

The most frequently irrigated sprinkler treatment received a total of 313 mm of irrigation; 70 and 127 mm more water than the SPR60/35 and SPR60/60 treatment respectively. The surface drip treatment received the same amount of water as the median sprinkler treatment, while the sub-surface drip system applied as much water as the most frequently irrigated sprinkler system (Fig. 8). Total drainage for the sprinkler and surface drip treatments was estimated at 35-60 mm. This was mainly due to rainfall in excess of the soil water storage capacity in the root zone of the growing crop, except for about 15 mm of excess irrigation in the most frequently irrigated sprinkler treatment. There appeared to be about 100 mm more deep drainage in the sub-surface system compared to the other treatments, associated with losses at most irrigations.

Differences in irrigation applied were reflected in total evapotranspiration (ET), with the most frequently irrigated sprinkler treatment having the highest ET and the least frequently irrigated the lowest. The drip tape was intermediate, equivalent to the median irrigation treatment. The estimated ET for the sub-surface system was about the same as the driest sprinkler system (Fig. 8).

The most frequently irrigated sprinkler treatment had a steadily increasing ET during the vegetative phase, which rose markedly during the head development period. The SPR60/35 treatment had a lower initial ET, but also substantially increased ET rate during the latter half of the growing period (Fig. 9). The driest sprinkler treatment had significantly lower ET during both the vegetative and head development phases. The surface drip treatment had similar ET values to the wettest sprinkler treatment for the first 70 DAT. From then until harvest, ET for the surface drip system was much lower. Similarly, the sub-surface drip system had a cumulative ET plot very similar to the median sprinkler treatment for the first 70 DAT, but then declined in comparison over the final 30 days prior to harvest.

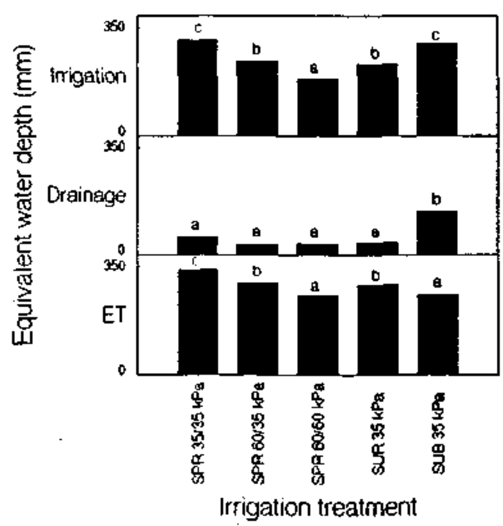


Figure 8. Changes in quantities of irrigation, total evapotranspiration and drainage losses under 5 irrigation regimes. Bars labelled with the same letter were not significantly different ($P<0.05$).

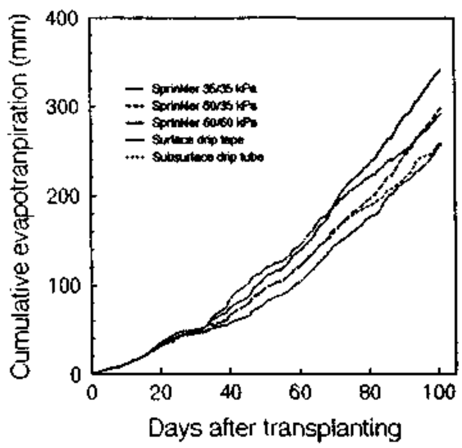


Figure 9. Cumulative evapotranspiration under 5 irrigation regimes.

There were no significant effects of irrigation treatment on the widths of cabbage plants at 24 DAT (mean 23 cm), 32 DAT (37 cm), 39 DAT (49 cm), 46 DAT (60 cm), 53 DAT (73 cm) nor 60 DAT (81 cm).

There were no significant effects of irrigation method or frequency on the number of cabbage heads harvested (around 19 000/ha = 95% cut out), nor was there a significant relationship between total ET and head number (Fig. 10). Individual heads on the plots irrigated with the sub-surface drip tube were 0.5-0.6 kg lighter than in the other treatments. There was a significant ($P<0.05$) curvi-linear relationship between total ET and mean cabbage head weight (W), as shown in Fig. 11;

$$W = -5.81 + 0.0594\ ET - 9.29\ ET^2 \qquad R^2 = 0.40$$

As a consequence of the smaller heads, total yields from sub-surface irrigated plots were about 11 t/ha less than the highest yielding treatments (Fig. 12). There was also a significant ($P<0.05$) trend for higher yields (Y) with higher ET values in the ranges encountered in this experiment. The trend was curvi-linear;

$$Y = -154.6 + 1.40\ ET - 0.00218\ ET^2 \qquad R^2 = 0.50$$

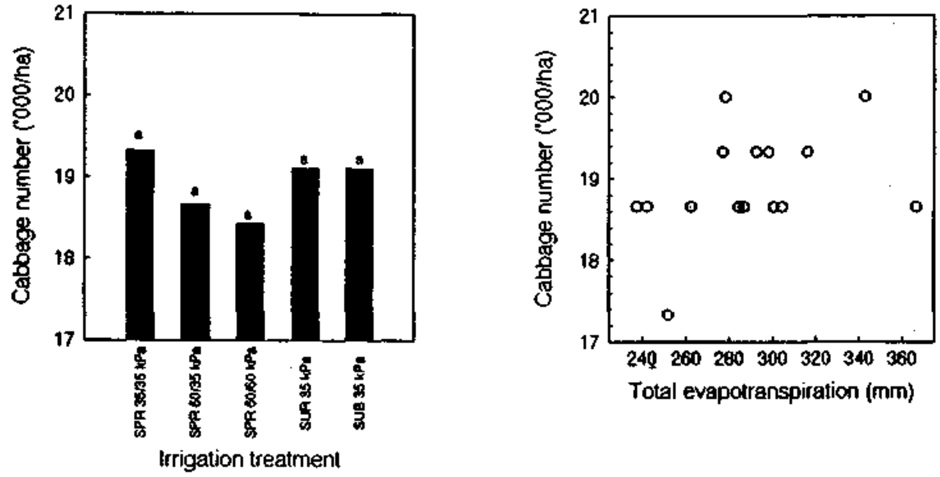


Figure 10. The number of marketable cabbage heads was unaffected by altering either the Critical Tensiometer Value, method of irrigation application, or the total evapotranspiration of winter grown cabbage.

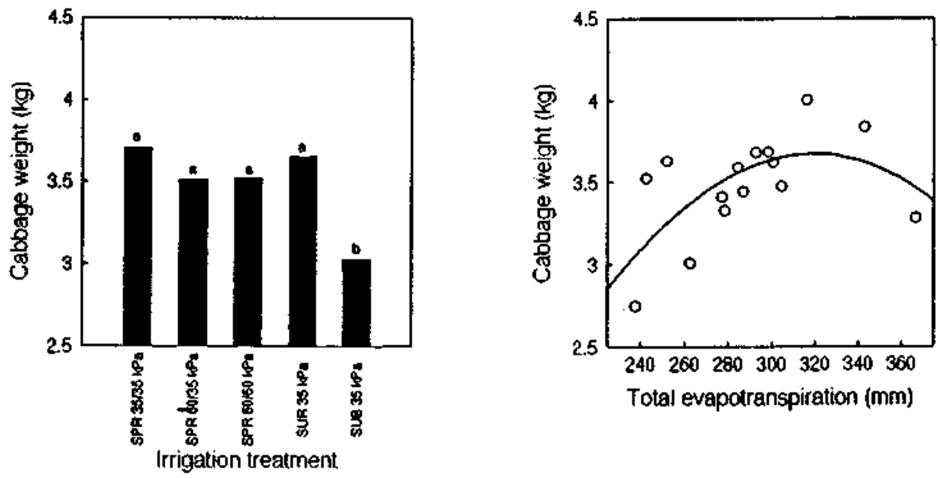


Figure 11. The mean weight of marketable cabbage heads was unaffected by altering the Critical Tensiometer Value, but was reduced by utilising sub-surface irrigation or reducing total ET below 300 mm.

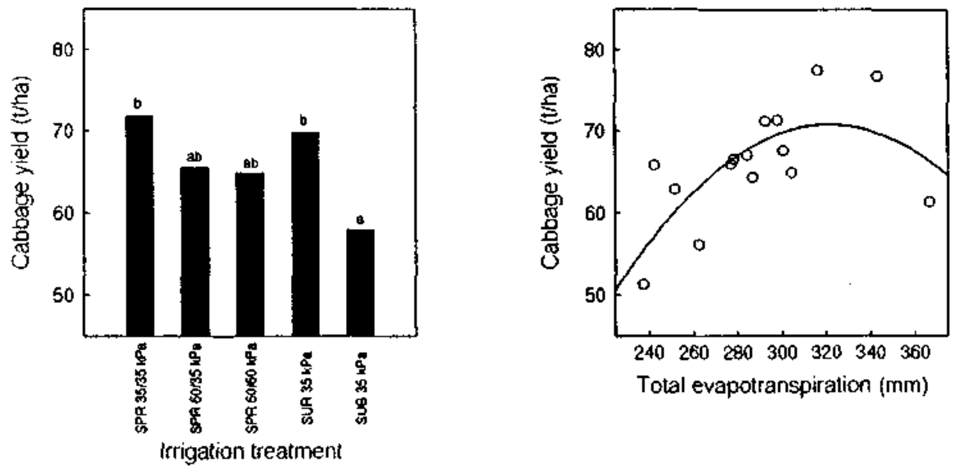


Figure 12. The total yield of marketable cabbage heads was reduced by utilising sub-surface irrigation or reducing total ET below 300 mm.

5. Discussion and conclusions

As in previous experiments, the tensiometer system was easy to install and use, gave accurate, reliable readings, required little maintenance and was relatively cheap. Although most water uptake from the cabbage occurred in the upper 40 cm of the soil profile, there still appeared to be some root activity below that depth, particularly in the less frequently irrigated treatments. For irrigation scheduling purposes, it may be more appropriate to install the deeper tensiometers at 60 cm, rather than at the 45 cm used in this experiment.

In this experiment we used a new version of the CAMNET probes that were completely enclosed by the synthetic semi-permeable membrane (i.e. did not have the small hole in the end of the probe). While this eliminated the problem of the sand matrix leaking from the probe, it did not improve probe response to unsaturated water flow. I believe that the design of the probe, including the membrane material, restricts movement of water into the probe under unsaturated flow conditions. Such conditions frequently occur when drip irrigation systems are used; where water is moving out (or upward) from point sources. The effective responses to rainfall, in contrast to slow responses to irrigation in the 2 drip systems used in this experiment, tend to confirm this hypothesis.

Calibration of the CAMNET probes seemed to shift over time. After heavy irrigation or rainfall, several probes would still not register 100% saturation. At the end of the experiment, we immersed the probes in a bucket of water. Some of the probes took 2-3 days to register their maximum value (from 95% to > 108%), which again indicated a problem with probe permeability. The failure rate of the probes in this experiment (2 out of 8) was a concern. We also noted problems with the first few readings after heavy irrigation or rainfall, indicating difficulties with either the electrical connections, seals, or possibly the interpreting software.

Apart from locking up on 2 occasions (with loss of a few days data), there were no problems with the remote data logger. The operating software effectively performed the tasks described in the manual, however it was neither flexible nor compatible with other programs. Of particular concern was the lack of graphic or data editing facilities. This could be overcome by enabling input/output in standard text and graphic formats. There are also several incorrect interpretations within the operating software, including assumptions that probes measure soil water content, and that an ET rate (mm/day) can be derived directly from probe readings.

Once we commenced managing irrigation with our scheduling systems (utilising watering regimes suggested by our previous research), virtually no drainage could be attributed directly to over-irrigation, except in the sub-surface irrigation treatment. The bulk of deep drainage was due to rainfall in excess of the storage capacity of the soil profile.

This experiment suggests that cabbage is less sensitive to water stress during the vegetative development stage, compared to the head development phase. Deficit irrigation during the vegetative phase may encourage activity of deeper roots, as well as provide a more effective reserve for capturing rainfall and reducing deep drainage. Cabbage water use appears to increase markedly once head development commences.

Results from this experiment suggest that a Critical Tensiometer Value for maximum production of winter-spring cabbage is probably 50-60 kPa during the vegetative phase, dropping to 40-50 kPa during the head development phase (the lower values would apply in conditions of high evaporative demand). On black earth soil types, this involves the following approximate irrigation sequences (given that no rainfall occurs). About 12-15 mm every 7-10 days for the first 8 weeks, increasing to 17-19 mm every 4-5 days for the 6 weeks until harvest. The target evapotranspiration for cabbage would probably be around 300-320 mm, with a total irrigation requirement of about 3-3.3 ML/ha, allowing for inefficiencies and drainage losses. This regime applies to sprinkler irrigation. Slightly lower overall quantities would probably be required for drip irrigation systems, supplied in smaller amounts on a more frequent basis. Obviously any rainfall during the intervening period would reduce these requirements, although there may still be a need to irrigate for other purposes, such as fertiliser or pesticide incorporation. The regime would also be affected by cultivar and agronomic practices.

The surface drip system performed well in this experiment, yielding as well as the best sprinkler treatment and using 70 mm less water. Interestingly, the water savings occurred during the head development phase, when reduced soil evaporation was likely to be less important than during early crop growth. Higher water use in the sprinkler irrigated treatments may have been due to windy conditions, increased evaporation from water on leaf surfaces, or luxury consumption of water with no growth increases.

There appeared to be several problems with using the AGRI-GRO tubing to supply water to the cabbage in this experiment. Despite frequent irrigation, we were unable to reduce the matric suction in the surface of the soil during the latter stages of the cabbage growing period. When we compared the amounts of water we were applying through the tubing (using a water meter on the irrigation pump to record total flow) with the increase in soil water in the root zone of the crop, there were often large discrepancies. In general, for every 10 mm of irrigation we would only pick up 3-6 mm increase in soil water content. I discounted losses through fittings or large leaks in the tubing, as these usually leave obvious areas of saturated soil around the leaks. It seemed more likely that water was draining from saturated zones around the tubing to below the root zone. Water did not appear to be moving readily from the saturated zone around the tube into the soil surrounding the tensiometer installations. A possible explanation is poor contact between the soil and the tubing, due to the trench installation method. This seems unlikely, given the shrink/swell nature of the black earth soils, and the series of wetting and drying cycles during the growth period. There was also an indication in a drop in leak rate of the tubing over time, suggesting pores within the tubing walls had become clogged.

We encountered similar problems with this product in a broccoli experiment conducted just prior to the cabbage experiment. There were no deleterious effects on broccoli yield from the lack of water spread in that experiment, however I expressed concern about possible yield reductions under conditions of high evaporative demand. These concerns were borne out in the cabbage experiment, where yield losses did occur. Obviously the wastage of a substantial amount of water via deep drainage using this application system is also a serious issue. Installation and retrieval of the pipe was labour and time-intensive; after 2-3 such operations the tubing tended to become brittle and break up.

To be a viable alternative to other irrigation systems, the sub-surface drip tubing would need to address the following issues.

1. It must be cost competitive with standard retrievable drip systems.
2. A rapid method for installing the tubing at a consistent depth, without damaging the tubing and ensuring good contact with the surrounding soil is required.
3. The system must maintain a consistent leak rate for the life of the crop; this may mean an improved manufacturing process, combined with a periodic flushing technique for removing internal contaminants.
4. Techniques for using the system to achieve better lateral and upward movement of water (to where the majority of the plant roots are) is required, particularly for periods of maximum crop growth and high evaporative demand.

It may be that this product has most application where it is permanently installed; e.g. in perennial plantings or amenity horticulture situations. Permanent installation in vegetables would require several changes to current production systems, probably including permanent bed / minimum tillage approaches.

We are relatively confident that the irrigation regimes and scheduling systems developed over the past 2 years will maximise cabbage production and irrigation efficiency on farms in south-east Queensland.

EXPERIMENT REPORT

Report **Final** **Date of Report:** 23-11-93

Initiation Date: 09-11-92 **Completion Date:** 02-2-93

Project Number: S8902

Project Title: Irrigation scheduling in vegetables

Experiment Number: S8902.12 **Officer Responsible:** Craig Henderson

Experiment Title: Irrigation scheduling for summer sweet corn.

Experiment Objectives

This experiment sought to determine the relationship between sweet corn yield and tensiometer values under various irrigation systems. It also attempted to determine the efficiency of irrigation by quantifying the amounts of applied water draining beyond the root zone during the growing period.

Summary of Results

The experiment was conducted at Gatton Research Station, from November 1992 - February 1993. Sweet corn (cv. *H9*) were grown using standard agronomy, with 5 irrigation treatments replicated 3 times in a RCB design. Plots were 3.0 m wide and 10 m long, with a total experimental area of 0.05 ha. The five irrigation treatments involved commencing irrigation at different Critical Tensiometer Values (**T** kPa), using tensiometers installed 15 cm below ground level in each plot. The **T** values were 20 kPa, 35 kPa, 50 kPa and 80 kPa, with the 35 kPa treatment further split into surface drip tape and sub-surface drip tubing irrigation systems. All other irrigation applications were via surface drip tape. Scheduling with tensiometers reduced drainage losses due to irrigation to $<5\%$ of application, however drainage associated with excess rainfall was substantial. A critical tensiometer value of 50 kPa maximised sweet corn yields (around 17 t/ha) while minimising irrigation requirements and drainage losses. Watering less frequently significantly reduced sweet corn yields. Sweet corn growth and yields were significantly lower on plots irrigated with sub-surface drip tubing, due to lower irrigation volumes and hence lower total evapotranspiration. There was a significant overall trend for lower yields on plots with lower total evapotranspiration.

EXPERIMENT REPORT

Irrigation scheduling for summer sweet corn

by C. Henderson and M. Webber
Department of Primary Industries
Gatton Research Station

Experiment No. S8902.12 9.11.92-2.2.93

1. Relevance to Industry

In many regions, including the Lockyer Valley, irrigation demands regularly exceed the reliable capacity of the water supply, resulting in scarcity or reliance on poorer quality water. Sweet corn is a major user of irrigation water from October through April in southern Queensland. With the introduction of new, better adapted cultivars, there is potential for major expansion of the sweet corn industry for both the fresh and processing markets. Many producers budget on applying around 4-6 ML/ha of irrigation to a sweet corn crop. Until recently, the frequency and amount of irrigation was relatively ad hoc, based on tradition and grower experience, combined with superficial observations of plant or soil conditions.

Some sweet corn growers interstate and overseas use tensiometers or neutron probes to monitor soil water status and schedule irrigations. Both methods have advantages and disadvantages, however tensiometers appear to have the best immediate potential for use in southern Queensland. Most water uptake in sweet corn occurs in the upper 0.3-0.5 m of the soil profile.

Matching irrigation to crop requirements maximises production by minimising plant water stress, nutrient deficiencies and some diseases, as well as preventing build up of salinity problems. By preventing overwatering, problems with leaching of nutrients and pesticides into groundwater (and beyond the zone of usefulness) are reduced, as well as a decrease in disease levels.

2. Objectives

This experiment sought to determine the relationship between sweet corn yield and tensiometer values under various irrigation regimes and application systems. It also attempted to determine the efficiency of scheduling systems, by quantifying the amounts of applied water draining beyond the root zone during the sweet corn growing period.

3. Materials and methods

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

The soil was prepared as per standard practice for sweet corn. An experimental DPI cultivar *H9* was sown on the 9 November 1992, with 1.00 m between the rows and 0.17 m intra-row spacing. A basal application of 80 kgN/ha as urea was applied 5 days prior to sowing and incorporated with 15 mm irrigation. A side dressing of 80 kgN/ha as urea was applied on 18 December 1992. A tank-mix containing 1 kg/ha of urea and 1 kg/ha of zinc sulphate was sprayed over the crop on 8 December 1992. Weeds were managed by spraying 2.52 kg/ha of metolachlor 2 days after planting (DAP), prior to the initial post-planting irrigation of 21 mm. Occasional hand-hoeing also took place as other weeds emerged. Insects were controlled with regular applications of insecticides, including methomyl, endosulfan, mevinphos, dicofol and carbaryl. One application of 1.76 kg/ha of mancozeb was sprayed on 21 December 1992.

The initial irrigations utilised standard solid-set pipes and overhead sprinklers over the whole experimental area, for the first 10 DAP. For all other irrigations, systems of drip tape or sub-surface drip tubing were used to individually water each plot. A schematic of plot layout is shown in Fig. 1. Each plot consisted of 3 rows of sweet corn side by side. The central row was the treatment area, while the two outside rows were buffer zones. The drip tapes were positioned immediately adjacent to the sweet corn rows. The tape used was 'T-Tape Row Crop' with drip emitters every 20 cm, and an output of about 7.3 $Lm^{-1}hr^{-1}$ at an operating pressure of 70 kPa. This corresponded to an application rate of approximately 9 mm/hr on a total area basis.

The rows watered with the sub-surface system had the 'AGRI-GRO' continuous drip tubing positioned directly under the sweet corn rows (Fig. 1). The tube was installed using a small trench digger, at a depth of about 20 cm. The tube was installed on 4 November 1992, with the whole experimental area cultivated and harrowed after installation. When purchased, the tubing had an initial output of around 5.4 $Lm^{-1}hr^{-1}$ at an operating pressure of 90 kPa. This corresponded to an application rate of approximately 7 mm/hr on a total area basis.

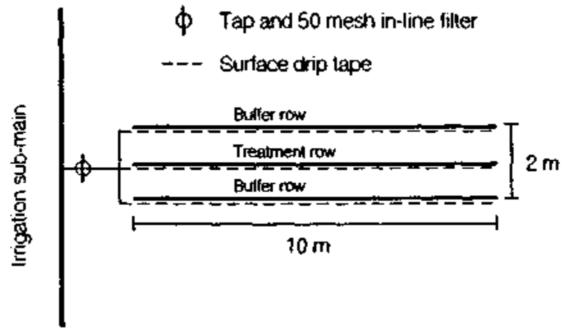


Figure 1. Surface drip tape and sub-surface drip tube systems design for an individual plot in an experiment investigating irrigation scheduling in summer sweet corn.

Tensiometers were installed 15 cm and 60 cm below ground level in each treatment row. *Loctronic* tensiometers were used, consisting of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum, while an electronic vacuum gauge attached to the syringe records the vacuum in the tensiometer air gap. Tensiometer readings were recorded daily, usually around 9 am.

Critical Tensiometer Values (T) were used to trigger irrigations in this experiment. Irrigation was applied when readings for the tensiometers installed 15 cm below the ground surface were greater than the **T** individually set for each treatment. Five irrigation treatments were investigated, involving scheduling regimes based on tensiometer readings:

1. Irrigated with surface drip tape at a shallow tensiometer value of 20 kPa.

2. Irrigated with surface drip tape at a shallow tensiometer value of 35 kPa.

3. Irrigated with surface drip tape at a shallow tensiometer value of 50 kPa.

4. Irrigated with surface drip tape at a shallow tensiometer value of 80 kPa.

5. Irrigated with sub-surface drip tubing at a shallow tensiometer value of 35 kPa.

Each plot was irrigated according to its allocated treatment. Plots with the same irrigation treatment were watered on the same days, based on average tensiometer values across the 3 replicate plots.

Aluminium neutron probe access tubes were installed to depths of 110 cm in each treatment bed, 10 cm on the opposite side of the sweet corn row to the drip tape and equidistant between 2 neighbouring plants. Neutron moisture meter readings were taken twice a week using a Campbell Pacific Nuclear Hydroprobe. A single reading was taken at 8 depth intervals, commencing 5 cm below the ground surface, incrementing by 10 cm. On each day that the neutron probe measurements were made, 5 standard counts was also conducted in a 200 L drum of water. Calibration equations for the neutron probe data were assumed to be the same as for previous experiments at this site.

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

The heights of the sweet corn plants were measured 18, 25, 32 and 42 DAP. Five plants were randomly selected and assessed in each plot. Sweet corn cobs were harvested by hand from the treatment rows on 2 February 1993, 85 days after planting. The number of marketable heads per row were counted, harvested and weighed. Five cobs from each plot were randomly selected and rated for maturity, cob colour, blanking and tip-fill.

4. Results

A total of 195 mm of rain fell during the growing period. There was regular rainfall between 8 and 36 DAP, with another substantial fall about 59 DAP (Fig. 2). In contrast with a previous sweet corn experiment, there was much greater differentiation between irrigation treatments in the total amounts of water received.

Using a simple spreadsheet, a daily water balance was calculated for each plot. Rainfall, irrigation, stored soil water, pan evaporation, evapotranspiration and drainage of soil water below 80 cm were determined from planting through to harvest. Details of the calculations are available from the authors.

For the first 40 DAP, shallow tensiometers in the 20 kPa treatment fluctuated between 0-30 kPa (Fig. 2). These plots received 5 irrigations during this period (average 17 mm). Between 40-60 DAP, the shallow tensiometers reached 40 kPa between irrigations; a total of 7 irrigations, averaging 14 mm every 2.5 days. In the final 4 weeks prior to harvest, shallow tensiometer values peaked at 50 kPa, with a further 7 irrigations (average 17 mm every 3 days). Deep tensiometers in the 20 kPa treatment fluctuated between 0-20 kPa for the growing period. Deep tensiometer data and water balance calculations suggest that substantial deep drainage occurred following the 2 irrigations in excess of 30 mm, as well as after rainfall events greater than 20 mm.

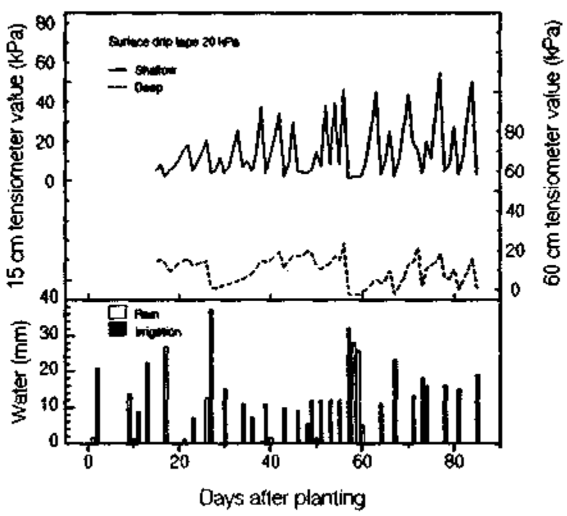


Figure 2. Fluctuations in soil matric suction at 15 and 60 cm below ground level, where sweet corn were irrigated using surface drip tape, when soil matric suction at 15 cm exceeded 20 kPa during the growing period.

Tensiometer readings for the 35 kPa treatment were similar to the 20 kPa treatment for the latter 2 growth periods; for the first 40 DAP they rose to 40-50 kPa between irrigations or rainfall (Fig. 3). During the first 40 DAP this treatment received 3 irrigations of average 23 mm. For the subsequent 3 week period, the 35 kPa plots were irrigated 7 times (average 12 mm every 2.5 days). During the final growth period the 35 kPa treatment received the same irrigation regime as the 20 kPa treatment. Deep tensiometers in the 35 kPa treatment fluctuated between 0-30 kPa for the first 60 DAP. For the final 3 weeks of the growing period, deep tensiometer values hovered around 30-40 kPa. The data suggests the only drainage from excess irrigation occurred where 37 mm was applied about 27 DAP. Other drainage was associated with rainfall in excess of soil storage capacity at the time.

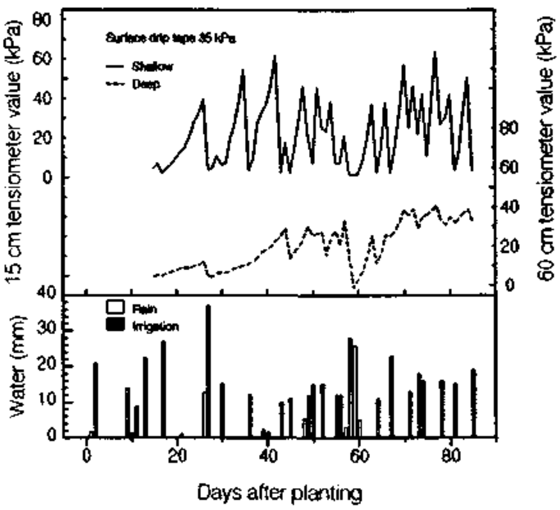


Figure 3. Fluctuations in soil matric suction at 15 and 60 cm below ground level, where sweet corn were irrigated using surface drip tape, when soil matric suction at 15 cm exceeded 35 kPa during the growing period.

Shallow tensiometers in the 50 kPa plots fluctuated between 0 and 60 kPa for most of the growing period (Fig. 4). For the first 40 DAP, this treatment received 4 irrigations, averaging 12 mm. Between 40 and 60 DAP, an average of 15 mm irrigation was applied every 2.5 days. From 60 DAP until harvesting, 5 irrigations (average 14 mm every 4 days) were received by this treatment. For the first 40 DAP, deep tensiometer values remained less than 10 kPa. For the remainder of the growing period, the matric suctions at 60 cm fluctuated between 10 and 40 kPa, except following heavy rainfall around 59 DAP. The data suggests that most deep drainage was associated with excess rainfall, rather than excess irrigation.

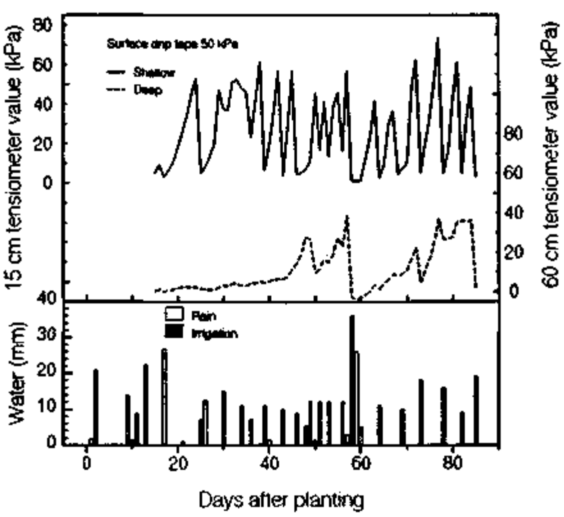


Figure 4. Fluctuations in soil matric suction at 15 and 60 cm below ground level, where sweet corn were irrigated using surface drip tape, when soil matric suction at 15 cm exceeded 50 kPa during the growing period.

Shallow tensiometers in the 80 kPa treatment slowly rose to about 60 kPa over the first 40 DAP (Fig. 5). For the remainder of the growing period these shallow tensiometer values quickly returned to 70-80 kPa within 3 days of irrigation or rainfall. Apart from the initial post-planting irrigation, these plots were not watered again during the first 40 DAP. During the next 3 weeks they were irrigated on 4 occasions, (average 16 mm every 4.5 days). During the final 4 weeks of the growing period, this treatment received only 1 irrigation (16 mm). Deep tensiometer values in these plots steadily increased from about 5 weeks after sowing, peaking at 60 kPa about 50 DAP. For the remainder of the growing period the matric suctions at 60 cm stayed about 50-60 kPa, except immediately following heavy rainfall around 59 DAP. Similar to the previous treatment, deep drainage was only associated with excess rainfall, not over-irrigation.

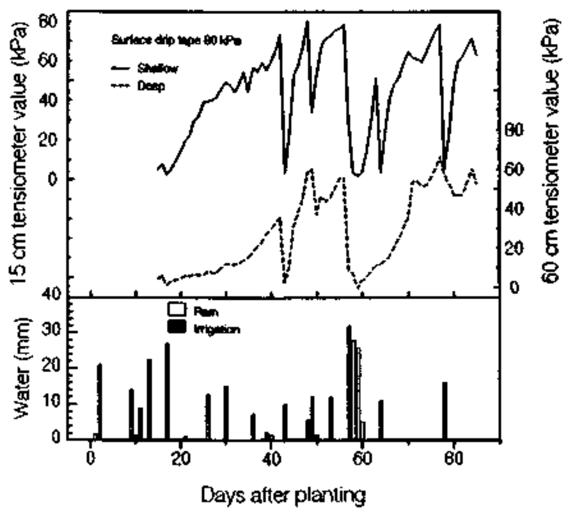


Figure 5. Fluctuations in soil matric suction at 15 and 60 cm below ground level, where sweet corn were irrigated using surface drip tape, when soil matric suction at 15 cm exceeded 80 kPa during the growing period.

Shallow tensiometers in the plots watered with the sub-surface drip tubing fluctuated between 0-50 kPa for most of the growing period (Fig. 6). These plots only received 3 irrigations (average 11 mm) for the first 40 DAP. Over the next 3 weeks there were a further 7 irrigations of 6 mm; with 6 irrigations during the final period prior to harvesting (average 8 mm). The depths of water applied were less than expected, because of a drop-off in the leak rate of the drip tubing, compared to initial specifications. From 6 weeks after sowing until harvesting, deep tensiometers in the sub-surface irrigated treatment fluctuated between 35-50 kPa. There was only minimal deep drainage from this treatment.

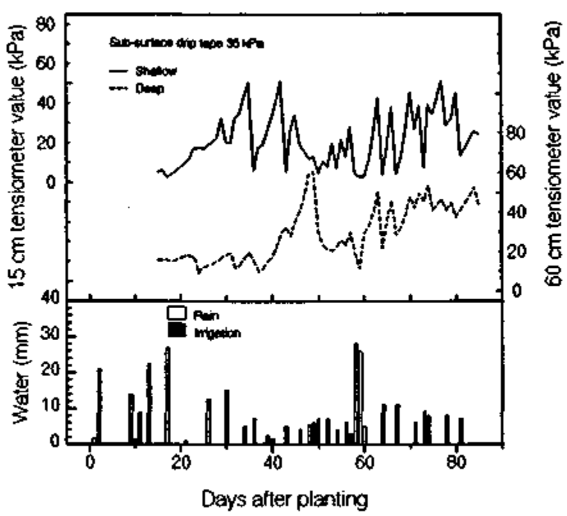


Figure 6. Fluctuations in soil matric suction at 15 and 60 cm below ground level, where sweet corn were irrigated using sub-surface drip tube, when soil matric suction at 15 cm exceeded 35 kPa during the growing period.

As T increased the total amount of irrigation applied to the sweet corn declined (Fig. 7). The reduction was greatest when T was increased from 50 to 80 kPa. There was a significant trend for less deep drainage in treatments with higher T values. In the sub-surface, 50 and 80 kPa treatments, all deep drainage was associated with rainfall in excess of the soil water storage capacity at the time. In the 20 and 35 kPa treatments, 25 and 15% of the drainage respectively was due to irrigation in excess of the soil water storage capacity.

There were significant declines in total evapotranspiration (ET) as T increased, with ET for the sub-surface irrigation treatment equivalent to the 80 kPa treatment (Fig. 7). Differences in total ET were caused by differences in ET rates as early as 4 weeks after planting, and continued through to harvesting (Fig. 8).

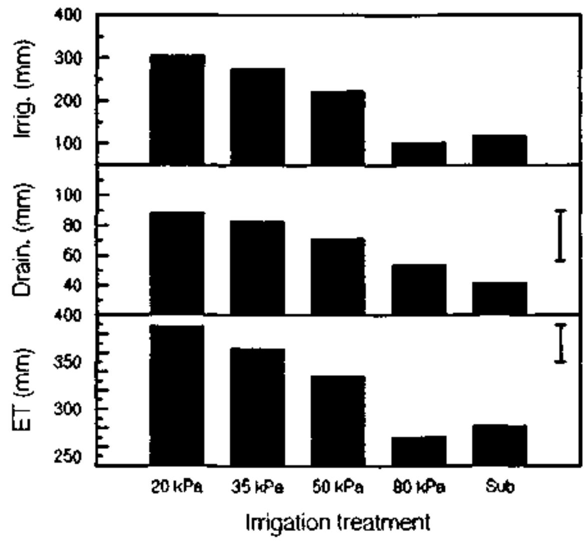


Figure 7. Changes in quantities of irrigation, total evapotranspiration and drainage losses under 5 irrigation regimes. Bars indicate the 5% L.S.D.

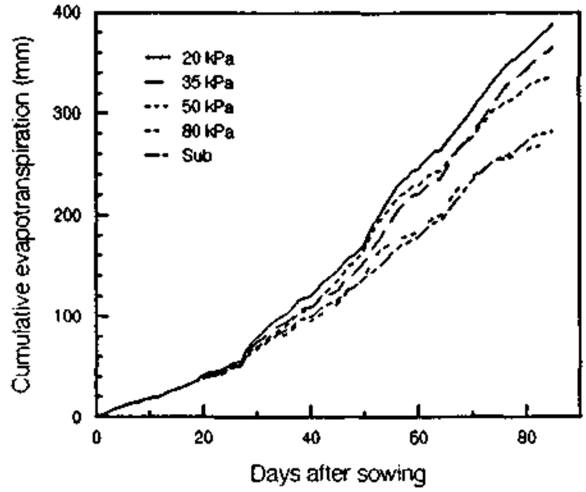


Figure 8. Cumulative evapotranspiration under 5 irrigation regimes.

There were no differences in heights of sweet corn plants watered with surface drip systems until the assessment at 42 DAP, when plants in the 50 and 80 kPa treatments were significantly shorter than those from the 20 kPa treatment (Fig. 9). The sub-surface irrigated sweet corn plants were always shorter than plants from the 20 kPa treatment.

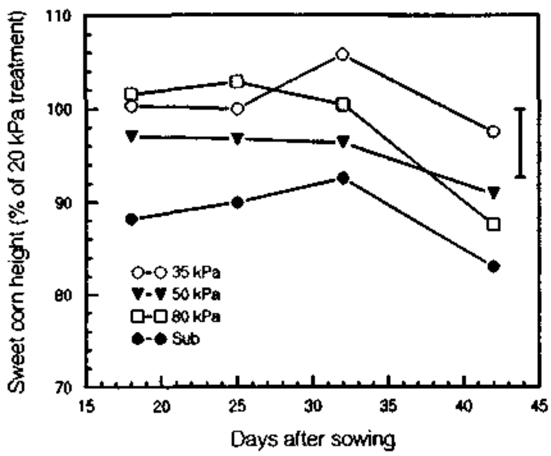


Figure 9. Comparative heights of sweet corn plants under 5 irrigation regimes.

There were no significant differences in yield between treatments watered at T values between 20 and 50 kPa (inclusive) as shown in Fig. 10. The 80 kPa and sub-surface treatments yielded significantly less than the other 3 treatments ($P<0.01$). Yield reductions were due to fewer cobs, although there was a trend for slightly smaller cobs in the 80 kPa treatment (Fig. 10). There appeared to be a curvi-linear relationship between ET and cob yield (Y) in 1992/93 (Fig. 10). Yield increased with total ET to a maximum of 17 t/ha at a total ET of about 340 mm. Increasing ET beyond this value did not improve sweet corn yield;

$$Y = -31.5 + 0.254\ ET - 0.000332\ ET^2 \quad R^2 = 0.67$$

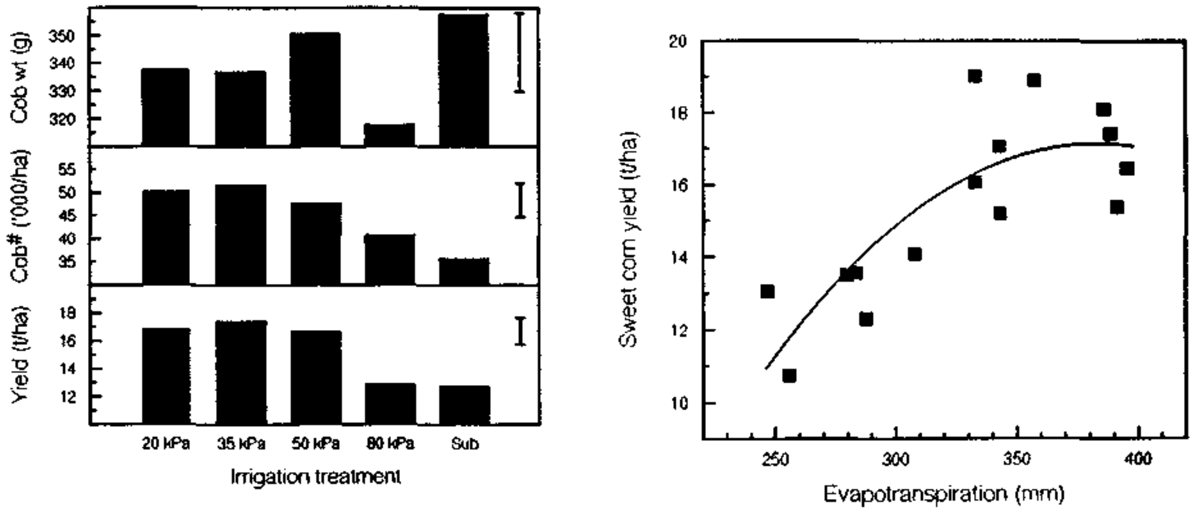


Figure 10. Sweet corn yield was reduced at Critical Tensiometer Values > 50 kPa, with yield significantly increased at higher ET totals.

5. Discussion and conclusions

As in previous experiments, the tensiometer system was easy to install and use, gave accurate, reliable readings, required little maintenance and was relatively cheap. Although most water uptake from the sweet corn occurred in the upper 50 cm of the soil profile, there was some root activity below that depth, particularly in the less frequently irrigated treatments.

Once we commenced managing irrigation with our scheduling systems (utilising watering regimes suggested by our previous research), virtually no drainage could be attributed directly to over-irrigation, except for a couple of occasions in the 20 kPa treatment. The bulk of deep drainage was due to rainfall in excess of the storage capacity of the soil profile. Because of the wetter soil surface, these rainfall excesses are more likely to occur in more frequently irrigated treatments. It is likely that deficit irrigation during the vegetative phase may encourage activity of deeper roots, as well as provide a more effective reserve for capturing rainfall and reducing deep drainage.

Initial indications are that a Critical Tensiometer Value for maximum production of summer sweet corn is probably 50-60 kPa pre-silking, dropping to 50 kPa during the pollination and cob development phases. On black earth soil types under trickle, this involves irrigation about every 4 days, applying 10 mm per irrigation for the first 7 weeks after planting, increasing to 15 mm per irrigation until harvest. Under overhead irrigation, the frequency would be reduced and the total depths increased. The target evapotranspiration for sweet corn would probably be around 340-370 mm, with a total irrigation requirement of about 3.5-4 ML/ha, allowing for inefficiencies and drainage losses. Obviously any rainfall during the intervening period would reduce these requirements, although there may still be a need to irrigate for other purposes, such as fertiliser or pesticide incorporation. The regime would also be affected by cultivar and agronomic practices.

There were several problems with the AGRI-GRO tubing in this experiment. In contrast to previous experiments, lateral and upward spread of water away from the drip tube was more rapid and extensive. Of more concern was the apparent leak rate of the tube, which was about half of that measured on previous occasions. Results of lower leak rates were smaller overall application volumes, which in turn reduced water use, growth and yield of the sweet corn. It seems probable that pores within the tubing walls had become clogged or restricted over time.

In general, the overall performance of the AGRI-GRO tubing deteriorated during the 10 months we evaluated it in vegetables. In the final 3 experiments on broccoli, cabbage and sweet corn, application rates from the tubing declined, while crop growth and yields were also adversely affected. Installation and retrieval of the pipe was labour and time-intensive; after 2-3 such operations the tubing tended to become brittle and break up.

To be a viable alternative to other irrigation systems, the sub-surface drip tubing would need to address the following issues.

1. It must be cost competitive with standard retrievable drip systems.
2. A rapid method for installing the tubing at a consistent depth, without damaging the tubing and ensuring good contact with the surrounding soil is required.
3. The system must maintain a consistent leak rate for the life of the crop; this may mean an improved manufacturing process, combined with a periodic flushing technique for removing internal contaminants.
4. Techniques for using the system to achieve better lateral and upward movement of water (to where the majority of the plant roots are) is required, particularly for periods of maximum crop growth and high evaporative demand.

It may be that this product has most application where it is permanently installed; e.g. in perennial plantings or amenity horticulture situations. Permanent installation in vegetables would require several changes to current production systems, probably including permanent bed / minimum tillage approaches.

We are relatively confident that the irrigation regimes and scheduling systems developed over the past 2 years will maximise sweet corn production and irrigation efficiency on farms in south-east Queensland.

EXPERIMENT REPORT

Report **Final** **Date of Report:** 20-12-93

Initiation Date: 23-2-93 **Completion Date:** 16-06-93

Project Number: P378

Project Title: Irrigation scheduling in vegetables

Experiment Number: P378.13 **Officer Responsible:** Craig Henderson

Experiment Title: Irrigation scheduling for autumn grown potatoes.

Experiment Objectives

This experiment sought to determine the relationship between potato yield and tensiometer values. It also attempted to determine the efficiency of irrigation by quantifying the amounts of applied water draining beyond the root zone during the growing period.

Summary of Results

The experiment was conducted at Gatton Research Station, from February-June 1993. Potato (cv. *Sebago*) were grown using standard agronomy, with 5 irrigation treatments replicated 3 times in a RCB design. Plots were 4.5 m wide and 10 m long, with a total experimental area of 0.065 ha. The five irrigation treatments involved commencing irrigation at different Critical Tensiometer Values (T kPa), using tensiometers installed 20 cm below hilltop level in each plot. The T values were; 30 kPa; 45 kPa; 60 kPa; 80 kPa and irrigating about every 10 days. Scheduling with tensiometers almost eliminated drainage losses, apart from an accidental over-irrigation due to equipment failure. The 80 kPa and 10 day irrigation treatments yielded < 50% of the other treatments (12-14 t/ha vs 28-30 t/ha of #1 grade potatoes). This was due to both fewer and smaller tubers. Water stress during the tuber initiation and early yield formation phases (between 40 and 80 days after planting) appeared to be the most critical factor affecting potato yield. There were highly significant relationships between total evapotranspiration and both the number and yield of potato tubers produced in the experiment.

EXPERIMENT REPORT

Irrigation scheduling for autumn grown potatoes

by C. Henderson and M. Webber
Department of Primary Industries
Gatton Research Station

Experiment No. P378.13 23.2.93-16.6.93

1. Relevance to Industry

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

Some vegetable growers use tensiometers or neutron probes to monitor soil water status and schedule irrigations. Both methods have advantages and disadvantages, however tensiometers appear to have the best immediate potential for use in potatoes in southern Queensland. Most water uptake in potatoes occurs in the upper 0.4-0.5 m of the soil profile.

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

2. Objectives

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

3. Materials and methods

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

The soil was prepared as per standard practice for potatoes. Cv. *Sebago* was planted on the 23 February 1993, with 0.75 m between the rows and 0.25 m intra-row spacing. A total of 400 kg/ha of compound fertiliser (52 kg N, 9 kg P, 53 kg K, 75 kg S) was applied immediately before planting. A side dressing of 100 kg N/ha as urea was applied on 19 March 1993. This was incorporated with a hilling operation and 26 mm of irrigation on the same day. Weeds were managed by spraying 0.28 kg/ha of metribuzin immediately after hilling and prior to irrigation. Occasional hand-hoeing also took place as other weeds emerged. Leaf diseases were managed by 5 applications of 1.76 kg/ha of mancozeb during the growing period. Insecticides methamidophos and pirimicarb were periodically sprayed for insect control.

The initial irrigations utilised standard solid-set pipes and overhead sprinklers over the whole experimental area, for the first 4 weeks after planting. For all other irrigations, systems of mini-sprinklers were used to individually water each plot. A schematic of plot layout is shown in Fig. 1, with 2 rows of potatoes per 'bed'. Each plot consisted of 6 rows of potatoes side by side. The central 2 rows were the treatment area, while the outer 4 rows were buffer zones.

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

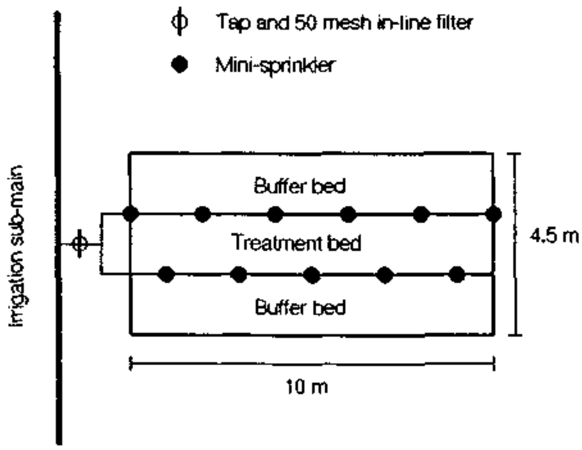


Figure 1. Mini-sprinkler system design for an individual plot in an experiment investigating irrigation scheduling in autumn grown potatoes.

Tensiometers were installed 15 cm, 20 cm and 45 cm below the tops of the hills in a treatment row in each plot. *Loctronic* tensiometers were used, consisting of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum, while an electronic vacuum gauge attached to the syringe records the vacuum in the tensiometer air gap. Tensiometer readings were recorded daily, usually around 9 am.

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

1. Irrigated at **T** of 30 kPa for the growing period (**SPR 30**).

2. Irrigated at **T** of 45 kPa for the growing period (**SPR 45**).

3. Irrigated at **T** of 60 kPa for the growing period (**SPR 60**).

4. Irrigated at **T** of 80 kPa for the growing period (**SPR 80**).

5. Irrigated about every 10 days during the growing period (**SPR 10D**).

Aluminium neutron probe access tubes were installed to depths of 110 cm in each treatment bed, 5 cm inside a potatoes row and equidistant between 2 neighbouring plants. Neutron moisture meter readings were taken twice a week using a Campbell Pacific Nuclear Hydroprobe. A single reading was taken at 8 depth intervals, commencing 5 cm below the ground surface, incrementing by 10 cm. On each day that the neutron probe measurements were made, 5 standard counts was also conducted in a 200 L drum of water. Calibration equations for the neutron probe data were assumed to be the same as for previous experiments at this site.

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

The heights of the potatoes plants were measured 38 and 44 days after planting (DAP). Five plants were randomly selected and assessed in each plot. At maturity, potatoes were dug by machine and hand harvested into bags on 16 June 1993. The potatoes were graded into 3 classes; smalls (<80 g), #1 grade (80-350 g), over-size (>350 g); counted and weighed.

4. Results

There was only 50 mm of rainfall during the 113 day growing period. Only one event of 23 mm at 80 DAP exceeded 8 mm (Fig. 2). Thus rainfall had little impact on the conduct of this experiment.

At 42 DAP there was a breakdown in the sprinkler timer system; as a result the 30 kPa, 45 kPa and 60 kPa treatments received a 194 mm irrigation, of which about 110 mm was lost in through-drainage. Although this drainage is reported in the results, in formulating an optimum irrigation strategy, this irrigation is assumed to be only 85 mm.

Using a simple spreadsheet, a daily water balance was calculated for each plot. Rainfall, irrigation, stored soil water, pan evaporation, evapotranspiration and drainage of soil water below 80 cm were determined from planting through to harvest. Details of the calculations are available from the authors.

In discussing the water use and growth of the potato crop, I have divided the growing period into 4 phases; (i) establishment and early vegetative growth = 0-40 DAP; (ii) tuber initiation = 41-55 DAP; (iii) yield formation = 56-102 DAP; (iv) ripening = 103-113 DAP. Irrigation treatment differences did not commence until the tuber initiation phase, apart from a single extra application of 13 mm at 35 DAP in the 30 kPa treatment. No plots were irrigated during the ripening period.

During the tuber initiation phase in the 30 kPa treatment, values for tensiometers at 20 cm rose rapidly to 60 kPa within 3-4 days of irrigation. This indicated very high rates of water use during this period. Note also that water uptake is greater at 20 cm than at 15 cm, indicating more root activity deeper in the hill. Irrigation frequency was increased during the yield formation phase, to try and maintain the shallow tensiometer values within the appropriate treatment levels (Fig. 2). During tuber initiation and yield formation, this treatment received an average 23 mm of irrigation every 5.2 days, with higher frequencies at the start of the yield formation period. The deep tensiometers indicated drainage occurred following the over-irrigation at 42 DAP and rainfall at 80 DAP (Fig. 2).

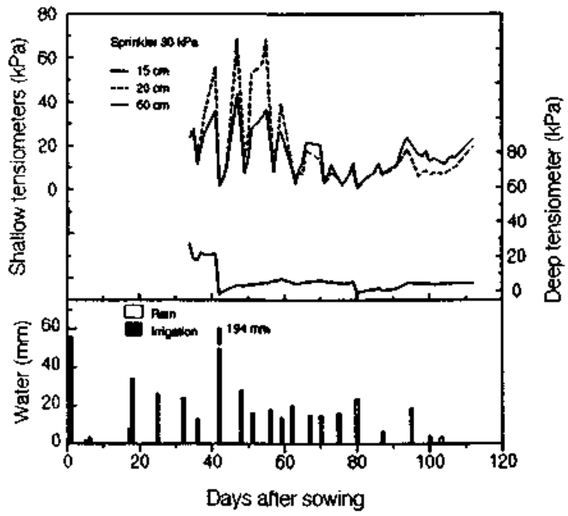


Figure 2. Fluctuations in soil matric suction at 15, 20 and 60 cm below the top of the hill, where potatoes were irrigated when soil matric suction at 20 cm exceeded 30 kPa during the growing period.

Tensiometer fluctuations in the 45 kPa treatment (Fig. 3) were very similar to the 30 kPa treatment for the first 90 DAP. These 2 treatments also had the same irrigation regimes during that period. Immediately prior to the commencement of the ripening phase, the 45 kPa treatment appeared to be using more water than the 30 kPa treatment; as a consequence the former received an additional irrigation of 21 mm. Overall, during the tuber initiation and yield formation periods, the 45 kPa treatment received an average 24 mm of irrigation every 4.8 days, with higher frequencies at the start of the yield formation phase. The deep tensiometers indicated drainage occurred following the over-irrigation at 42 DAP and rainfall at 80 DAP (Fig. 3).

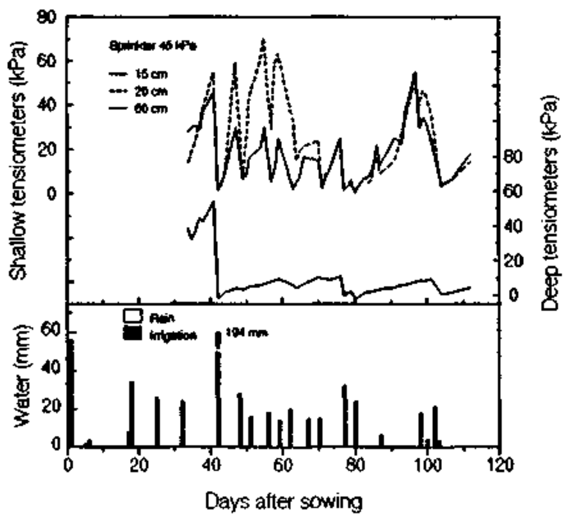


Figure 3. Fluctuations in soil matric suction at 15, 20 and 60 cm below the top of the hill, where potatoes were irrigated when soil matric suction at 20 cm exceeded 45 kPa during the growing period.

The shallow tensiometers in the 60 kPa treatment fluctuated between 0-70 kPa for most of the growing period (Fig. 4). For the first 90 DAP, these potatoes received a similar irrigation regime to the 30 and 45 kPa treatments; average 28 mm about every 5.5 days. This treatment was not irrigated during the last 23 days prior to harvesting. Deep tensiometer values suggest the only deep drainage in this treatment occurred following the excessive irrigation at 42 DAP.

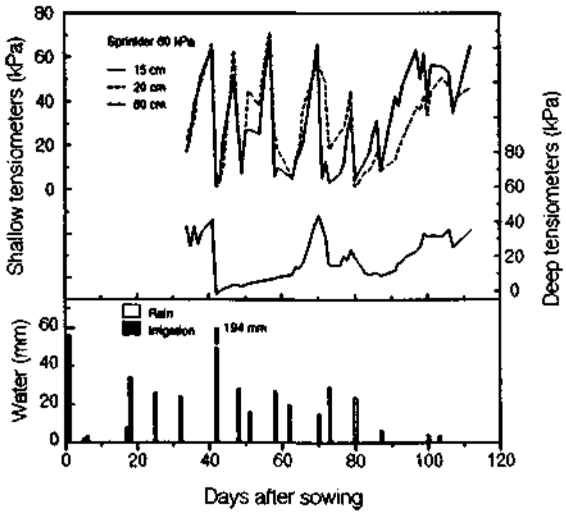


Figure 4. Fluctuations in soil matric suction at 15, 20 and 60 cm below the top of the hill, where potatoes were irrigated when soil matric suction at 20 cm exceeded 60 kPa during the growing period.

Interestingly, the shallow tensiometers in the 80 kPa treatment (Fig. 5) fluctuated less than the corresponding tensiometers in the more frequently irrigated treatments. It is possible that early water stress at the time of tuber initiation killed most of the feeder roots responsible for water uptake in the hill. During tuber initiation and yield formation this treatment was irrigated with 24 mm every 10.4 days, with no irrigation during the 23 days prior to harvesting. Deep tensiometer values suggest there was no deep drainage in this treatment (Fig. 5).

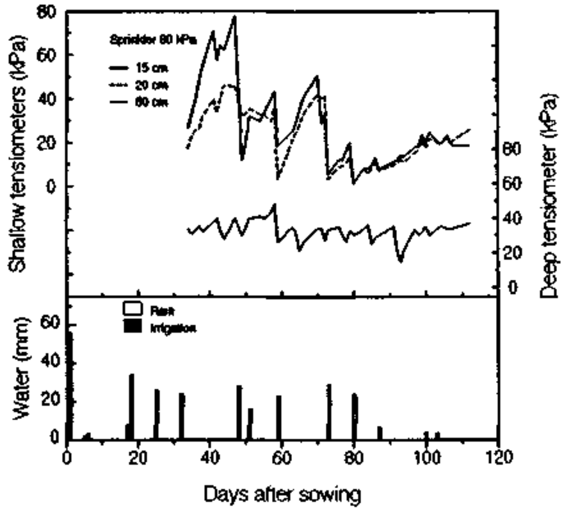


Figure 5. Fluctuations in soil matric suction at 15, 20 and 60 cm below the top of the hill, where potatoes were irrigated when soil matric suction at 20 cm exceeded 80 kPa during the growing period.

The shallow tensiometers in Treatment 5 fluctuated between 0-50 kPa for the first 80 DAP (Fig. 6). From then until harvest, there appeared to be less water uptake compared to the more frequently irrigated treatments. This suggests earlier senescence of the potato bushes in this treatment, similar to the potatoes irrigated in Treatment 4. On average, the potatoes in Treatment 5 were irrigated with 24 mm every 7 (not 10) days. Deep tensiometer values indicate there was no deep drainage in this treatment (Fig. 6).

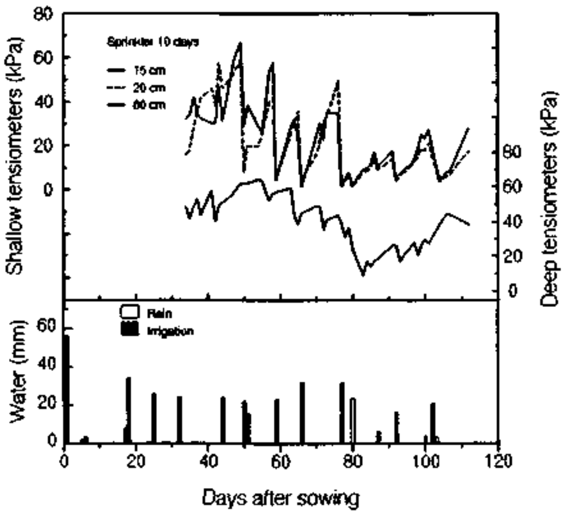


Figure 6. Fluctuations in soil matric suction at 15, 20 and 60 cm below the top of the hill, where potatoes were irrigated every '10' days.

The total irrigation quantities of 531 mm, 508 mm and 469 mm, for the 45 kPa, 30 kPa and 60 kPa treatments respectively, are about 110 mm in excess of what we intended to apply, due to the irrigation malfunction at 42 DAP. The deep drainage for these 3 treatments is almost entirely due to this single accident. The 45 kPa treatment, which had the most irrigation, also had the greatest total evapotranspiration (ET) of 360 mm; about 30 mm more than the 30 kPa and 60 kPa treatments (Fig. 7). Treatment 5 had a significantly lower ET of 310 mm, while the 80 kPa ET was 75 mm lower still. The low ET value of Treatment 5 was due to lower ET rates for the whole of the growing period from 40 DAP on (Fig. 8). Reduced ET in Treatment 4 was caused by lower ET rates in the period 45-80 DAP. The 45 kPa treatment had the highest total ET because of continued high ET rates during the 3 weeks prior to harvest, when compared with the other 2 frequently irrigated treatments (Fig. 8).

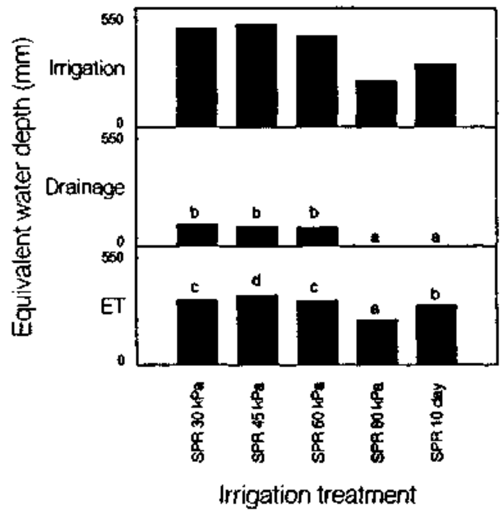


Figure 7. Changes in quantities of irrigation, total evapotranspiration and drainage losses under 5 irrigation regimes. Bars labelled with the same letter were not significantly different ($P<0.05$).

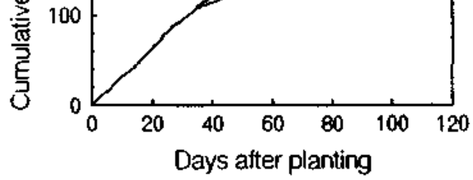


Figure 9. Cumulative evapotranspiration under 5 irrigation regimes.

There were no significant effects of irrigation treatment on potato plant heights at 38 DAP (mean 40 cm). However, just 6 days later, the plants in the 80 kPa and 10 day irrigation treatments were significantly shorter than the other 3 treatments (43 cm vs 48 cm), reflecting a response to the absence of irrigation during that period.

The 3 most frequently irrigated treatments all produced a similar total number of tubers across the grade ranges (Fig. 9). There was a trend for the 45 kPa treatment to have slightly fewer smalls and slightly more #1 grade and over-size than the other 2 treatments. The 80 kPa and 10 day irrigation treatments produced fewer tubers than the other 3 treatments across the whole range of sizes. They had a much higher proportion of small potatoes compared to the more frequently irrigated potatoes. There were very strong relationships between the numbers of tubers harvested ('000/ha), both #1 grade (#1N) and total (TN), and total evapotranspiration (ET mm) of the potato crop:

#1N = 78.2 + 79.1 / (1 + e ^ (-0.269 * (ET - 325))) $R^2 = 0.87^{***}$

TN = 144.5 + 123.3 / (1 + e ^ (-0.297 * (ET - 316))) $R^2 = 0.85^{***}$

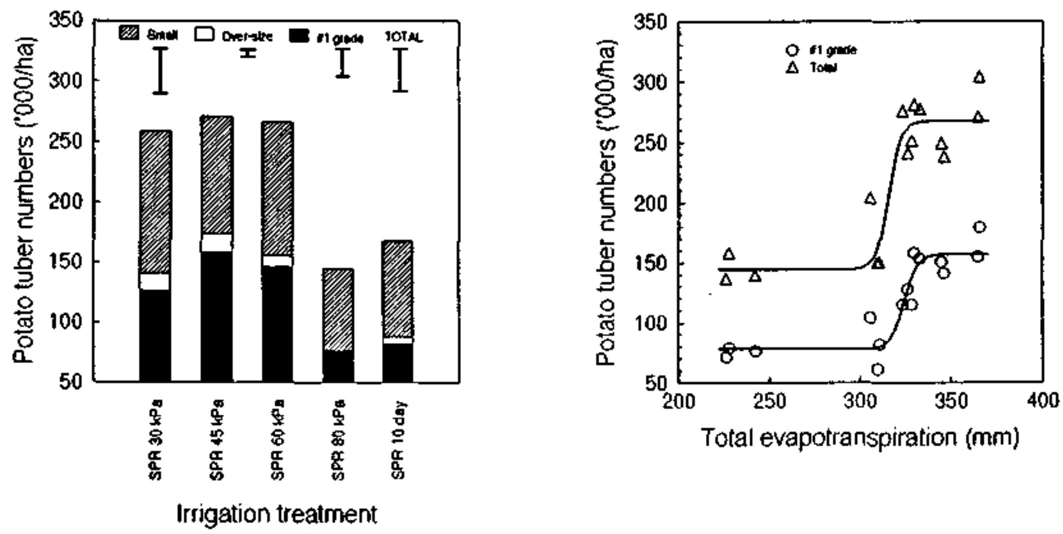


Figure 9. The numbers of potato tubers were significantly affected by altering Critical Tensiometer Value, or the total evapotranspiration of autumn grown potatoes.

Potato yields (Fig. 10) reflected differences in tuber numbers. Because the 45 kPa treatment had converted significantly more small tubers into #1 grade, it had the highest yields of the frequently irrigated treatments. Yields of the 30 kPa and 60 kPa treatments were 3-5 t/ha lower, due to slightly smaller potatoes in each of the size classes. The lower yields of the 2 least frequently irrigated treatments were due to fewer and smaller tubers. As expected, there were good relationships between yields of #1 grade potatoes (#1Y), all potatoes (TY) and ET:

#1Y = 10.88 + 19.18 / (1 + e ^ (-0.145 * (ET - 323))) $R^2 = 0.93^{***}$

TY = 13.96 + 27.07 / (1 + e ^ (-0.127 * (ET - 320))) $R^2 = 0.96^{***}$

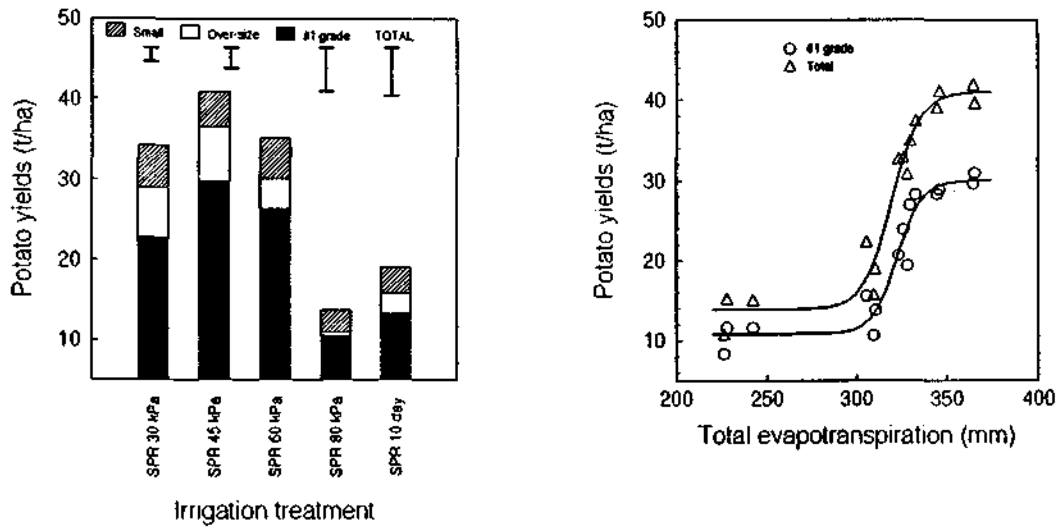


Figure 10. The yields of potato tubers were significantly affected by altering Critical Tensiometer Value, or the total evapotranspiration of autumn grown potatoes.

5. Discussion and conclusions

As in previous experiments, the tensiometer system was easy to install and use, gave accurate, reliable readings, required little maintenance and was relatively cheap. Optimum tensiometer location appeared to be 20 cm below the top of the hill; shallower tensiometers seemed less responsive, probably due to fewer functioning roots in the near-surface soil layer. Apart from the accidental over-irrigation, scheduling using tensiometers resulted in virtually no deep-drainage from excess irrigation.

Periods of water stress in the hill that lasted for more than 3-4 days seemed to adversely affect root performance in that zone; i.e. once dry for that length of time, future water uptake by potato plants from that surface zone seemed inhibited. Water uptake by potato roots appeared to substantially decline once tensiometer values increased above 60 kPa.

Water stress during the tuber initiation and early yield formation phases was the critical factor that reduced the numbers of tubers produced in the 80 kPa and 10 day irrigation treatments. Improved water relations (shown by higher ET rates) late in the growing period did not markedly increase the yields of the 10 day irrigation treatment. In the more frequently irrigated potatoes, it seemed that the slightly higher yields of the 45 kPa treatment compared to the 30 kPa and 60 kPa treatments was due to improved water status late in the growing period, just prior to maturity. It would have been interesting to look at the effects of this additional late irrigation on the specific gravity of potatoes produced.

It should be noted there was a moderate to severe outbreak of purple-top wilt in this experiment, that became apparent late in the growing period. Although no objective measurements were made, it seemed that the disease was worse in the 2 driest treatments; perhaps made more visible by an inability to maintain a high vegetative growth rate.

Results from experiments and observations to date suggest that a Critical Tensiometer Value for maximum production of autumn grown potatoes is probably 40-50 kPa, with the lower value in conditions of high evaporative demand. On black earth soil types, this involves the following approximate irrigation sequences (given that no rainfall occurs). Growers should be looking to apply about 28 mm every 7-8 days during the establishment and early vegetative phases (i.e. from potato emergence to 5-6 weeks after sowing). During the more stress- sensitive tuber initiation and yield formation phases, irrigation frequency would probably need to be increased to 25 mm every 5 days, paying particular attention to water use during the early part of this stage. It may be possible to further increase yields by maintaining moist soil conditions later into the season than traditionally thought desirable. This should be balanced against other considerations such as ease of harvest, dirt contamination of the potatoes, tuber quality and disease management. 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.

From these results the target evapotranspiration for autumn potatoes is probably around 350 mm, with a total irrigation requirement of 4-4.5 ML/ha, allowing for inefficiencies and drainage losses. Obviously any rainfall during the intervening period would reduce these requirements, although there may still be a need to irrigate for other purposes, such as fertiliser or pesticide incorporation. The regime would also be affected by cultivar and agronomic practices.

This experiment was repeated for a winter potato crop in 1993, the results for which are available in another report.

EXPERIMENT REPORT

Report **Final** **Date of Report:** 13-1-94

Initiation Date: 24-6-93 **Completion Date:** 25-10-93

Project Number: P378

Project Title: Irrigation scheduling in vegetables

Experiment Number: P378.15 **Officer Responsible:** Craig Henderson

Experiment Title: Irrigation scheduling for winter grown potatoes.

Experiment Objectives

This experiment sought to determine the relationship between potato yield and tensiometer values. It also attempted to determine the efficiency of irrigation by quantifying the amounts of applied water draining beyond the root zone during the growing period.

Summary of Results

The experiment was conducted at Gatton Research Station, from June-October 1993. Potato (cv. *Sebago*) were grown using standard agronomy, with 5 irrigation treatments replicated 3 times in a RCB design. Plots were 4.5 m wide and 10 m long, with a total experimental area of 0.065 ha. The five irrigation treatments involved commencing irrigation at different Critical Tensiometer Values (T kPa), using tensiometers installed 20 cm below hilltop level in each plot. The T values were; 30 kPa; 45 kPa; 60 kPa; 80 kPa and irrigating about every 10 days. Scheduling with tensiometers almost eliminated drainage losses. Rain during the experiment interfered with treatment differentiation. Irrigation treatments did not differ until after tuber initiation; there was no difference in final tuber numbers between the treatments. Due to smaller tubers, the 80 kPa irrigation treatment yielded < the other treatments (29 t/ha vs 38-40 t/ha of #1 grade potatoes). Increasing ET rates in the 30 kPa irrigation treatment during the latter half of the yield formation period created larger tubers with lower dry matter contents compared to the other 3 relatively well-irrigated treatments. There were significant relationships between total evapotranspiration, size and total dry matter content of potatoes in the experiment. Given 100 mm of rainfall, maximum potato yields were achieved with 230-260 mm of irrigation (around 20 mm every 8 days during tuber bulking).

EXPERIMENT REPORT

Irrigation scheduling for winter grown potatoes

by C. Henderson and M. Webber
Department of Primary Industries
Gatton Research Station

Experiment No. P378.15 24.6.93-25.10.93

1. Relevance to Industry

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

Some vegetable growers use tensiometers or neutron probes to monitor soil water status and schedule irrigations. Both methods have advantages and disadvantages, however tensiometers appear to have the best immediate potential for use in potatoes in southern Queensland. Most water uptake in potatoes occurs in the upper 0.4-0.5 m of the soil profile.

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

2. Objectives

This experiment sought to determine the relationship between potato yields and tensiometer values, under various irrigation regimes. It also attempted to determine the efficiency of scheduling systems, by quantifying the amounts of applied water draining beyond the root zone during the potato growing period. This was a repeat of an experiment conducted in autumn of the same year.

3. Materials and methods

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

The soil was prepared as per standard practice for potatoes. Cv. *Sebago* were planted on the 24 June 1993, with 0.75 m between the rows and 0.25 m intra-row spacing. A total of 400 kg/ha of compound fertiliser (52 kg N, 9 kg P, 53 kg K, 75 kg S) was applied immediately before planting. A side dressing of 100 kg N/ha as urea was applied on 4 August 1993. This was incorporated with a hilling operation and 26 mm of irrigation 2 days later. Weeds were managed by spraying 0.28 kg/ha of metribuzin immediately prior to the irrigation. Occasional hand-hoeing also took place as other weeds emerged. Leaf diseases were managed by 2 applications of 1.76 kg/ha of mancozeb and 1 spray of 0.625 kg/ha of metalaxyl during the growing period. The fungicide iprodione was applied as a drench on 3 August and 24 September 1993, in an attempt to control soil borne diseases. The insecticide methamidophos was periodically sprayed for insect control.

The initial irrigations utilised standard solid-set pipes and overhead sprinklers over the whole experimental area, for the first 8 weeks after planting. For irrigations during the latter part of the season, systems of mini-sprinklers were used to individually water each plot. A schematic of plot layout is shown in Fig. 1, with 2 rows of potatoes per 'bed'. Each plot consisted of 6 rows of potatoes side by side. The central 2 rows were the treatment area, while the outer 4 rows were buffer zones.

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

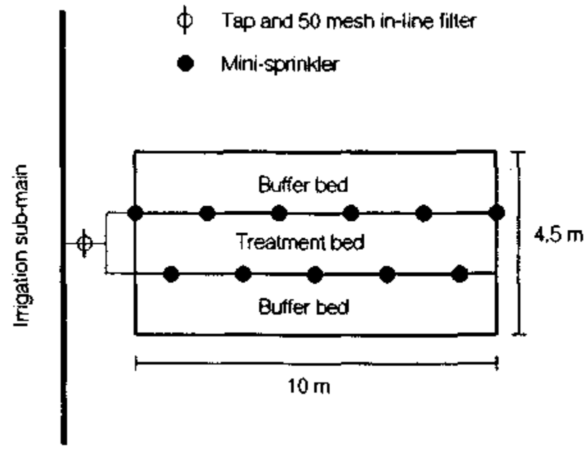


Figure 1. Mini-sprinkler system design for an individual plot in an experiment investigating irrigation scheduling in winter grown potatoes.

Tensiometers were installed 15 cm, 20 cm and 45 cm below the tops of the hills in a treatment row in each plot. *Loctronic* tensiometers were used, consisting of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum, while an electronic vacuum gauge attached to the syringe records the vacuum in the tensiometer air gap. Tensiometer readings were recorded daily, usually around 9 am.

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

1. Irrigated at T of 30 kPa for the growing period (SPR 30).

2. Irrigated at T of 45 kPa for the growing period (SPR 45).

3. Irrigated at T of 60 kPa for the growing period (SPR 60).

4. Irrigated at T of 80 kPa for the growing period (SPR 80).

5. Irrigated about every 10 days during the growing period (SPR 10D).

Aluminium neutron probe access tubes were installed to depths of 110 cm in each treatment bed, 5 cm inside a potatoes row and equidistant between 2 neighbouring plants. Neutron moisture meter readings were taken twice a week using a Campbell Pacific Nuclear Hydroprobe. A single reading was taken at 8 depth intervals, commencing 5 cm below the ground surface, incrementing by 10 cm. On each day that the neutron probe measurements were made, 5 standard counts was also conducted in a 200 L drum of water. Calibration equations for the neutron probe data were assumed to be the same as for previous experiments at this site.

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

At maturity, potatoes were dug by machine and hand harvested into bags on 22 October 1993. The potatoes were graded into 3 classes; smalls (<80 g), #1 grade (80-350 g), over-size (>350 g); counted and weighed. A sample of #1 grade potatoes from each plot were tested to determine specific gravity, from which dry matter contents were determined.

4. Results

There was 99 mm of rain during the 120 day growing period. There were substantial falls of 10-20 mm about every 2 weeks during the late tuber initiation and yield formation phases (Fig. 2). I suspect this rain interfered with the expression of treatment differences in this experiment.

Using a simple spreadsheet, a daily water balance was calculated for each plot. Rainfall, irrigation, stored soil water, pan evaporation, evapotranspiration and drainage of soil water below 80 cm were determined from planting through to harvest. Details of the calculations are available from the authors.

In discussing the water use and growth of the potato crop, I have divided the growing period into 4 phases; (i) establishment and early vegetative growth = 0-45 DAP; (ii) tuber initiation = 46-65 DAP; (iii) yield formation = 66-110 DAP; (iv) ripening = 111-120 DAP. Because of a labour shortage, the installation of the sprinkler systems and separate irrigation treatments did not commence until 60 days after planting (DAP), well into the tuber initiation period. During this first 60 days, all potatoes received 5 irrigations, averaging 33 mm. No potatoes were irrigated during the ripening period.

Values for the 15 cm and 20 cm tensiometers in the 30 kPa treatment fluctuated between 0 kPa and 30 kPa for the whole of the tuber initiation and yield formation period. During the late tuber initiation phase, this treatment received 1 irrigation of 14 mm (Fig. 2). None of the other 4 treatments were irrigated at that time. Soil conditions appeared relatively wet during the period 65-75 DAP. Taking into account the 2 significant rainfalls at 83 DAP and 103 DAP, this treatment received an average 17 mm of water every 6.4 days during yield formation, with higher frequencies toward the end of this growth stage. The deep tensiometer data, coupled with information from the water balances, suggest that there was slight drainage following rainfall at 17 DAP and 66 DAP, and a few mm after the irrigation at 55 DAP (Fig. 2).

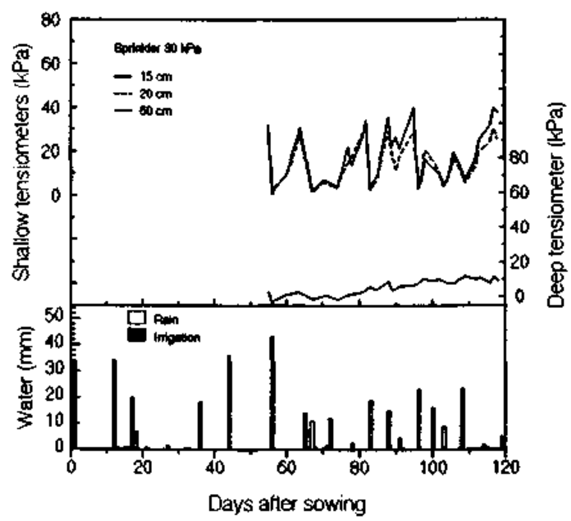


Figure 2. Fluctuations in soil matric suction at 15, 20 and 60 cm below the top of the hill, where potatoes were irrigated when soil matric suction at 20 cm exceeded 30 kPa during the growing period.

Tensiometer fluctuations in the 45 kPa treatment (Fig. 3) were greater than in the 30 kPa treatment, particularly during the latter half of the yield formation period. Values for the deep tensiometers indicate substantial water uptake from the deeper soil zones between 80-110 DAP (Fig. 3). During yield formation, this 45 kPa treatment received about 17 mm of water every 7.5 days.

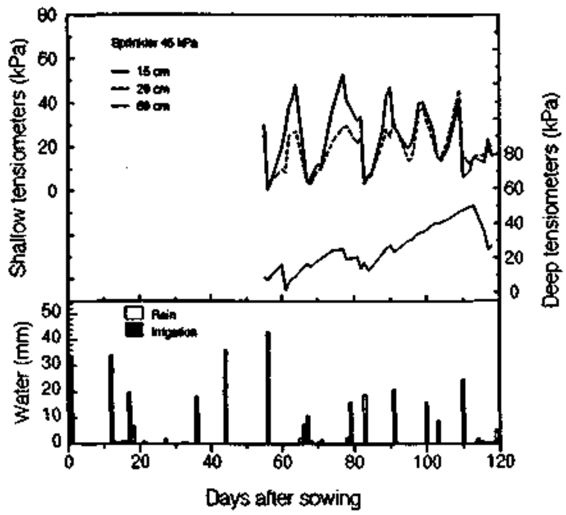


Figure 3. Fluctuations in soil matric suction at 15, 20 and 60 cm below the top of the hill, where potatoes were irrigated when soil matric suction at 20 cm exceeded 45 kPa during the growing period.

The shallow tensiometers in the 60 kPa treatment fluctuated between 0-60 kPa from 60 DAP until harvest (Fig. 4). Similar to the previous treatment, there seemed to be substantial water uptake from the deeper parts of the root zone in the 60 kPa plots. These potatoes received about 20 mm of water every 9 days during tuber bulking.

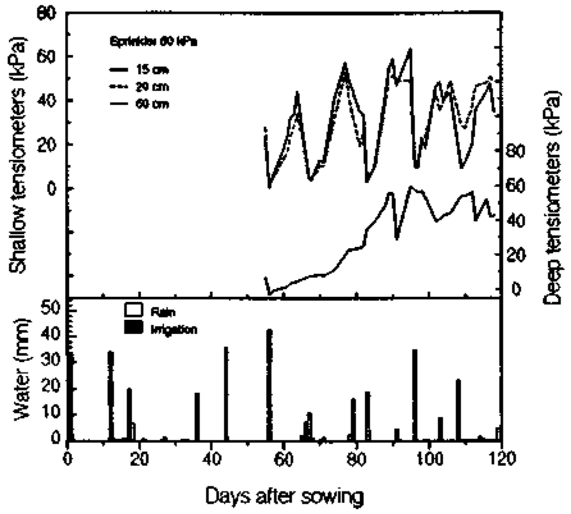


Figure 4. Fluctuations in soil matric suction at 15, 20 and 60 cm below the top of the hill, where potatoes were irrigated when soil matric suction at 20 cm exceeded 60 kPa during the growing period.

Shallow tensiometers in the 80 kPa treatment (Fig. 5) peaked at 60 kPa prior to the rain at 83 DAP. Tensiometer values fell immediately after this rain, then rapidly rose again to around 60 kPa. They maintained these values until about 100 DAP, after which the tensiometer readings slowly declined. From 90 DAP until harvest, there appeared to be less water uptake in these plots compared to the more frequently irrigated treatments. This suggests earlier senescence of the potato bushes in this treatment (not surprising given the lack of irrigation). As with the 45 kPa and 60 kPa treatments, there was substantial water use from the deeper root zones in these potatoes, though possibly a little less than in the former 2 treatments. The 80 kPa treatment was not irrigated from 60 DAP until harvesting.

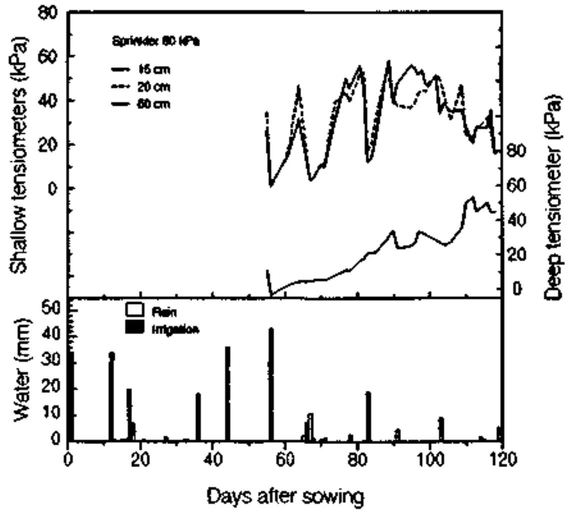


Figure 5. Fluctuations in soil matric suction at 15, 20 and 60 cm below the top of the hill, where potatoes were irrigated when soil matric suction at 20 cm exceeded 80 kPa during the growing period.

The shallow tensiometers in Treatment 5 reached peak values similar to the 80 kPa treatment, however there were also several troughs of low values in between (Fig. 6). This treatment was watered every 9 days on average, at about 20 mm a time. This regime was similar to the 60 kPa treatment.

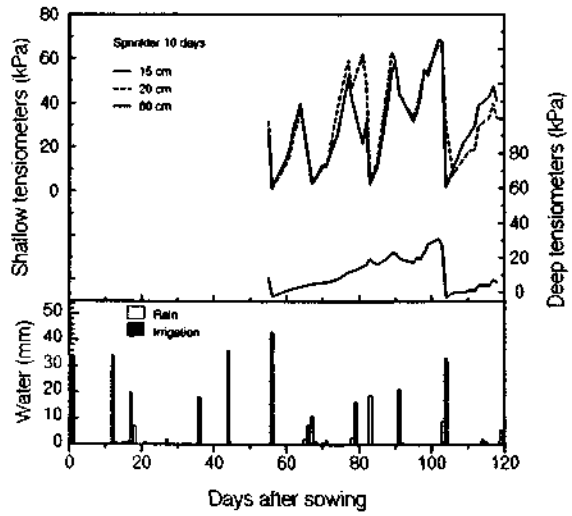


Figure 6. Fluctuations in soil matric suction at 15, 20 and 60 cm below the top of the hill, where potatoes were irrigated every '10' days.

The total irrigation quantities of for the 45 kPa, 60 kPa and 10 day treatments were 235-243 mm. The 30 kPa plots received an additional 25 mm, while the 80 kPa potatoes were irrigated with 165 mm (Fig. 7). There were no significant differences in deep drainage from any of the treatments, averaging 45 mm. Only 10 mm of this was due to excess irrigation; the bulk followed rain in excess of the soil water storage capacity at the time. The 30 kPa treatment, which had the most irrigation, also had the greatest total evapotranspiration (ET) of 292 mm; about 20 mm more than the 45 kPa, 60 kPa and 10 day treatments (Fig. 7). Treatment 4 had a significantly lower ET of 217 mm, which appeared to be due to lower ET rates from 85 DAP until harvesting (Fig. 8). The 30 kPa treatment seemed to have higher ET rates than the 45 kPa and 60 kPa treatments during the first half of the yield formation period, while the 45 kPa potatoes seemed to have lower ET rates than the other 3 irrigated treatments during the latter half of this growth stage (Fig. 8).

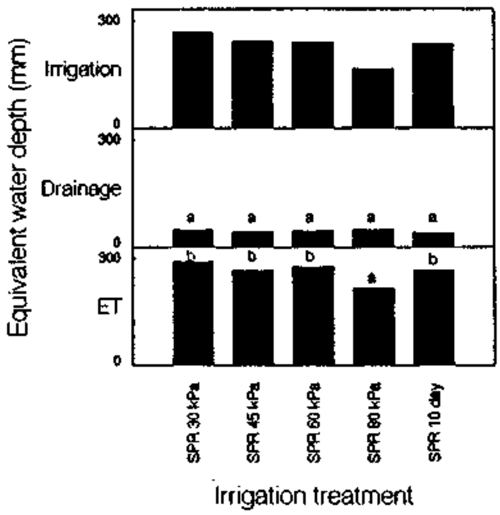


Figure 7. Changes in quantities of irrigation, total evapotranspiration and drainage losses under 5 irrigation regimes. Bars labelled with the same letter were not significantly different ($P<0.05$).

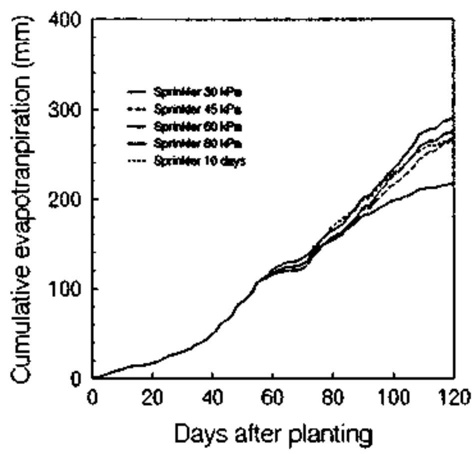


Figure 8. Cumulative evapotranspiration under 5 irrigation regimes.

There was no significant effect of irrigation treatment on the total number of potatoes produced (Fig. 9). There was a trend for more over-size potatoes in the 30 kPa treatment compared to the 45 kPa, 60 kPa and 10 day treatments, with virtually no over-size tubers in the 80 kPa plots. In contrast to the autumn potato experiment, in this investigation there were no significant relationships between the numbers of tubers harvested ('000/ha), neither #1 grade (#1N) nor total (TN), and total evapotranspiration (ET mm) of the potato crop. The best-fit equations were quadratics:

$$\#1N = -260 + 3.66\,ET - 0.00707\,ET^2 \quad R^2 = 0.13^{ns}$$

$$TN = 80.1 + 1.41\,ET - 0.00247\,ET^2 \quad R^2 = 0.08^{ns}$$

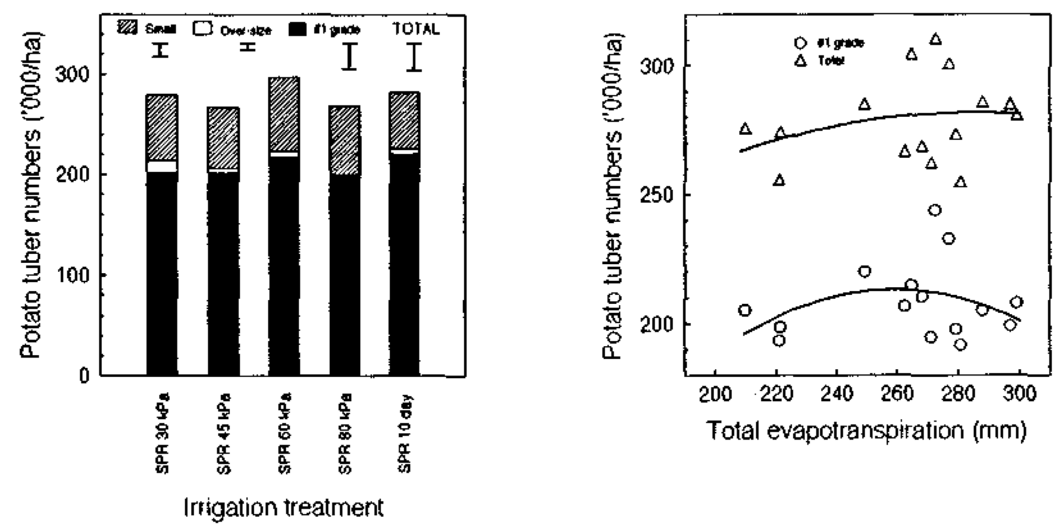


Figure 9. The numbers of potato tubers were unaffected by altering Critical Tensiometer Value, or the total evapotranspiration of winter grown potatoes.

There were no differences in the yield of small potatoes across the experiment, with all treatments producing 3.8-4.9 t/ha (Fig. 10). The 80 kPa treatment produced around 10 t/ha less #1 grade potatoes than the other 4 treatments. This was because the average tuber weight for the 80 kPa plots was 146 g, compared to 172 g for the 45 kPa, 60 kPa and 10 day treatments. Average individual tuber weights for the 30 kPa plots were about 12 g heavier still. The 80 kPa plots had virtually no over-size potatoes. The 60 kPa and 10 day treatments had nearly identical yields of over-size potatoes, with the 30 kPa plots having significantly higher yields of this grade and the 45 kPa plots trending slightly lower. Mean over-size tuber weights for the 30 kPa, 60 kPa and 10 day treatments were 430 g, while the 45 kPa over-size tubers averaged 395 g.

Total yields obviously reflected the sums of the 3 size grades. There was a quadratic relationship between yields of #1 grade potatoes (#1Y) and ET; with a linear relationship between total potato yields (TY) and ET:

$$\#1Y = -91.78 + 0.908\ ET - 0.00160\ ET^2 \qquad R^2 = 0.45^{*}$$

$$TY = 4.71 + 0.137\ ET \qquad R^2 = 0.48^{**}$$

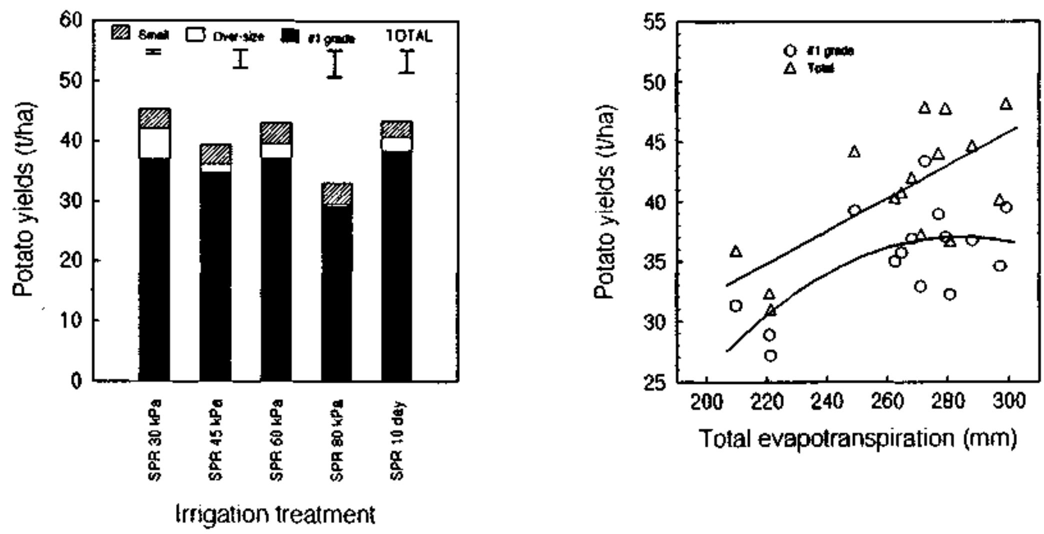


Figure 10. The yields of potato tubers were significantly affected by altering Critical Tensiometer Value, or the total evapotranspiration of winter grown potatoes.

As would be expected, the tubers from the least-irrigated treatment had the highest dry matter contents (Fig. 11). There was less difference between the other 4 treatments, although the 30 kPa treatment had significantly lower tuber dry matters than the 45 kPa or 60 kPa potatoes. There was a significant negative linear relationship between tuber dry matter (DM) and total evapotranspiration:

DM = 24.9 - 0.0260 **ET** $\qquad R^2 = 0.48^{**}$

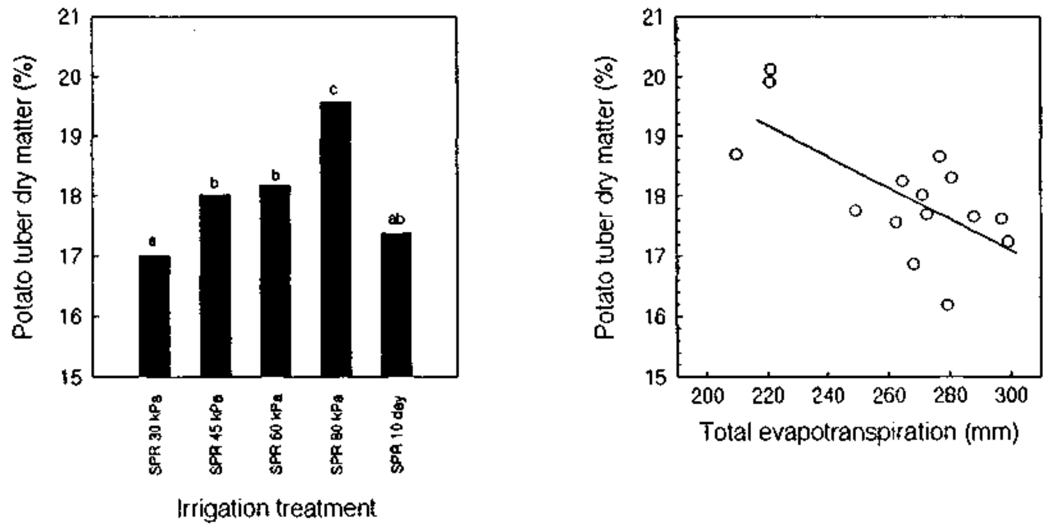


Figure 11. The dry matter content of potato tubers were significantly affected by altering Critical Tensiometer Value, or the total evapotranspiration of winter grown potatoes.

5. Discussion and conclusions

In all except the 45 kPa treatments, the 15 cm and 20 cm tensiometers gave very similar values during the latter half of the growing period, indicating the position of the tensiometer within the hill may be less critical than previously expected. This may not apply in hot conditions, particularly during the early growth stages. Optimum tensiometer location is still probably 20 cm below the top of the hill. Scheduling with tensiometers resulted in virtually no deep-drainage from excess irrigation.

Although not recorded, plant emergence in this experiment was somewhat less than hoped, possibly due to sub-optimal seed quality. I observed that emergence was particularly patchy in 2 plots allocated to the 45 kPa treatment. I believe this may explain trends toward slightly lower ET and yields for this treatment, compared to the 30 and 60 kPa plots.

Similar to the autumn experiment, the potato plants' water uptake seemed to substantially decline once tensiometer values increased above 60 kPa. Due to the periodic rainfall, this really only occurred in the 80 kPa treatment. In contrast to the autumn experiment, there was no opportunity for treatment differentiation during the tuber initiation period, due to the late commencement of irrigation treatments, and the rain at 65 DAP. Thus it is not surprising that there was virtually no difference in the total numbers of tubers produced by each of the treatments. Any yield differences could therefore only be expressed during the bulking up of tubers into various size grades.

The lower yields of the 80 kPa plots are obviously due to lower ET rates (and hence photosynthate accumulation) during the yield formation period (70-110 DAP). With slightly more frequent irrigation during the latter stages of yield formation, the 30 kPa treatment maintained higher ET rates than the other 3 high yielding treatments. It appears this higher transpiration resulted in greater accumulation of both starch and water in the potato tubers, bringing about a greater weight and lower dry matter content in both the #1 grade and over-size tubers. This is clearly evident in Fig. 11, where the yield of #1 grade potatoes reached a plateau at an ET of 270 mm, while overall tuber yield continued to increase with higher ET values.

Note that due to the weather and water use patterns, the 10 day treatment was nearly an identical irrigation regime to 60 kPa treatment. Thus it is not surprising that the potato performance in these 2 treatments was also very similar.

Results from experiments and observations to date suggest that a Critical Tensiometer Value for maximum production of autumn grown potatoes is probably 40-50 kPa, with the lower value in conditions of high evaporative demand. On black earth soil types, this involves the following approximate irrigation sequences (given that no rainfall occurs). Growers should be looking to apply about 28 mm every 7-8 days (9-10 days in winter) during the establishment and early vegetative phases (i.e. from potato emergence to 5-6 weeks after sowing). During the more stress-sensitive tuber initiation and yield formation phases, irrigation frequency would probably need to be increased to 25 mm every 5 days (7-9 days in winter/early spring), paying particular attention to water use during the early part of this stage. It may be possible to further increase yields by maintaining moist soil conditions later into the season than traditionally thought desirable. This should be balanced against other considerations such as ease of harvest, dirt contamination of the potatoes, tuber quality and disease management. 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.

From these results the target evapotranspiration for winter/spring potatoes is probably 280-300 mm, with a total irrigation requirement of about 3.5 ML/ha, allowing for inefficiencies and drainage losses. Obviously any rainfall during the intervening period would reduce these requirements, although there may still be a need to irrigate for other purposes, such as fertiliser or pesticide incorporation. The regime would also be affected by cultivar and agronomic practices.