VG303

Improved profitability in bean, beetroot and sweetcorn production

Craig Henderson
QLD Department of Primary Industries

Know-how for Horticulture™

VG303

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Horticull Research & Development Corporation
Level 6
7 Merrivtreet
Gordon W 2072
Telephoı (02) 9418 2200
Fax: (02) 9418 1352
E-Mail: hrdc@hrdc.gov.au

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Craig Henderson

Industry and technical summary

In detailed experiments at QDPI Gatton Research Station, we investigated agronomic options for improving the profitability of green bean, beetroot and sweet corn production. Practices we looked at included irrigation and weed management, seedling disease control, cultivar selection, planting arrangement and sowing depth. Drought conditions and consequent problems with water supply and quality meant absolute yields were occasionally less than expected, however relative performance comparisons still enabled valid conclusions.

We used tensiometers to schedule irrigation and optimise watering efficiency. Best yields were generally obtained by watering all 3 vegetables when shallow tensiometers (15 cm below ground level) reached readings of 40-50 kPa. When watering green beans with poor quality water, we needed to start irrigating at lower tensiometer values for best pod yields.

The selection of appropriate cultivars was a vital component in bean and sweet corn production. Planting heat-susceptible beans, or non-virus-resistant sweet corn (including major currently available cultivars), reduced yields by 50-100%! Correct implementation of all other agronomic principles could not compensate for planting the wrong cultivar.

There were no significant seedling diseases in any of our bean nor beetroot plantings. Although preventative seed dressings (eg. APRON®) are relatively cheap insurance ($5-15/ha), they should be used as part of an overall disease management program. This would include components such as cover cropping and rotations, recording of previous disease incidences, and perhaps testing of soil samples for disease propagules before planting.

Our research demonstrated commercially good weed control could be achieved in beetroot by sequentially applying low rates of currently registered herbicides. This reduced costs and required less chemical use compared to standard commercial practices. These strategies also reduced risks of crop damage, thus increasing average yields. We also looked at spraying post-emergence products such as STARANE®, as alternatives or adjuncts to pre-emergence herbicides, in horticultural areas where hormones or residual chemicals are seldom used.

In our research, bean yields and pod quality were optimised by irrigation scheduling to minimise water stress, selecting heat-tolerant cultivars, sowing at 2.5 cm, and side-dressing with 2 application of nitrogen fertiliser following a basal application. Beetroot production was most profitable where irrigation was scheduled, and post-emergence herbicides were sprayed at earlier growth stages than currently recommended. These sequential spray strategies require more accurate timing and application management than standard commercial practices. Best sweet corn production was achieved by growing disease-resistant, sub-tropical sweet corn under a scheduled irrigation regime. The optimal planting arrangement was a row spacing of 75 cm, with 18-20 cm between seeds within the row. Narrower rows or higher plant populations did not improve performance.

Economic analyses suggest implementation of all these agronomic practices would increase grower returns by $300-500/ha, compared to current commercial techniques. Vegetable producers have been made aware of this project via talks at field days, group meetings, and press releases to newspapers, magazines and radio. Results are being included in various QDPI information packages (eg. Agrilink, Farmnotes, FarmFax, etc.), and disseminated via other extension people and agribusiness outlets as part of their standard agronomic advice.

Introduction

The cost-price squeeze has adversely affected the profitability of fresh and processing production of green beans, beetroot and sweet corn. Prices for these vegetables in the processing industry have declined sharply due to pressures from international imports. As a consequence, there have been significant closures and amalgamations of vegetable processing facilities throughout Australia during the last 7 years. Real prices received by fresh market vegetable growers have also declined significantly during that time. As vegetable growers and processors are price-takers, their only solution (if they are to remain in production) is to reduce their per unit production costs. This will be achieved by a combination of higher yields and/or reduced costs per hectare.

Irrigation management

In the 3 vegetables investigated in this study, previous research had shown potential for substantial yield increases from improved irrigation management (Henderson 1994a). Traditional growers had generally irrigated on a regular basis, without any objective methods of matching watering with crop requirements. Such a strategy often results in water stress during critical periods (such as silking in sweet corn), or over-watering at other times. In beans and sweet corn, the critical periods when water stress has the most deleterious effects are during the flowering and pod/cob-fill stages. Beets are slightly less sensitive to water stress, however maximum yields are still achieved by meeting water requirements throughout the growing period (Stanley and Maynard 1990, Doorenbos and Kassam 1979).

Monitoring water status

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

Using tensiometers in vegetables

Tensiometers can be used successfully to monitor soil water status in shallow root zones, particularly in horticultural crops that are frequently irrigated (Campbell and Mulla 1990, Taylor 1972). They have not been widely adopted in many areas because of a perception that they are difficult and time-consuming to operate. Whilst this may have been true of earlier models, the latest tensiometers are user-friendly and effective. We decided to base our irrigation scheduling strategies on tensiometers because they are easy to use, relatively cheap to install and maintain, and can be operated by individual producers with a minimum of training and experience. Overseas research and our previous experience suggest that beans, beetroot and sweet corn should all be watered at tensiometer values between 40-60 kPa in the main root zone (Taylor 1972, Henderson 1994a).

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

Cultivar selection

Previous work had shown marked differences in the performance of green bean and sweet corn cultivars, depending on the time of year they were grown (Henderson 1994b). In particular, the heat and water quality tolerances of bean cultivars, and the disease-resistance of sweet corn cultivars, is highly variable. Selecting an appropriate cultivar can have a critical impact on the quantity and quality of produce obtained from these crops at different times in the growing season.

Crop establishment

From sowing, until the first few weeks after emergence, is a vital phase in all 3 vegetable crops. Beans and beetroot in particular are prone to fungal seedling diseases such as *Rhizoctonia, Fusarium, Aphanomyces* and *Pythium spp.*, occasionally requiring re-planting of affected areas (Persley 1994). Management options, such as soil testing for the presence of disease propagules, crop rotation, cover crops and soil amendments, as well as fungicidal seed-dressings, are either currently available to growers, or are being developed (R. O'Brien pers. comm.).

Weed management

Weed control has conventionally been a significant component of pre-harvest production costs in both beans and beetroot. With the development of new herbicides and application strategies, there are opportunities to achieve commercially acceptable levels of weed control using less chemical, and with fewer risks of crop damage. For example, weed management in sugarbeet in the USA and Europe frequently involves the use of split applications of low rate herbicides (Anon. 1990, Dexter 1994, Griffiths 1994). This compares with a single application of high rates practiced in Australia. By reducing herbicide costs and risks of crop damage, the overall profitability of production could be improved.

Project objectives

This project sought to investigate strategies for improved yield and quality, and/or reduced production costs in the target crops green beans, beetroot and sweet corn. The range of factors to be looked at included cultivar selection, early seedling disease management, planting arrangements, irrigation and weed management. The research involved detailed factorial experiments on each of the vegetables, using QDPI Research Station facilities. At the end of the project, the objective was to integrate the findings into new information production packages, and follow-up with targeted extension programs through producer and agri-business networks, as well as conventional extension services.

Materials and methods

Gatton Research Station experiments

Nine experiments investigating various agronomic aspects of green bean, beetroot and sweet corn production were conducted at Gatton Research Station during this project. Green bean experiments looked at issues such as sowing depth, fungicidal seed dressings, cultivar selection, nitrogen nutrition and irrigation management. After initial experimentation on interactions of weed management, irrigation scheduling and seed treatments in beetroot, we focussed our efforts on the weed management component in this crop. With sweet corn, cultivar selection, planting patterns, irrigation and weed management were all investigated. Full methodologies, data, results and conclusions for each of these experiments conducted within the project are included as Appendices 1-9. Crops, cultivars, planting and harvest dates are shown in Table 1.

Table 1. Agronomic details for 9 experiments investigating production of green beans, beetroot and sweet corn.

Code	Appendix	Crop	Cultivar	Planting date	Harvest date
BEAN1	1	Green beans	*Labrador*	13-10-93	16-12-93
BEAN2	2	Green beans	*Labrador* *Bronco* *New Pioneer*	13-10-93	13-12-93
CROP3	3	Green beans, Beetroot, Sweet corn	*Labrador* *New Globe* *Pacific H5*	07-03-96	16-05-96 06-06-96 25-06-96
BEET1	4	Beetroot	*New Globe*	24-04-94	06-09-94
BEET2	5	Beetroot	*Early Wonder Tall Top*	30-03-95	21-06-95
BEET3	6	Beetroot	*New Globe*	22-04-96	15-08-96
CORN1	7	Sweet corn	*Florida StaySweet,* *Pacific H5*	21-01-94	27-05-94
CORN2	8	Sweet Corn	*Pacific H5*	16-01-95	10-04-95
CORN3	9	Sweet corn	*Golden Sweet,* *Pacific H5*	19-09-96	02-01-96

The experiments were conducted on a black earth soil (*Ug5.15*) at Gatton Research Station (lat. 27°33'S, long. 152°20'E). Apart from the treatment details given below, or in the relevant Appendices, the crops were grown using agronomic practices standard in commercial production (eg. plant spacings, crop nutrition, irrigation practices, pest management). From 1993 until the end of 1995, the Lockyer Valley was severely drought affected. Water supplies at Gatton Research Station became very restricted. Only underground bores were available, yielding small amounts of poor quality water. Analyses showed conductivities of 300 mS/m, total dissolved ions of 1850 mg/L and chloride concentrations of 720 mg/L. This water is categorised as only suitable for medium-high salinity tolerant vegetables (Wobke 1990). Of the 3 crops we were investigating, only beetroot was in this category. As a result of this poor quality water, crop yields in some of the experiments were substantially less than we would have expected. Nevertheless, the relativities of the treatments are still valid, and enable conclusions as to appropriate agronomic practices to be made.

Pertinent details for experiments in each of the crops are given below in point form. For a more comprehensive description, refer to the relevant Appendices.

BEAN1

Experiment design - Split plot, all sprinkler irrigated

Blocks - 3 irrigation regimes

a) Dry - watered when shallow tensiometers reached values of 70-80 kPa prior to flowering

b) Moderate - watered when shallow tensiometers reached values of 50 kPa prior to flowering

c) Wet - watered when shallow tensiometers reached values of 20 kPa prior to flowering

Main plot treatments - 3 fungicidal seed dressings

a) Control treatment - seed coated with THIRAM® fungicide (as purchased)

b) Seed-dressing treatment - seed coated with THIRAM® and APRON® fungicides

c) Total treatment - seed coated with THIRAM® and APRON® fungicides, with the sowing furrow sprayed with RIZOLEX® fungicide

Sub-plot treatments - 2 depths of sowing

a) Shallow - seed sown 2.5 cm below the soil surface

b) Deep - seed sown 7 cm below the soil surface

Measurements

- Standard weather data (rainfall, pan evaporation, max and min temperatures) - daily
- Tensiometer values - daily
- Irrigation - as applied
- All fertiliser and pesticide applications - as applied
- Bean emergence
- Bean root disease assessments
- Bean plant biomass at flowering
- Bean pod yields
- Bean pod quality (size, colour, contamination with foreign matter)

BEAN2

Experiment design - Split plot, all sprinkler irrigated

Blocks - 3 irrigation regimes

a) Dry - watered when shallow tensiometers reached values of 70-80 kPa prior to flowering

b) Moderate - watered when shallow tensiometers reached values of 50 kPa prior to flowering

c) Wet - watered when shallow tensiometers reached values of 20 kPa prior to flowering

Main plot treatments - 2 nitrogen nutrition treatments

a) Control treatment - 60 kg/haN as urea applied at sowing

b) Side-dressing treatment - 60 kg/haN as urea applied at sowing, plus 2 additional applications of 25 kg/haN (as urea) during the growing period

Sub-plot treatments - 3 green bean cultivars

a) cv. *Labrador*

b) cv. *Bronco*

c) cv. *New Pioneer*

Measurements

- Standard weather data (rainfall, pan evaporation, max and min temperatures) - daily
- Tensiometer values - daily
- Irrigation - as applied
- All fertiliser and pesticide applications - as applied
- Bean emergence
- Bean root disease assessments
- Bean plant biomass at flowering
- Bean pod yields
- Bean pod quality (size, colour, contamination with foreign matter)

CROP3

Experiment design - Randomised complete block, all drip irrigated

Blocks - 3 crop species

a) Green beans cv. *Labrador*

b) Beetroots cv. *New Globe*

c) Sweet corn cv. *Pacific H5*

Main plot treatments - 2 irrigation regimes

a) Regular - watered with a specific amount of irrigation on a semi-regular basis, irrespective of climatic conditions (apart from heavy rain)

b) Scheduled - watered depending on tensiometer readings, using indicative values from previous research

Measurements

- Standard weather data (rainfall, pan evaporation, max and min temperatures) - daily
- Tensiometer values - daily
- Irrigation - as applied
- All fertiliser and pesticide applications - as applied
- Crop yields
- Produce quality (size, colour, foreign matter contamination, insect damage, uniformity)
-

BEET1

Experiment design - Split-split plot, all irrigated with sprinklers

Blocks - 2 sowing times

a) Beetroot cv. *New Globe* sown on 21 April 1994
b) Beetroot cv. *New Globe* sown on 12 May 1994

Main plot treatments - 2 irrigation regimes

a) Regular - watered with a specific amount of irrigation on a semi-regular basis, irrespective of climatic conditions (apart from heavy rain)
b) Scheduled - watered depending on tensiometer readings, using indicative values from previous research

Sub-plot treatments - 10 weed management treatments

a) PYRAMIN® (chloridazon) herbicide sprayed immediately after sowing, followed by commercial rates of BETANAL® (phenmedipham) and TRAMAT® (ethofumesate) herbicides 4-5 weeks after sowing
b) RAMROD® (propachlor) herbicide sprayed immediately after sowing, followed by commercial rates of BETANAL® and TRAMAT® herbicides 4-5 weeks after sowing
c) RAMROD® (propachlor) herbicide sprayed immediately after sowing, followed by commercial rates of BETANAL® herbicide 4-5 weeks after sowing
d) Commercial rates of BETANAL® and TRAMAT® herbicides sprayed 4-5 weeks after sowing
e) BETANAL® and RAMROD® herbicides sprayed 4-5 weeks after sowing
f) Low rates of BETANAL® herbicide sprayed 2-3 weeks after sowing
g) Very low rates of BETANAL® herbicide sprayed 2-3 weeks after sowing
h) Low rate mixtures of BETANAL® and TRAMAT® herbicides sprayed 2-3 weeks after sowing
i) Very low rate mixtures of BETANAL® and TRAMAT® herbicides sprayed 2-3 weeks after sowing
j) Weeds removed by hand every fortnight as they emerged

Sub-sub-plot treatments - 2 fungicidal seed dressings

a) Control treatment - seed coated with THIRAM® fungicide (as purchased)
b) Seed-dressing treatment - seed coated with THIRAM® and APRON® fungicides

Measurements

- Standard weather data (rainfall, pan evaporation, max and min temperatures) - daily
- Tensiometer values - daily
- Irrigation - as applied
- All fertiliser and pesticide applications - as applied
- Beetroot plant emergence
- Beetroot plant biomass at baby beet stage
- Beetroot yields
- Beetroot quality (size grades)
- Weed counts during the growing period
- Weed counts and biomass at beetroot harvest

BEET2

Experiment design - Randomised complete block, all irrigated with sprinklers

Main plot treatments - 9 weed management treatments

a) Very low rates of BETANAL® herbicide sprayed at the cotyledon stage of the beetroot and again one week later
b) Low rates of BETANAL® herbicide sprayed at the cotyledon stage of the beetroot and again one week later
c) Moderate rates of BETANAL® herbicide sprayed at the cotyledon stage of the beetroot and again one week later
d) Low rates of BETANAL® herbicide sprayed at the 2 true leaf stage of the beetroot and again one week later
e) Moderate rates of BETANAL® herbicide sprayed at the 2 true leaf stage of the beetroot and again one week later
f) Low rates of BETANAL® and TRAMAT® herbicides sprayed at the 2 true leaf stage of the beetroot and again one week later
g) Commercial rates of BETANAL® herbicide sprayed at the 4 true leaf stage of the beetroot
h) Commercial rates of BETANAL® and TRAMAT® herbicides sprayed at the 4 true leaf stage of the beetroot
i) Weeds removed by hand as they emerged

Measurements

- Standard weather data (rainfall, pan evaporation, max and min temperatures) - daily
- Tensiometer values - daily
- Irrigation - as applied
- All fertiliser and pesticide applications - as applied
- Beetroot plant heights just before the baby beet stage
- Beetroot yields
- Beetroot quality (size grades)
- Weed counts during the growing period
- Weed counts and biomass at beetroot harvest

BEET3

Experiment design - Randomised complete block, all irrigated with sprinklers

Main plot treatments - 5 weed management treatments

a) Low rates of BETANAL® and TRAMAT® herbicides sprayed at the 4 true leaf stage of the beetroot
b) Moderate rates of BETANAL® herbicide sprayed at the 4 true leaf stage of the beetroot and again one week later
c) Low rates of BETANAL® and TRAMAT® herbicides sprayed at the 4 true leaf stage of the beetroot and again one week later
d) Commercial rates of BETANAL® and TRAMAT® herbicides sprayed at the 4-6 true leaf stage of the beetroot
e) Weeds removed by hand as they emerged

Measurements

- Standard weather data (rainfall, pan evaporation, max and min temperatures) - daily
- Tensiometer values - daily
- Irrigation - as applied
- All fertiliser and pesticide applications - as applied
- Beetroot plant widths just before the baby beet stage
- Beetroot yields
- Beetroot quality (size grades)
- Weed counts during the growing period
- Weed counts and biomass at beetroot harvest

CORN1

Experiment design - Split-split plot factorial, all irrigated with sprinklers

Blocks - 2 sowing times

a) Sweet corn sown on 25 January 1994
b) Sweet corn sown on 17 February 1994

Main plot treatments - 2 irrigation regimes

a) Regular - watered with a specific amount of irrigation on a semi-regular basis, irrespective of climatic conditions (apart from heavy rain)
b) Scheduled - watered depending on tensiometer readings, using indicative values from previous research

Sub-plot treatments - 2 row spacings

a) Rows spaced 100 cm apart
b) Rows spaced 75 cm apart

Sub-sub-plot treatments - 2 sweet corn cultivars and 2 sowing populations

Factor 1 - 2 cultivars

a) Sweet corn cv. Florida StaySweet
b) Sweet corn cv. Pacific H5

Factor 2 - 2 sowing populations

a) Low population - sweet corn sown at 50,000 seeds/ha
b) High population - sweet corn sown at 70,000 seeds/ha

Measurements

- Standard weather data (rainfall, pan evaporation, max and min temperatures) - daily
- Tensiometer values - daily
- Irrigation - as applied
- All fertiliser and pesticide applications - as applied
- Sweet corn plant emergence
- Sweet corn plant heights 3-4 weeks after sowing
- Sweet corn yields
- Sweet corn cob quality (size, insect damage, tip and bottom fill, kernel blanking/symmetry)

CORN2

Experiment design - Split-plot, all irrigated with drip lines

Main plot treatments - 2 row spacings

a) Wide - Rows spaced 75 cm apart
b) Narrow - Rows spaced 37.5 cm apart

Sub-plot treatments - 2 sowing population

a) Low population - sweet corn sown at 70,000 seeds/ha
b) High population - sweet corn sown at 100,000 seeds/ha

Measurements

- Standard weather data (rainfall, pan evaporation, max and min temperatures) - daily
- Tensiometer values - daily
- Irrigation - as applied
- All fertiliser and pesticide applications - as applied
- Sweet corn plant heights 5 weeks after sowing
- Sweet corn yields
- Sweet corn cob quality (size, insect damage, tip and bottom fill, kernel blanking/symmetry)

CORN3

Experiment design - Randomised complete block, all irrigated with sprinklers

Blocks - 2 sweet corn cultivars

a) Sweet corn cv. *Pacific H5*
b) Sweet corn cv. *Golden Sweet*

Main plot treatments - 4 weed management strategies

a) Short-term - DUAL® (metolachlor) herbicide sprayed at 3 L/ha after sowing
b) Long-term - DUAL® (metolachlor) herbicide sprayed at 4 L/ha after sowing
c) Eradication - DUAL® (metolachlor) herbicide sprayed at 4 L/ha after sowing, and the crop hand-weeded twice during the growing period
d) Future - DUAL® (metolachlor) herbicide sprayed at 3 L/ha after sowing, followed by STARANE® (fluroxypyr) herbicide 5 weeks after sowing, and the crop hand-weeded once during the growing period

Measurements

- Standard weather data (rainfall, pan evaporation, max and min temperatures) - daily
- Tensiometer values - daily
- Irrigation - as applied
- All fertiliser and pesticide applications - as applied
- Sweet corn plant heights 4 weeks after sowing
- Sweet corn yields
- Sweet corn cob quality (size, insect damage, tip and bottom fill, kernel blanking/symmetry)
- Weed counts 4-5 weeks after sowing
- Weed counts and biomass after the sweet corn were harvested

Results and discussion

General irrigation management and scheduling methods

In previous projects we confirmed that most water uptake by well-grown vegetable crops is in the top 20-30 cm of the soil profile, although some roots will obviously penetrate substantially deeper (Henderson 1994a). The key issue when scheduling vegetable irrigation on the basis of soil water status is the need to intensively monitor this section of the soil profile. In experiments with beans, beets and sweet corn, we found they had very shallow root systems in the clay-loam soils of the Lockyer Valley. When irrigated for maximum production of high quality produce, 80-85% of water uptake was from the upper 30 cm of the soil profile for green beans and beetroot, and upper 40 cm for sweet corn. In all 3 vegetables, around 60% of water uptake was from the upper 20 cm of the soil profile. Even in virtually non-irrigated crops, there was little water uptake from deeper than 60 cm (Henderson 1994a).

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

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

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

Interpretation of results

In detailed experiments at Gatton Research Station, tensiometer, rainfall and irrigation values were plotted in a series of stacked graphs as shown in Fig. 1. They show the changes in readings for the shallow and deep tensiometers in response to crop water use, rainfall and irrigation as the season progressed. The top graph shows readings for the shallow tensiometer (scale on left side); the middle graph for the deep tensiometer (scale on right). Underneath are the corresponding irrigation and rainfall values.

The example in Fig. 1 comes from the sweet corn crop grown in CORN3, watered with a hand-shift irrigation system. In previous studies we found that maximum sweet corn yields were obtained by ensuring that shallow tensiometer values did not exceed 50 kPa during the growing period. In the example shown, shallow tensiometer readings were not greater than 50 kPa except just before harvesting. However, with only a single irrigation in the 3 week period between 50 and 70 days after planting, it is possible that some water stress may have occurred. In most instances, optimum irrigation occurs when the deep tensiometer values are relatively stable at about 20-30 kPa. In this example, deep tensiometer values tended to rise, particularly in the period between 8 and 11 weeks after planting. When deep tensiometer values rise to levels above 40 kPa, it indicates the crops are extracting moisture from deep in the soil profile. This is often a sign of water stress in the main root zone. Note that 60 mm irrigation at 58 days after planting did not saturate the root zone, or cause deep drainage (shown by deep tensiometer values not dipping back to zero), suggesting the soil was relatively dry.

Situations where significant amounts of irrigation or rainfall are draining beyond the crop root zone are indicated by dips in deep tensiometer values to less than 10 kPa. For example, there was probably some deep drainage (maybe 25 mm) when 21 mm of rain followed 37 mm of irrigation around 4 weeks after planting (Fig. 1).

By looking at the tensiometer values in conjunction with irrigation and rainfall, we can also calculate how much water is needed to refill the crop root zone at various tensiometer values. For example, at both 8 and 10 weeks after planting, when the shallow tensiometers were just over 50 kPa, and the deep tensiometers were 20-40 kPa, it required about 60 mm of water to nearly fill the profile (indicated by the deep tensiometer falling to about 10 kPa). These are probably circumstances where irrigation had been delayed beyond the ideal interval, resulting in greater than normal extraction from the root zone. Normally, we would be looking to apply nor more than 40 mm per irrigation in this soil type.

By assuming the water holding capacities of the root zone at various tensiometer values, we can then estimate the amount of irrigation or rain that will have drained (or run-off) if that amount is exceeded. By knowing the amounts of water applied, and the quantities lost through drainage or run-off, we can then calculate water used by the crop (evapotranspiration), using a simple water budget approach. In the example shown in Fig. 1, during the stress period between 7 and 12 weeks after planting, the crop received 147 mm of irrigation and 36 mm of rain, with no evidence of drainage or run off. There was little difference in soil water storage at the beginning and end of this period, therefore we can calculate that the average evapotranspiration was 6.1 mm/day. This is probably about 10-20% less than expected at that time of year.

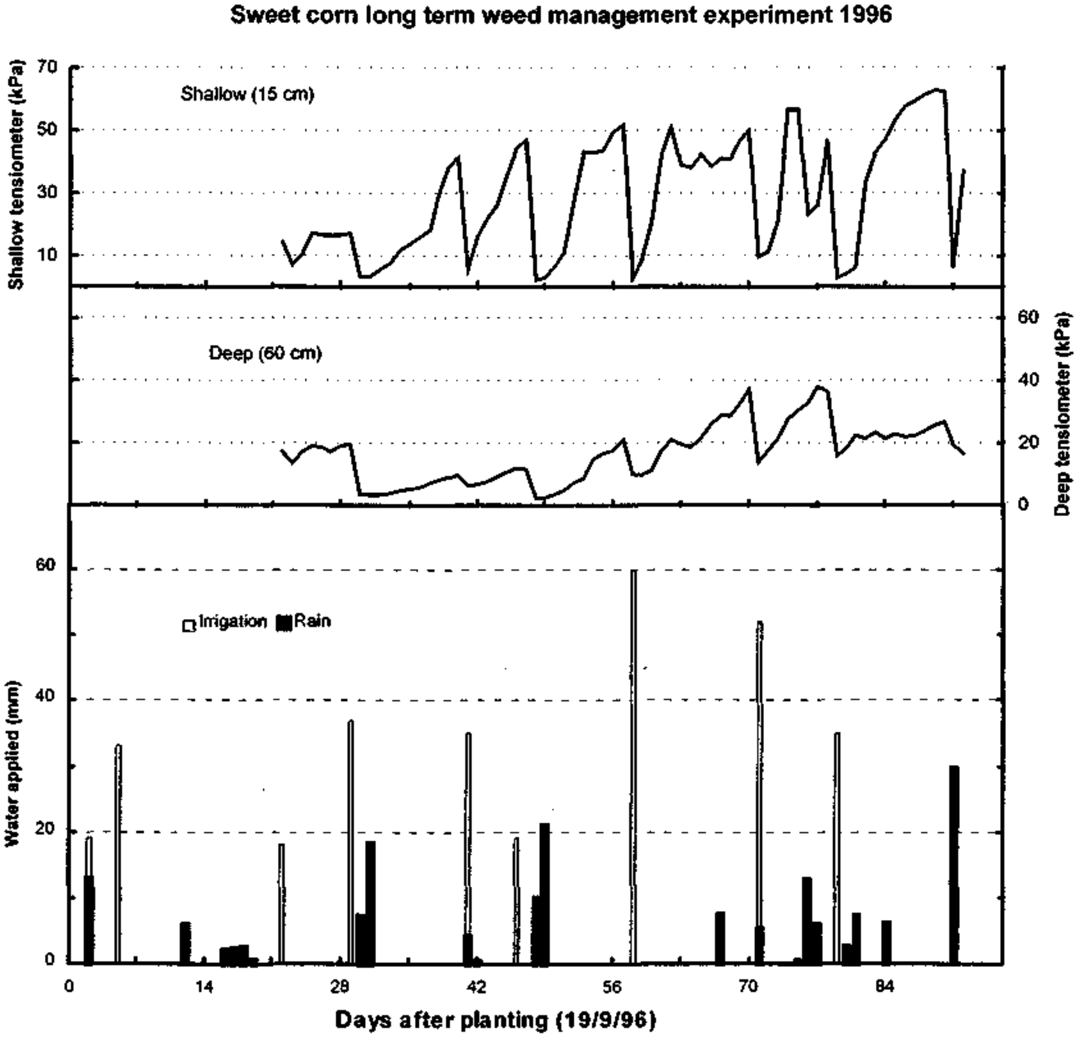


Figure 1. Example of tensiometer changes and irrigation regime in a sweet corn crop.

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

Individual crop agronomy

Green beans

Irrigation

Of the 3 crops we investigated, the green beans were most adversely affected by the poor quality irrigation water we were forced to use because of the prolonged drought. With a conductivity of 300 mS/m, and chloride contents of 720 mg/L, this water should not have been used for growing green beans. We were able to access better quality water for the final experiment (CROP3) that included a green bean component.

In the initial 2 green bean experiments, rain after flowering meant no irrigation was required during the pod-set and fill periods. Besides the poor quality water, during flowering there were several days of heatwave conditions, with maximum temperatures above 35 °C. This combination was disastrous for bush growth and particularly pod-set. In CROP3, very heavy rain also meant there was little differentiation between *regular* and *scheduled* irrigation strategies.

Bean yields increased with increasing irrigation, as shown by the results from BEAN1 and BEAN2 (Fig. 2, 3). There were no advantages from stressing beans to promote smaller bush size and increase flowering. Tensiometer data (for details see Appendices 1 and 2), suggests that a water stress period between 25-35 days after sowing in the *optimum* irrigation blocks was the main determinant of their poorer biomass production and pod yields, compared to the most frequently irrigated beans. The increased vegetative growth in the *wet* blocks may also have enabled the development of superior root systems, increasing access to nutrients and water availability. This resource would have been important during periods of high evaporative demand around flowering.

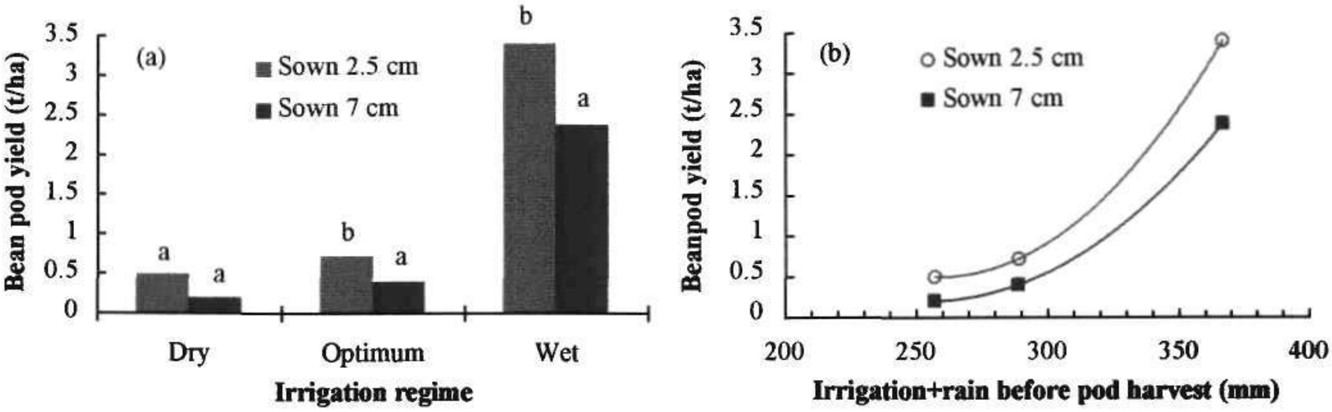


Figure 2. Marketable pod yields of the green bean cultivar Labrador in experiment BEAN1 were significantly increased by irrigation and reduced by deep sowing. Sowing depth treatments within the same irrigation block labelled with the same letter are not significantly different.

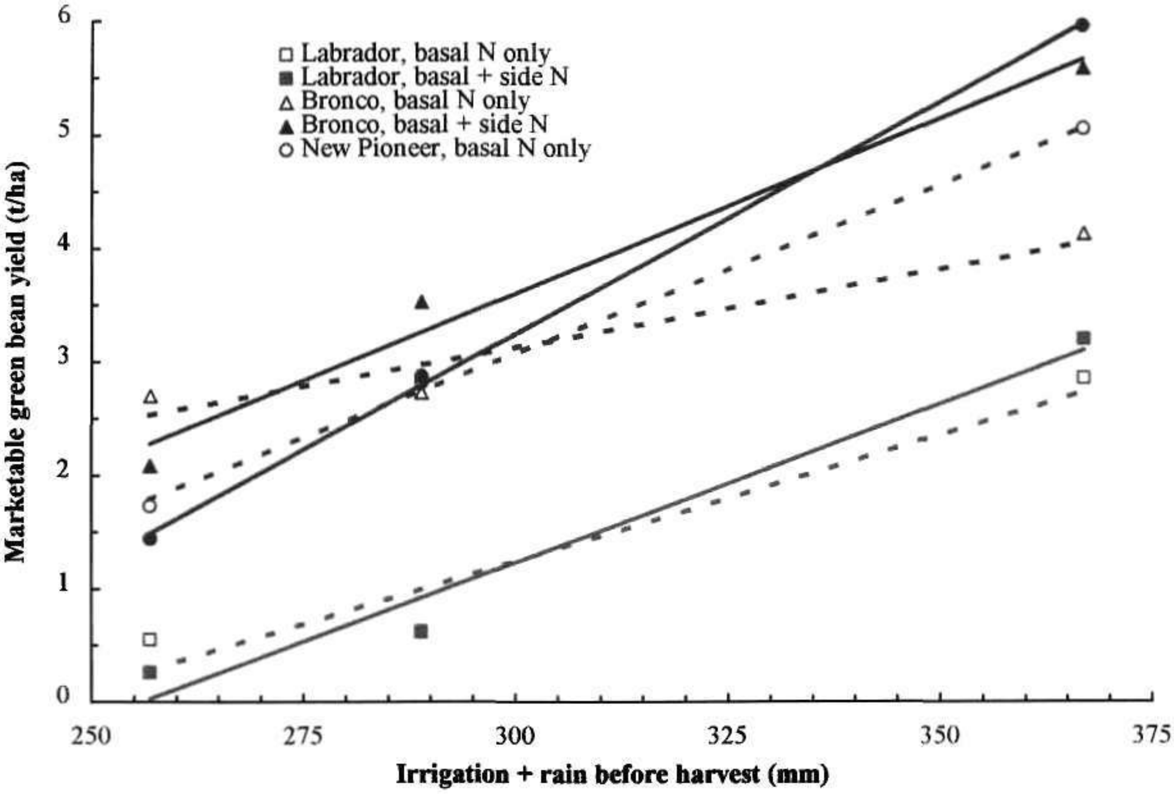


Figure 3. Green bean pod yields in experiment BEAN2 were linearly related to total water application prior to harvest, with responses affected by N nutrition in cultivars *Labrador*, *Bronco* and *New Pioneer*.

Not only did the amount of pre-flowering irrigation affective the vegetative biomass of green bean plants, it also affected the number of pods set for each kg of flowering biomass. For example, in the *optimum* blocks, the cultivar *Labrador* set an average of 58 pods for each kg of flowering biomass, while *Bronco* set 347 pods/kg biomass. In the *wet* blocks, the pod-set improved to 190 pods/kg biomass and 415 pods/kg biomass respectively. In all cultivars, increased irrigation before flowering increased pod-set. This may have been due to more total floral production, or reduced flower and/or pod abortion. One hypothesis is that larger bushes (and by inference, more extensive root systems) allowed the plants to better cope with hot weather at flowering.

Cultivar selection

The *Labrador* beans were particularly badly affected by the hot conditions, with almost total flower and pod abortion. The yield of this cultivar in the most frequently irrigated, highest nitrogen treatment was only 3.2 t/ha (Fig. 3), compared to 5.6 t/ha for *Bronco* and 6.0 t/ha for *New Pioneer*. Note that *Labrador* had similar biomass to the others at flowering. This suggests that a lower photosynthetic capacity during the post-flowering growth stages was not the reason for its relatively poor yields.

Agronomic interactions

There were also very marked interactions between irrigation, cultivar and nitrogen nutrition (Fig. 3). In the treatments supplied with most N fertiliser, increasing irrigation frequency from the *optimum* to the *wet* regime improved yields of *Bronco* by 58%, *New Pioneer* by 102%, and *Labrador* by 390%. Additional N nutrition increased yields of all cultivars in the *wet* blocks (*Bronco* 32%, *New Pioneer* 19%, *Labrador* 10%), and decreased yields of all cultivars in the driest block. In the *optimum* block, additional N increased yields of *Bronco*, but did not affect yields of *New Pioneer* nor *Labrador*.

Seedling disease

Because of the dry condition during the establishment phases, there were very few root-rot diseases in our experiments. As a consequence, there were no significant effects of sowing depth nor fungicidal seed treatments on the presence of seedling diseases (Fig. 4). However, plants from seeds sown 2.5 cm deep consistently out-yielded those sown at 7 cm (Fig. 2).

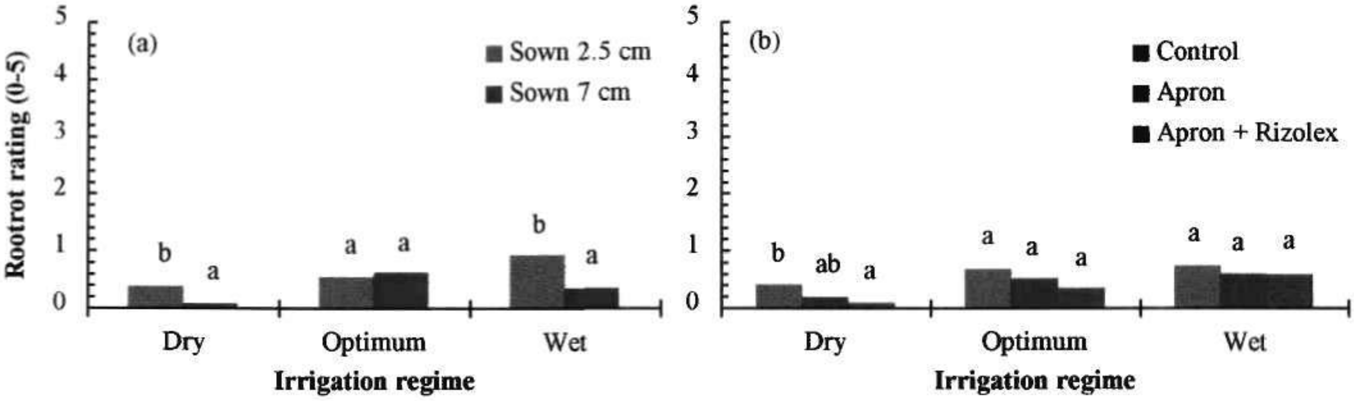


Figure 4. Neither (a) sowing depth nor (b) fungicidal seed treatments have agronomically significant impact on the severity of root rot in green bean seedlings under 3 irrigation regimes.

Conclusion

Although our overall bean yields in these experiments were low, these investigations still clearly demonstrated the importance of getting all inputs correct. For example, if we were looking to produce a beanette for processing, then by getting everything right (frequent irrigation, split nitrogen applications, use of cultivar *Bronco*), yields of marketable pods were 5.6 t/ha. Getting one input wrong substantially reduced production; wrong cultivar (-43%), not enough irrigation (-63%), insufficient nitrogen (-26%). Our experiments also confirmed the idea that any irrigation scheduling tool (eg. tensiometers) should only be used as guided for irrigation management, not as absolute indicators. In our green bean experiments, we should have been more aware that using very poor quality water, meant more irrigation than normal was required, particularly in weather of high evaporative demand. Our investigations also emphasised the inherent dangers of stressing beans prior to flowering in order to suppress bush development. This strategy could inhibit root system development, and hence the capacity of the plant to cope with extreme weather during the flowering and pod-set period. Because of the dry conditions and absence of disease, we had no agronomic advantage from application of additional fungicidal seed treatments. However, in situations where the risks of 'damping-off' diseases are more substantial, application of APRON® seed dressing (at a cost of $15-20/ha) is relatively cheap insurance.

Beetroot

Irrigation

In the 3 experiments conducted with beetroot, irrigation scheduling meant water was used more efficiently, while yields were maintained or improved (Figs. 5). The profitability of irrigation scheduling in beetroot using tensiometers is shown in Table 2. We assume that tensiometer scheduling costs $40/ha, irrigation $50/ML, and beetroot has an on-farm net value of $110/t. As with most high value crops, enhanced profitability comes mainly about through increased production, not through savings in water usage. In conditions where there is intermittent rain during a growing period, profits from irrigation scheduling can be even greater. This is because predicting plant water needs in such circumstances without some objective methodology is even more difficult.

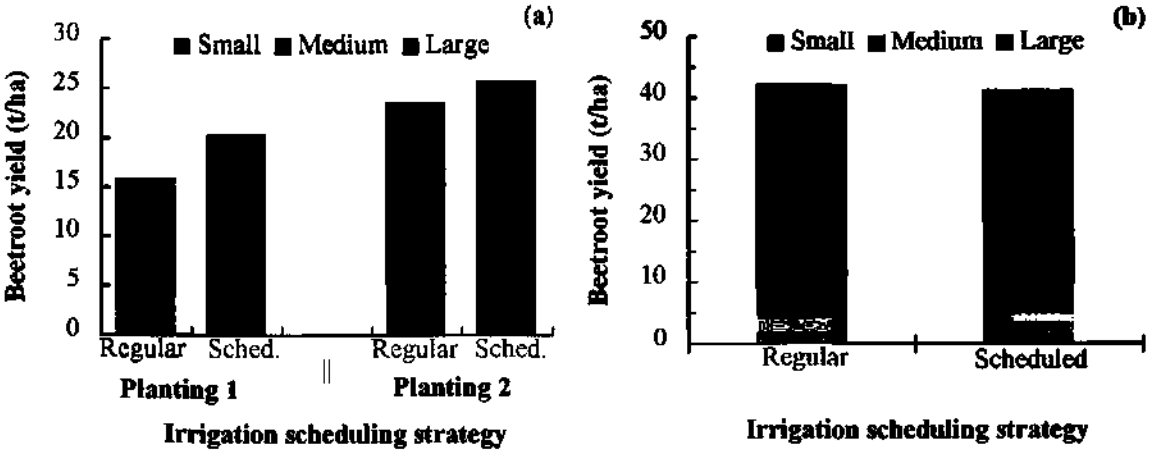


Figure 5. Irrigation scheduling (a) increased beetroot yields in 2 plantings (BEET1), but (b) had no effect in a third (CROP3).

Table 2. The effects of irrigation scheduling (compared to conventional irrigation practices) on water usage, yield and profitability in 3 beetroot plantings.

	Water saving		Yield increase		Increased profit
	ML/ha	Value ($/ha)	t/ha	Value ($/ha)	($/ha)
BEET1 planting 1	0.34	17	4.55	501	478
BEET1 planting 2	-0.17	-8	2.26	249	201
CROP3	-0.05	-2	-0.78	-86	-128
Cumulative total	**0.12**	**7**	**6.03**	**664**	**551**
Average per crop	**0.04**	**2**	**2.01**	**221**	**184**

Seedling disease

In our experimental work, there was no significant improvement in the emergence, growth nor yields of beetroot plants where seed was treated with APRON® fungicide before sowing. This was probably because during most establishment phases, weather was relatively dry. Crop rotation and fallow practices at Gatton Research Station also tend to reduce the incidences of soil-borne diseases, such as *Pythium* and *Aphanomyces*. If beetroots are to be sown into a paddock with an history of seedling disease problems, then an insurance seed-dressing is probably warranted. At about $5/ha, the costs of such a practice are negligible, although a more integrated approach to disease management is preferred.

Weed management

The major agronomic benefits in beetroot production investigated in this project were obtained from adjusting weed management strategies. Traditional commercial approaches have involved application of maximum rate mixtures of BETANAL® (phenmedipham) and TRAMAT® (ethofumesate) post-emergence, when the beetroots have 4-6 true leaves. Pre-emergence herbicides PYRAMIN® (chloridazon) or RAMROD® (propachlor) may also be sprayed immediately after sowing. In more recent times, there has been less use of the pre-emergence options. In the following discussion, a standard commercial herbicide application is considered to be spraying a mixture of 5 L/ha of BETANAL® and 2 L/ha of TRAMAT® when the beetroot has 4-6 true leaves.

In this summary section of the report, TRAMAT® rates will relate to the current formulation comprising 500 g/L ethofumesate. Note that some of the early experimental work involved a previous formulation comprising 200 g/L ethofumesate, so rates in the Appendices should be converted to take this into account.

PYRAMIN® and RAMROD® herbicides were used in BEET1 only. Compared to the commercial standard, each of these herbicides marginally improved control of fat hen (*Chenopodium album*) and deadnettle (*Lamium amplexicaule*) in the second planting. The level of this improved control was not commercially significant.

In all 4 beetroot sowings, hand-weeding resulted in the highest or equal highest yields of any treatments (Figs 6, 7). Note that in these Figures, the *Control* treatment is generally a very low dose of herbicide, associated with substantial numbers of weeds still remaining after treatment. In 2 of the 4 experiments, none of the weed management strategies significantly affected beetroot yields (Figs 6b, 7b). In the other 2 experiments, the commercial standard mixture of BETANAL® and TRAMAT® (*Commercial*) resulted in significant yield reductions (Figs. 6a, 7a).

As previously indicated, overseas experience and use patterns indicate less risk of crop damage from beet herbicides when the total dose is split across at least 2 applications, separated by 5-10 days. In the *Split-BETANAL®* treatments, 2 sequential applications of 2.5 L/ha of BETANAL® were sprayed about 1 week apart. The first application was generally when the beetroot crop had 2-3 true leaves. The *Split-BETANAL® + TRAMAT®* treatment had very low rates of TRAMAT® (usually 0.2 L/ha, but 0.6 L/ha in BEET1) mixed with each BETANAL® spray. In those experiments where crop damage was significant, both split application treatments were less phytotoxic than the standard commercial practice (Figs. 6a, 7a). For more details on treatments and consequences, refer to Appendices 4-6.

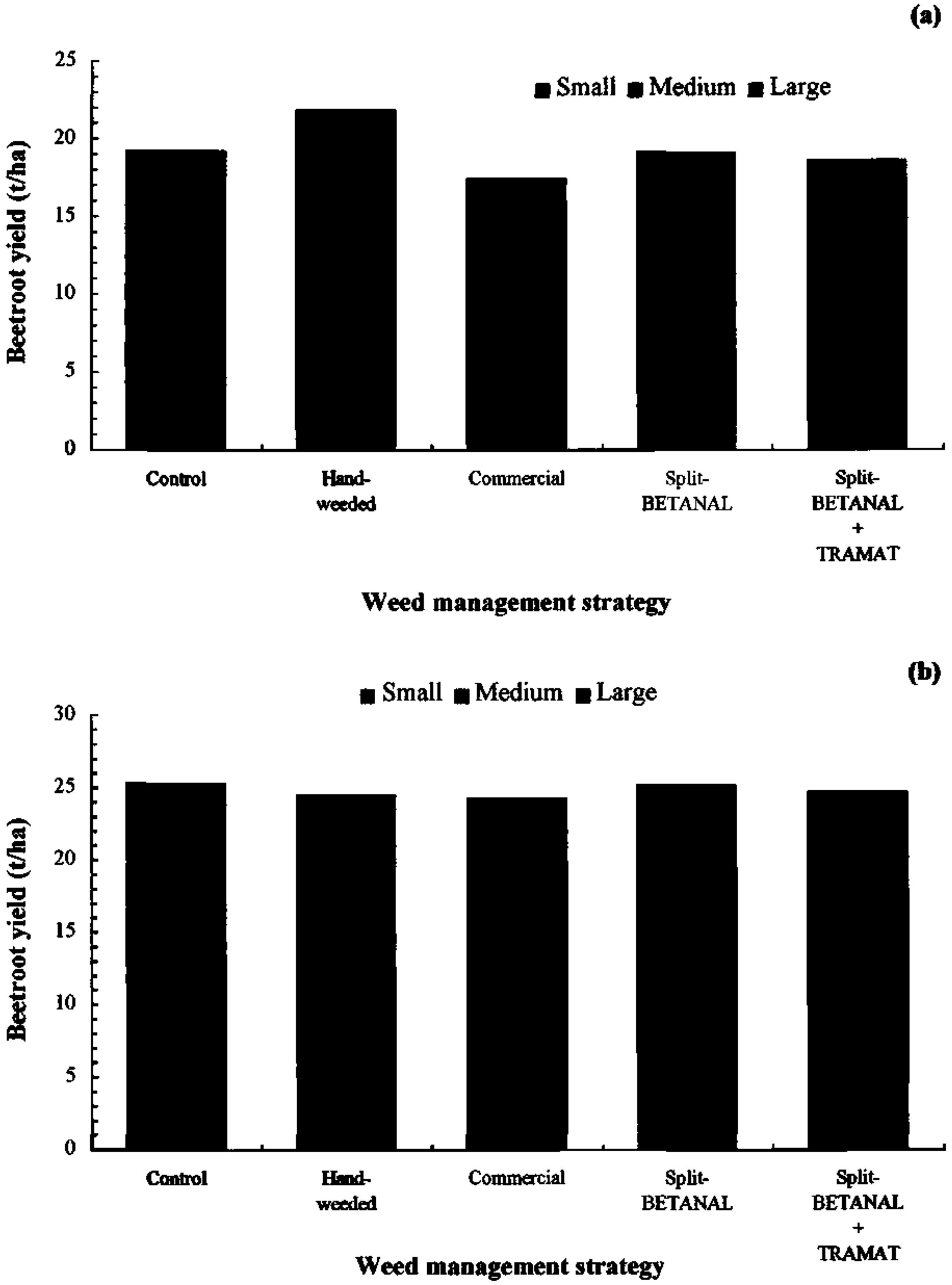
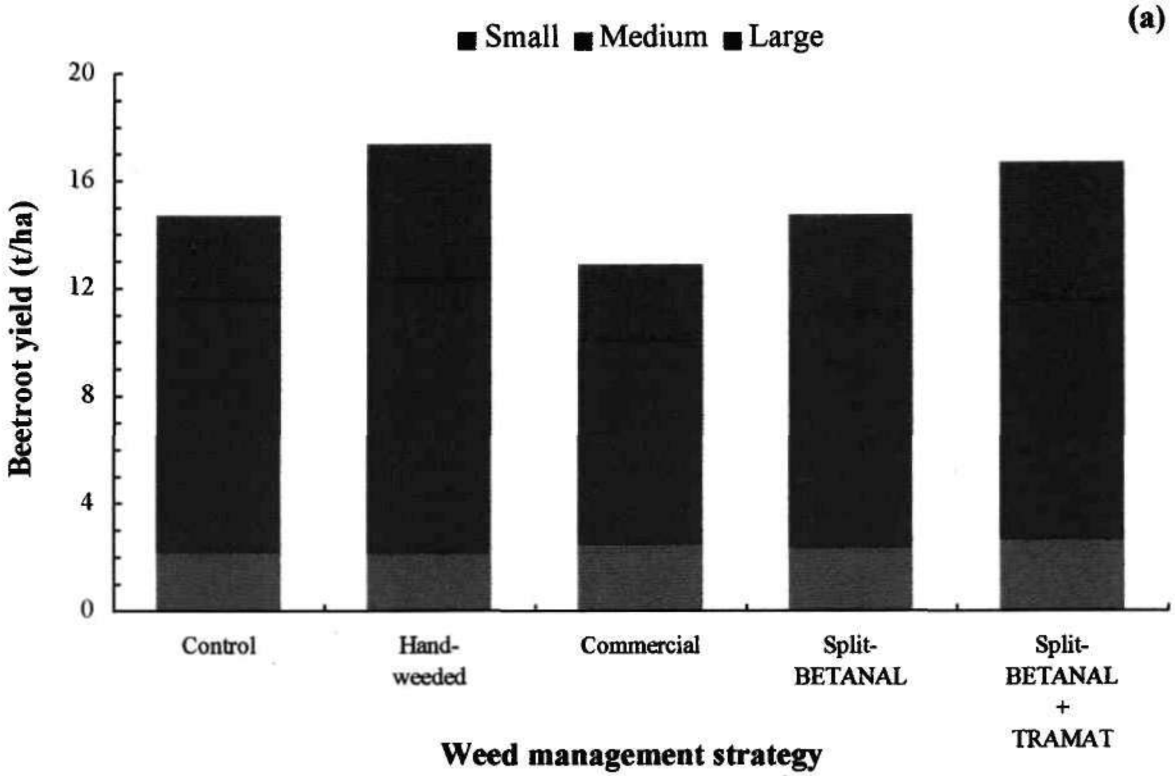


Figure 6. **Weed management strategies (a) significantly affect beetroot yields in Planting 1 of BEET1, but (b) have no effect on beetroot yields in Planting 2.**



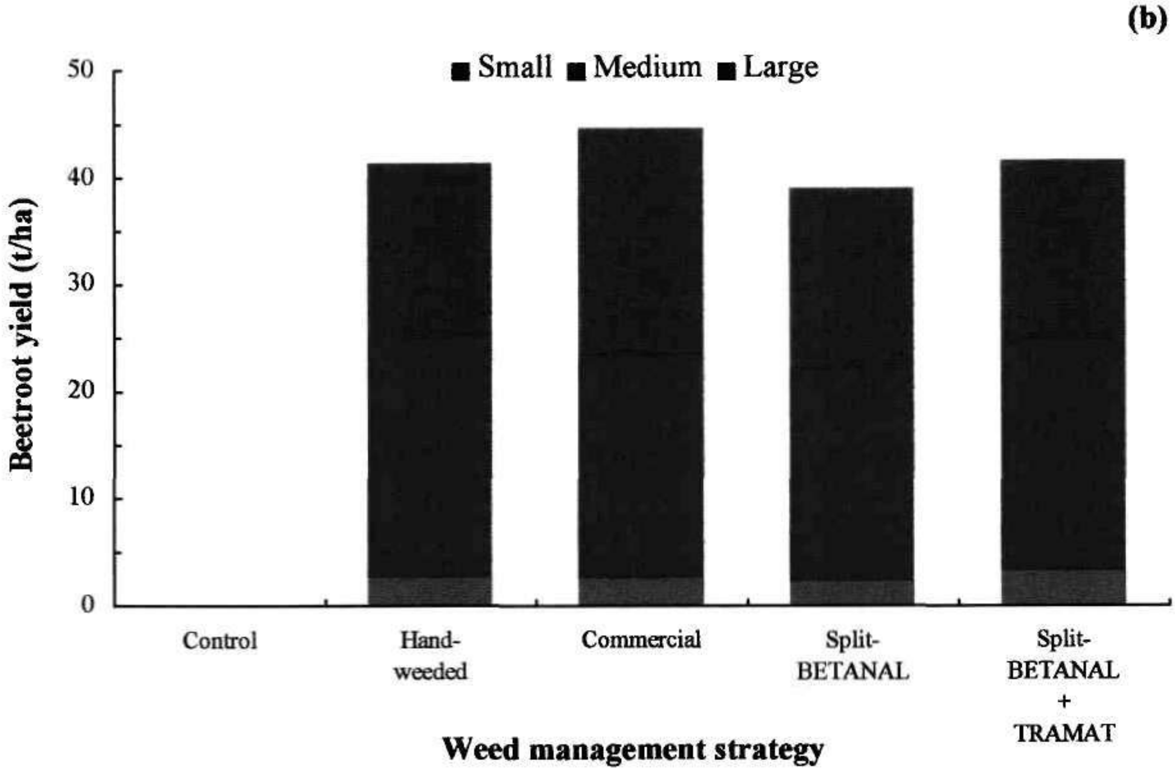
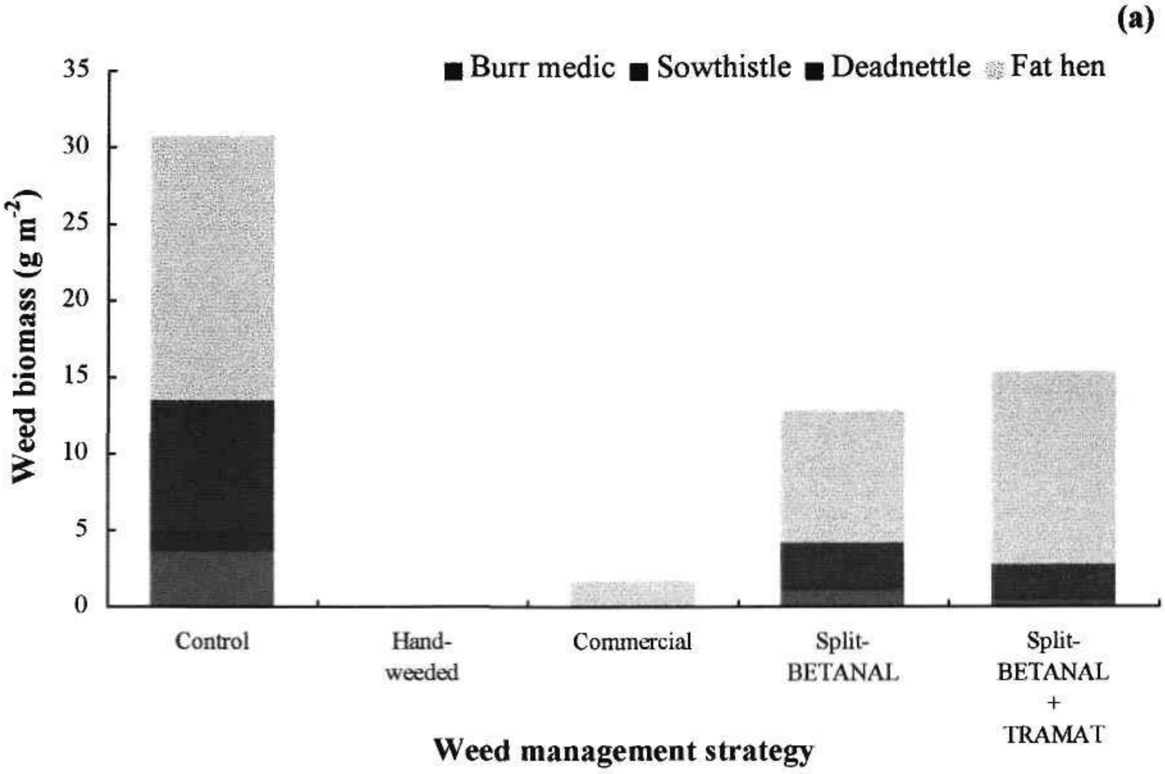


Figure 7. Weed management strategies (a) significantly affect beetroot yields in BEET2, but (b) have no effect on beetroot yields in BEET3.

In each of the beetroot plantings, the standard commercial single application of BETANAL®/TRAMAT® mixtures gave acceptable weed control (Figs. 8-10). Split applications of BETANAL® alone gave variable results; in some cases weed control was excellent, in others less so. The addition of very low rates of TRAMAT® (usually one-tenth of the maximum registered rate) consistently improved weed-kill. The only exception was with fleabane in BEET3 (Fig. 10b). Note that in the first planting of BEET1, the second component of the split applications was not applied, and some of the weeds recovered. This was why the level of control was not as good as the *commercial* treatment (Fig. 8a). In all plantings, the split application treatment with BETANAL® and TRAMAT® gave commercially acceptable weed control. For more detailed information of control of individual weed species, refer to Appendices 4-6.

We assume that in all herbicide strategies the applications are only sprayed over the central third of each beetroot row, and that inter-row weeds are controlled by cultivation. Taking into account the costs of application and herbicides, the commercial standard comprising 5 L/ha BETANAL® and 2 L/ha TRAMAT®, sprayed when the beetroot have 4-6 true leaves, costs about $165/ha. The proposed split-application strategy with low-rates of TRAMAT® costs $105/ha, a saving of $60/ha. Over all 4 plantings, the average yield increase from the split-application treatment compared to the *commercial* strategy was 7%. Assuming a 40 t/ha beetroot crop, and an on-farm net price of $105/t, this yield improvement, from reduced crop damage, is worth about $295/ha. Thus the increase in profit from adopting a split-application herbicide strategy averages $350/ha per crop, compared to the standard commercial practice.

We are liaising with the relevant herbicide company (AGREVO® P/L) with regard to possible changes in registrations to reflect our proposed application strategies. In the meantime, we will be looking to test the commercial viability of these weed management strategies over larger areas, in producers' crops, and in situations with greater weed burdens.



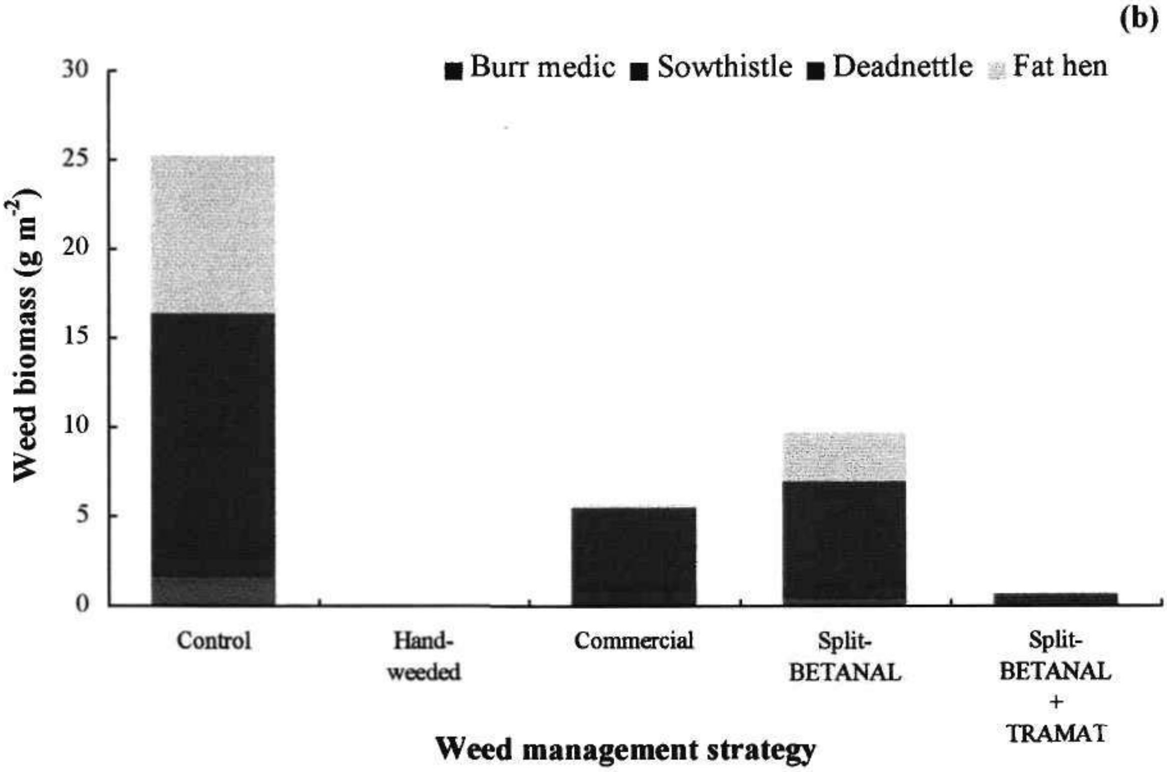


Figure 8. Weed management strategies significantly affect weed biomass present when beetroot are harvested in BEET1 (a) Planting 1 and (b) Planting 2.

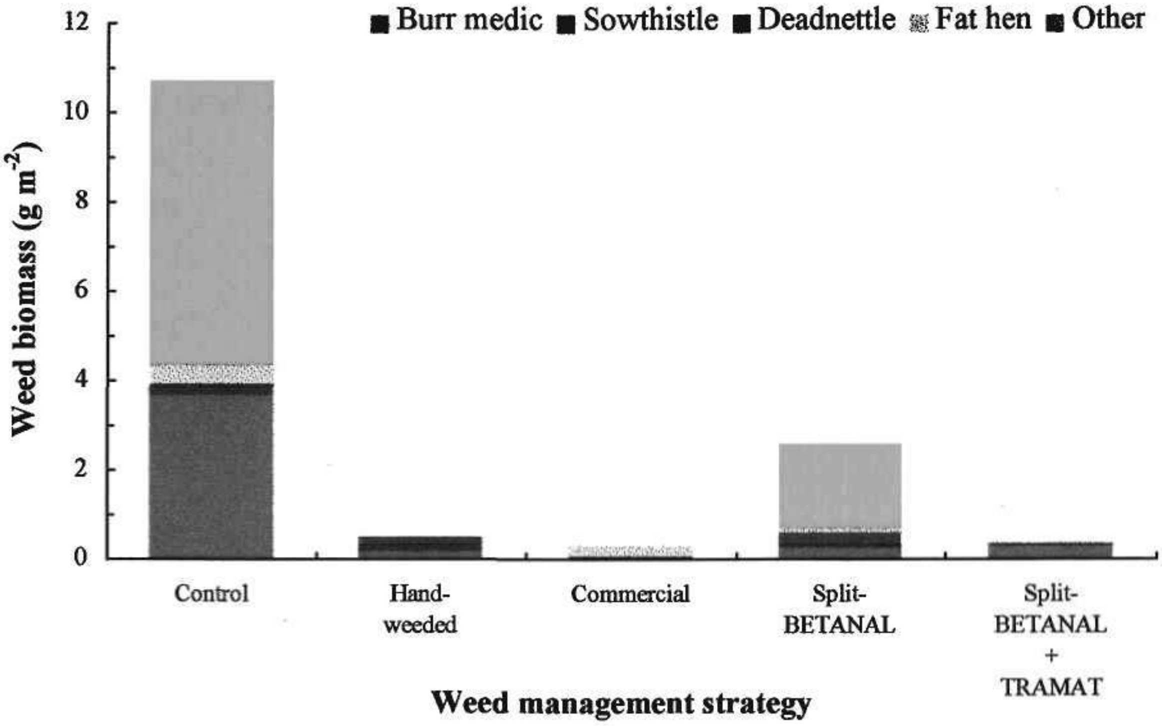


Figure 9. Weed management strategies significantly affect weed biomass present when beetroot are harvested in BEET2.

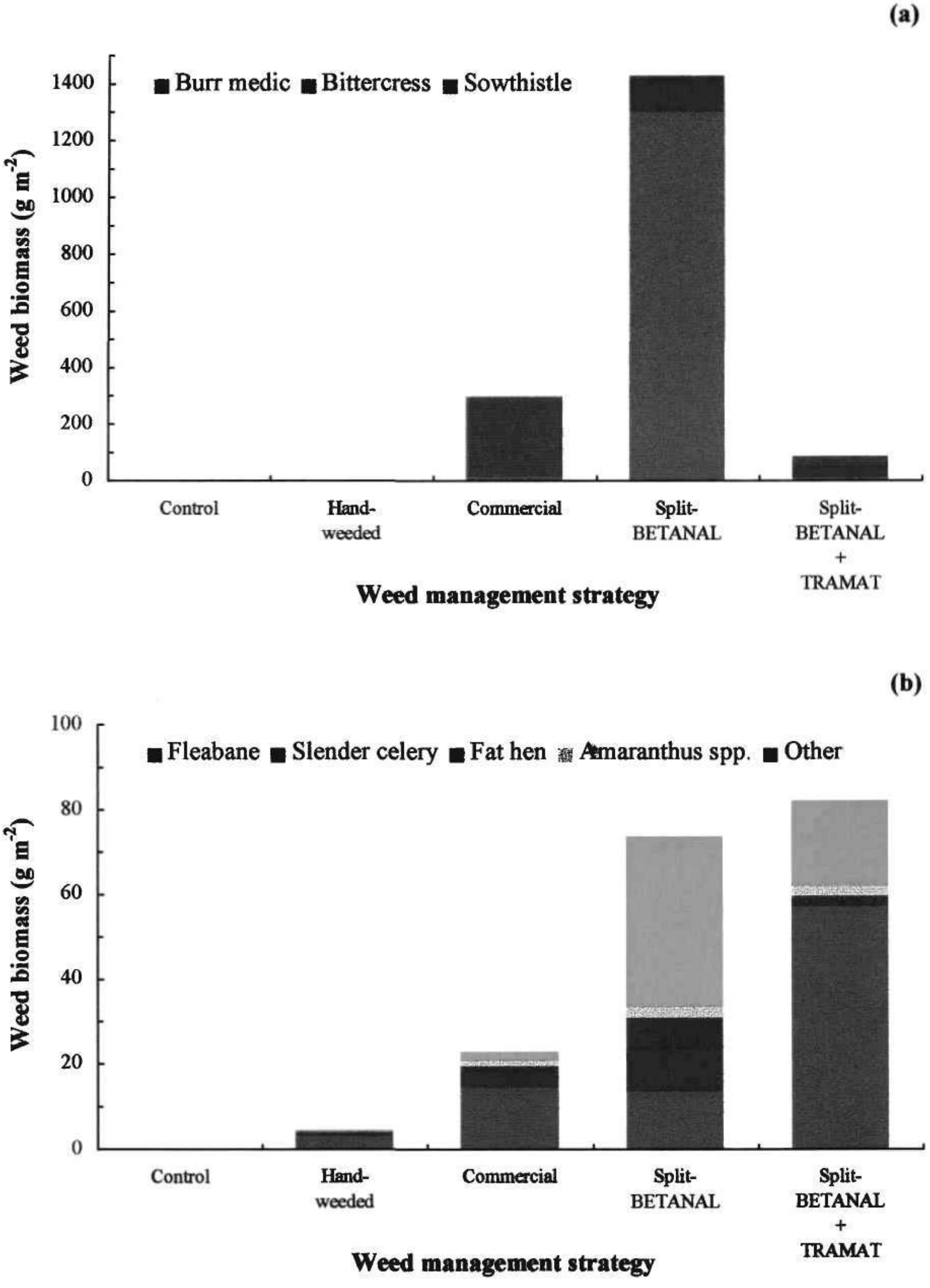


Figure 10. Weed management strategies significantly affect weed biomass present when beetroot are harvested in BEET3 (a) high population species and (b) less common species.

Conclusions

As in most vegetable crops, irrigation scheduling was shown to be profitable in beetroot, increasing the efficiency of water use, but more importantly from an economic perspective, maximising yields. In our studies, the other agronomic component that warranted fine-tuning was weed management. By adopting split application strategies for herbicides already registered in beetroot, amounts of pesticides used could be reduced, whilst still maintaining a commercially acceptable level of weed control. Apart from less environmental impact and lower pesticide costs, the major economic benefit was reduced risk of crop damage and hence higher average yields. From our experiments, the total value of increased irrigation efficiency and improved weed control was around $500/ha/crop.

Sweet corn

Irrigation

In only 2 experiments were effects of irrigation management on water use and crop production directly compared. In neither CORN1 nor CROP3 was there any significant benefit on sweet corn yields from irrigation scheduling, compared to watering on a semi-regular basis. Nevertheless, highest yields were consistently in blocks where irrigations were scheduled. The profitability of irrigation scheduling in sweet corn is shown in Table 3. We assume that tensiometer scheduling costs $40/ha, irrigation $50/ML, and sweet corn has an on-farm pre-harvest net value of $275/t. As with most high value crops, enhanced profitability comes mainly from increased production, not through savings in water usage. In conditions where there is intermittent rain during a growing period, profits from irrigation scheduling can be even greater. This is because predicting plant water needs in such circumstances without some objective methodology is even more difficult.

In previous research (Henderson 1994a), we found sweet corn generally required 3.5-4 ML/ha of water for optimum yields and quality. This was consistently the amount used in growing the sweet corn under a scheduled irrigation regime. In addition, the risks of deep drainage from excessive irrigation are consistently lower where a scheduling system is in place. This reduces the chance of leaching fertilisers and pesticides, which has both agronomic and environmental benefits.

Table 3. The effects of irrigation scheduling (compared to conventional irrigation practices) on water usage, yield and profitability in 3 sweet corn plantings.

	Water saving		Yield increase		Increased profit
	ML/ha	Value ($/ha)	t/ha	Value ($/ha)	($/ha)
CORN1 Planting 1	0.50	25	2.62	720	705
CORN1 Planting 2	0.80	40	0.91	250	250
CROP3	-0.05	-2	0.49	135	93
Cumulative total	**1.25**	**63**	**4.02**	**1105**	**1048**
Average per crop	**0.42**	**21**	**1.34**	**368**	**349**

Cultivar selection

The choice of an appropriate cultivar is vitally important to the profitability of sweet corn production. In south-east Queensland, mosaic virus, and to a lesser extent common rust, basically prevent the successful production of susceptible sweet corn from January until the end of the growing season. This is demonstrated in the experiment CORN1, where yields and cob quality of a virus-susceptible cultivar *Florida StaySweet* were much worse than the resistant cultivar *Pacific H5* (Fig. 11). Note that no cobs from *Florida StaySweet* were considered marketable at the second time of planting. Even in CORN3, where sweet corn was sown on 19 September 1996, the cultivar *Golden Sweet* was severely infected with mosaic virus at a very early stage. As a consequence of this infection, growth of this cultivar was stunted, and unhusked cob yields were around 8 t/ha lower than from *Pacific H5*.

These results emphasis the vital importance of correct cultivar selection. Although there may currently be some cob quality concerns with some virus-resistant cultivars, the future of susceptible cultivars in sub-tropical production areas must be clouded. In collaboration with the seed industry, QDPI has a continuing focus on improvement of cob quality in virus-resistant cultivars, as well as development of other resistance genetics.

In CORN3, there was more heliothus damage in *Golden Sweet* cobs compared to cobs from *Pacific H5* plants. The occurrence in the former was around 95%; closer to 60% in the latter. The poor insect control reflects the magnitude of this problem; it is probably the major factor limiting sweet corn production in southern Queensland (as well as other parts of Australia). Better performance from *Pacific H5* is probably due to a tighter wrap of leaves around the tip, restricting early larval migration into the head and increasing insecticide exposure.

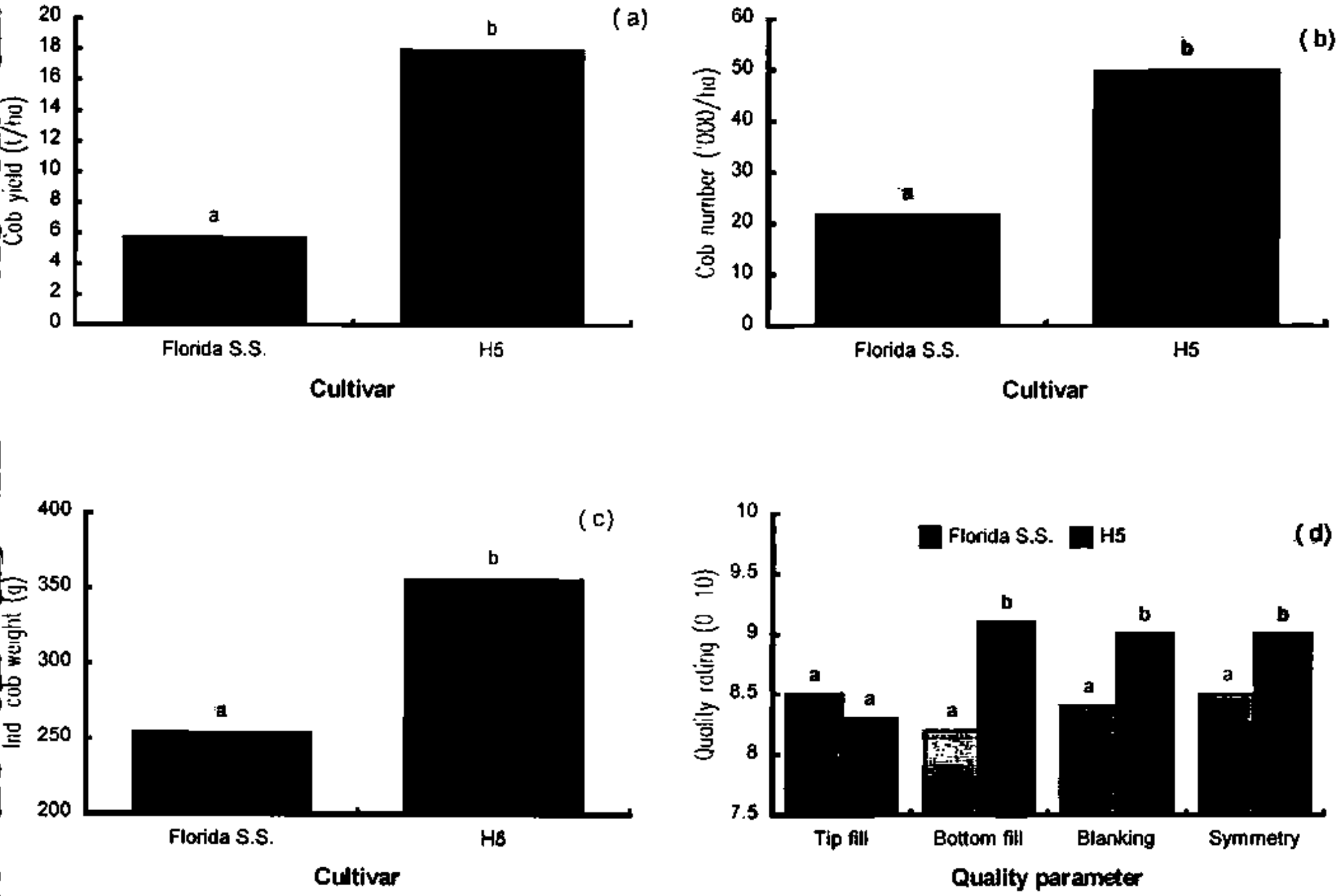


Figure 11. **When planted on 25 January 1994, the virus resistant sweet corn cultivar *Pacific H5* gave superior (a) unhusked cob yields, (b) cob numbers, (c) individual cob weights and (d) cob quality, when compared with the virus susceptible cultivar *Florida StaySweet*. Bars labelled with the same letter are not significantly different.**

Planting arrangement

In experiments CORN1 and CORN2 (Appendices 7 and 8) we examined the interactions between row-spacings and planting populations on sweet corn production. In Figs. 12 and 13 I have summarised the results, amalgamating yield differences to give an overall picture. All results refer to the cultivar *Pacific H5*, as poor general performance of other cultivars would have confounded the conclusions.

Changing inter-row spacings from 1 m to 0.75 m whilst maintaining the same overall plant population improved yields by around 1.1 t/ha on average (Fig. 12a). We also examined benefits from going to a very narrow spacing, considering early inter-plant competition would be reduced, and faster canopy closure may reduce weed emergence. In the single experiment (CORN2), these narrow row spacings were not found to improve yields (Fig. 12a), cob quality or weed control. Changing row spacings had no impact on the size of individual marketable cobs (Fig. 12b).

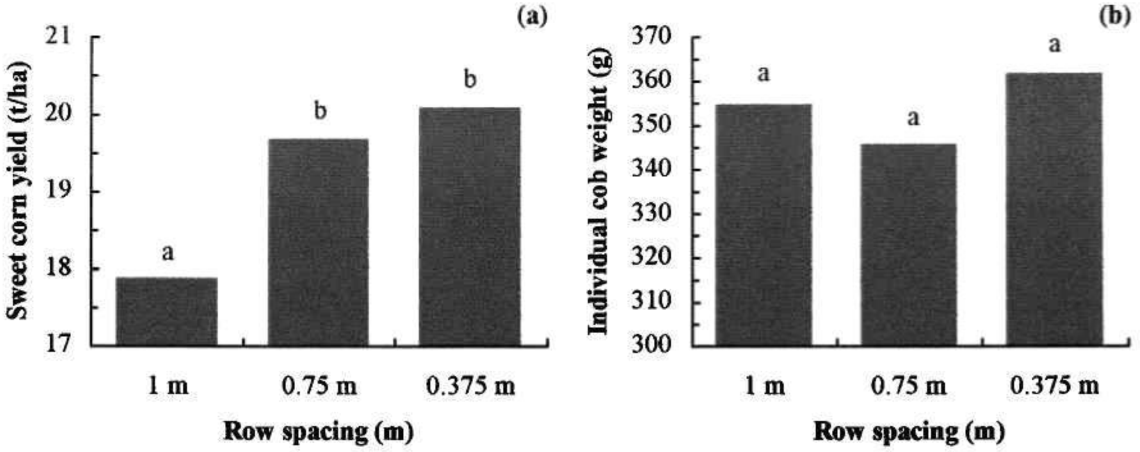


Figure 12. Reducing row spacing (a) increases sweet corn yields, but (b) has no effect on individual cob size.

Increasing the planting population from 50,000 seeds/ha to 70,000 seeds/ha significantly increased yields by 1.8 t/ha on average (Fig. 13a), with no drop in individual cob size (Fig. 13b). Further increasing the planted population to 100,000 seeds/ha marginally reduced yields, but also significantly reduced the size of individual cobs (Fig. 13). The ratio of cobs to seeds planted also fell from 96% to 72%. From these results, it would appear the optimum planting arrangement for sweet corn, grown using current agronomic practices, is an inter-row spacing of 75 cm, sowing 85-95% germinable seed every 18-20 cm. In CORN2, this resulted in unhusked marketable cob yields of 22-25 t/ha in the best plots. From our experiments, getting the row spacings or planting populations wrong probably reduces yields by about 1.5-2 t/ha on average. This would be worth $400-$550/ha.

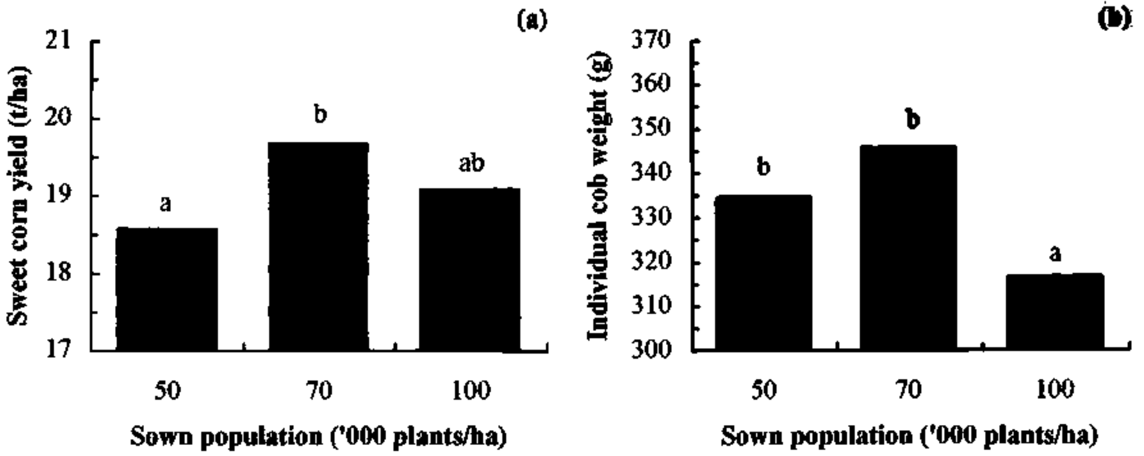


Figure 13. Increasing planted sweet corn populations (a) to 70,000/ha optimises yields, while (b) increasing it to 100,000/ha reduces individual cob size.

Weed management

Managing weeds in sweet corn is less difficult than in many other vegetable crops. Provided early weed control is effective, vigorous, tall cultivars grow sufficiently quickly to out-compete most weeds. Climbing species such as bellvine (*Ipomoea plebia*) can cause problems, twining around stems to reach light, smothering leaves and cobs in the process.

Many sweet corn crops can be grown without the use of any herbicides, particularly in paddocks where there is a history of successful weed control. Early inter-row cultivation may be sufficient, especially if equipment can give a level of weed kill within the crop row.

Although there are several herbicides registered for pre- and post-emergence use in sweet corn, hormones (eg. 2,4-D), or chemicals with longer-term residuals such as atrazine, are seldom used in horticultural areas, for obvious reasons. Pre-emergence herbicides like DUAL® (metolachlor) are frequently used in circumstances where substantial populations of grass and broadleaf weeds are thought to be present. In our experimental work, we generally apply 2.5-3 L/ha DUAL®; this often being the only weed management required. There is a role for post-emergence herbicides to manage unexpected weed populations, or species that escape early post-planting management strategies. In CORN3, the broadleaf herbicide STARANE® (fluroxypyr) was applied as a directed spray 5 weeks after planting (Appendix 9). The sweet corn was completely unaffected by this treatment, comprising 0.7 L/ha STARANE®, a use which is already registered in NSW. In this particular experiment, overall weed populations were too low to enable the weed control benefits of this herbicide to be assessed.

Conclusions

The experimental work outlined in this report demonstrated the importance of agronomic management to profitable sweet corn production. The 2 most vital components are probably correct cultivar selection and effective insect management. Cultivar selection is the most important tool in producing a cob that the market wants to buy and eat. It is also the key factor for managing mosaic virus, rust, and other diseases endemic in sub-tropical sweet corn production. Our results also indicate that cultivar selection, and its influences on cob conformity, can influence the success of insect management. Tight wrapper leaves, that slow the entry of heliothus larvae into the cob, may just be the edge that is the difference between successful and unsuccessful management.

As with the other vegetables, there is a role for irrigation scheduling in profitable sweet corn production. In a high water use crop, efficient irrigation practices can help conserve relatively scarce water resources. In several experiments we were able to substantially reduce water use by scheduling compared to just regular watering. There is also potential for yield improvements, which is where any substantial profit gains would be made.

Planting patterns and weed management in sweet corn are fairly straightforward. Settling on a basic inter-row spacing of 75 cm, sowing a seed every 20 cm, will get fairly close to optimal yields. Obviously there is some flexibility around this arrangement to suit individual producers' machinery. Benefits from going to narrower rows or higher plant populations are difficult to justify on the basis of improved agronomic outcomes.

It is not possible to put an average value on the cultivar selection decision; suffice to say that getting it wrong may mean no yield from a particular crop! Our work has shown that irrigation scheduling and establishing the correct planting pattern are probably worth around $700/ha. Studies on weed management indicate that there are several options for achieving relatively cheap, effective control. Whilst weed management might not be as important in a highly competitive crop such as sweet corn, successful control can have important implications for weed management in other crops grown in rotation.

Extension/adoption by industry

The major component of this project was investigating ways of improving profitability of growing beans, beetroot and sweet corn. The 9 major experiments referred to in this report evaluated potential changes to agronomic practices for each of these crops, including cultivar selection, nutrition, seedling disease management, irrigation scheduling, planting patterns, and weed management. These studies have built on, and been complementary to other work in a range of vegetable crops. As they have been developed, results from these investigations were incorporated in the various extension activities related below.

We have continued a strong push on irrigation scheduling in vegetables. Extension information has outlined the general principles of irrigation scheduling in vegetable crops. Growers of beans, sweet corn and beetroot have seen the benefits of scheduling at various field days. If producers recognised that irrigation management was important in their enterprise, then we took the time to individually demonstrate a relatively cheap, simple and effective method of irrigation scheduling using tensiometers. Even if producers or their staff did not feel they had the time nor expertise to run such a program themselves, they may have been sufficiently interested to engage a consultant. Currently there are consultants in the region using either tensiometers or the ENVIROSCAN® electronic system in irrigation scheduling.

In conjunction with the major QDPI sweet corn cultivar breeding and evaluation project, producers are very aware of the importance of correct cultivar selection in profitable production. There is a very much industry-driven focus on development of disease-resistant cultivars that are highly desirable to both domestic and export markets. Most sub-tropical sweet corn growers are only growing the disease-resistant material during much of the production period.

Weed management in all 3 vegetables is continually being reviewed. As strategies are developed, we are liaising with the respective chemical companies to obtain some form of registration if a new herbicide use is a component. As far as possible, growers are kept informed of the work and potential outcomes, within the restrictions imposed by chemical use legislation. In all 3 vegetables, there is a very good chance that new strategies, reducing overall pesticide impacts, and improving the level of weed control, will be available within the next few years. At this stage, the respective chemical companies are cooperative, and interested in pursuing the development of the new herbicide uses.

Vegetable producers were made aware of the project via talks at field days, group meetings, and press releases to local newspapers and radio stations. The results are also to be included in the various information packages being developed by QDPI (eg. Agrilink, Farmnote series, FarmFax service). Many of the techniques are already being disseminated through other extension people and agribusiness outlets as part of their standard agronomic advice.

Project extension activities

Field walks/days

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

• *Beetroot weed management*, GRS (+handout)	9/8/96
• *Weed/irrigation management in vegetables* (Ausveg group), GRS (+handout)	10/7/96
• *Weed management in vegetables* (producers, agribusiness), GRS (+handout)	19/6/96
• *Vegetable irrigation* (producers, agribusiness), Cambooya (+handout)	29/5/96
• *Weed management in vegetables*, EXPO 14 (+posters)	22-23/5/96
• *Irrigation management: vegetable case studies*, Pomona (+handout)	14/11/95
• *Weed management display*, EXPO 13 (posters)	25-26/5/94

General seminars to producers, agribusiness and producer groups

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

• *Alternative weed management and irrigation systems*, Bowen producers	22/5/95
• *Alternative weed management and irrigation systems*, Mareeba producers	24/5/95
• *Alternative weed management methods*, Toowoomba	7/12/94

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

- Tour of GRS weed/irrigation experiments (Horticulture Conference delegates) 21/8/96
- Tour of GRS weed/irrigation experiments for Horticulture Consultative group 5/5/94

Conferences

- *Integrated weed management in vegetables*, paper and poster presented at 11th Australian Weeds Conference, Melbourne September 1996
- *Reduced herbicide use in beetroot production*, paper and poster presented at 11th Australian Weeds Conference, Melbourne September 1996
- *Reduced herbicide use in beetroot production*, paper presented at 3rd Australian Horticulture Technical Conference, Gold Coast 19-22/8/96
- *Integrated weed management in vegetables*, poster displayed at Ausveg Conference, Brisbane (Also used by HRDC at another conference later in the month) 9/7/96

Other non-publishing extension activities relevant to producers and agribusiness

- Key data and action enabling changes in herbicide registrations, approvals and labels, eg. additions of vegetable crops to STOMP®, DUAL® and potentially other herbicides.
- Discussions and explanations of research activities with:
  Local consultants (David Carey, Graeme Thomas, John Hall, Peter Broomhall, Julian Winch, Brendan Nolan)
- Other Australian consultants (Ian Macleod, Tas; Neil Delroy, WA)
- Other Australian scientists and extension officers
- Rural radio (eg. Judy Kennedy 18/4/96, 29/2/96)

Significant activities with individual growers

- Answering individual irrigation enquiries from producers and agribusiness, both local and throughout Australia. These may include on-farm visits.

ficant extension publications

- *proving profits by better weed management in beetroot production*, (major article in ood Fruit & Vegetables magazine) May 1997
- *anaging weeds in vegetables*, (major article in Good Fruit & Vegetables magazine) October 1996
- *eeds a priority for research team*, (major article in Good Fruit & Vegetables magazine) October 1996
- *nsiometers in vegetables made easy* (QDPI article), updated September 1996
- *tegrated weed management in vegetables*, Proceedings of the 11th Australian Weeds onference September 1996
- *duced herbicide use in beetroot production*, Proceedings of the 11th Australian Weeds onference September 1996
- *tegrated weed management* poster September 1996
- *duced herbicide use in beetroot production* poster September 1996
- *duced herbicide use in beetroot production*, Proceedings of the 3rd Australian orticulture Technical Conference August 1996
- *rigating horticultural crops - be waterwise and be money sensible* (DPINote) August 1996
- *oot-zone tensiometer values for commencing vegetable irrigation in southern QLD* rticle for agribusiness) August 1996
- *rip irrigation* (National Marketplace News) March 1996
- *rigation scheduling in vegetables* (video) July 1995
- *rigation scheduling* (Chronicle Country) February 1995
- *vestigating vegetable production systems in the USA* (HRDC Final Report) February 1995
- *erbicide strategies for controlling key weeds of vegetables* (HRDC Final Report) May 1994
- *search activity summaries* in Gatton Research Station Booklet April 1994
- *rigation scheduling for shallow-rooted vegetables* (HRDC Final Report) February 1994

les contained in QFVG Research Reports (circulated to all QLD vegetable producers)

- 96 - requested not to provide articles!
- 95 - *Vegetable production systems in the USA*
- 94 - *Herbicide strategies for vegetables*
  - *Irrigation scheduling in vegetables*

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

- 1995/96 - *Weed management in vegetables*
- 1994/95 - *Weed management in vegetables*
  - *Sweet corn, green bean and beetroot production*

Field walk notes

• *Weed management in beetroot*	9/8/96
• *Weed management in vegetables*	19/7/96
• *Weed management in vegetables*	10/7/96
• *Weed management in vegetables*	19/6/96
• *Irrigating horticultural crops - be waterwise not money stupid*	29/5/96
• *Improving the irrigation efficiency with tensiometers: vegetable case studies*	14/11/95

General comment

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

Directions for future research

In all 3 crops the irrigation requirements for optimal production are relatively well established. There is probably still concern by some green bean growers about the need to water-stress the plant early to reduce bush size, promote flowering, and limit disease incidence. It may require regionally focussed extension programs to demonstrate the production benefits from optimal irrigation management. In both sweet corn and beetroot, the major irrigation focus should be on demonstrating the various methods of irrigation scheduling. To a large extent this requirement is being catered for by local consultants, and further intensive research work is not required.

In green beans, much of the current work is correctly focussing on the development of marketing chains, and the establishment of quality assurance protocols to successfully serve those markets. The key agronomic components appear to be crop establishment and disease management issues. These are currently being addressed by a number of inter-linked projects. Serve-Ag P/L in Tasmania are also pursing new herbicide options in green beans, which will enhance flexibility in weed management.

The beetroot industry is mainly focussed on processing, and is centralised in the Lockyer and Fassifern Valleys. Much research has already been done on key agronomic factors such as disease prediction and prevention, weed management and irrigation optimisation. The real need now is large-scale commercial evaluation of much of this research, and ensuring implementation by industry. Because the processing industry already has a ready made producer/processing company network, it makes most sense to use this network as the extension vehicle. Future work over the next few years should very much focus on extension of current information. In the disease and weed management areas, this also requires the cooperation of respective chemical companies where new regulated pesticide uses are a component. This can be time-consuming, and often a greater than normal level of persistence and determination.

In our sweet corn experimental work, and in consultation with industry, it was very apparent that cultivar development and insect management were the outstanding research issues that still require targeted and considerable attention. Both issues are being addressed by current and proposed QDPI/HRDC projects. As sweet corn is an industry with a real export potential, these research areas should probably be given priority. If we cannot develop products desired by potential new markets, and methods of sustainably managing key pests such as heliothus, then most other research and extension work will have little relevance.

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

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

Financial/commercial benefits

The experimental work in this project showed how profitability of producing beans, beetroot and sweet corn can be improved by paying careful attention to cultivar selection, seedling disease management, nutrition, planting arrangement, irrigation and weed management. In beans and sweet corn, cultivar selection was shown to be vitally important; incorrect choices can mean complete crop failures. Managing seedling diseases requires attention to previous paddock history, perhaps some soil testing for the presence of particular diseases, and the use of preventative seed treatments where conditions warrant this practice. These preventative seed treatments are relatively cheap compared to overall production costs.

Yields and quality of all 3 vegetables are dependent on effectively matching water supply with crop demand. Where irrigation is sub-optimal, ie. too infrequent, or of insufficient quantity/quality, then marketable yields suffer. Excessive irrigation is a waste of resources, can affect produce quality, and may also have deleterious environmental impacts. This project confirmed the economic benefits of irrigation scheduling. In our experiments we used tensiometers, an effective and relatively inexpensive technique. Compared to an electronic monitoring system, the capital costs of tensiometers (around $100 each) is a substantial saving. There is also the advantage that they are simple to use, therefore the producer need not necessarily employ a consultant. Some producers, particularly those commencing new or extensive, high value operations, or with specific irrigation management problems, may benefit from more intensive, expensive, irrigation management systems, in conjunction with expert counsel from an irrigation adviser (public or private). However, for producers irrigation scheduling for the first time, tensiometers are a cost-effective way of developing skills and understanding in the management of water resources in relation to crop requirements.

The project demonstrated scope for reducing amounts of herbicides applied for weed control, particularly in beetroot production. This has economic value to growers in reducing their costs; there are also environmental and cropping flexibility benefits as well.

I conducted simple analyses of the benefits of this research to vegetable growers in Queensland, based on gross margins for Lockyer Valley crops. These gross margins are most sensitive to prices and yields, so can only be used as comparative guides. I costed irrigation scheduling at $ 40/ha (eg. 4 tensiometers per 5 ha paddock, monitoring 3 times per week), based on standard depreciation schedules, and labour for maintaining and reading tensiometers. Costs of other agronomic changes are also included. The benefits of correct cultivar selection are not investigated, because if the grower gets that wrong then it is likely that the crop will be completely uneconomic! The main changes included in the analyses are irrigation and weed management, and optimising planting patterns. Increased harvesting and post-harvesting costs associated with greater yields are taken into account. The other assumptions for each of the vegetables are given in Table 4. These yield and price increases, rates and time-frames of adoption are all conservative. I used a standard cost/benefit computer package for analysing both on-farm and across-industry situations.

Table 4. Assumptions used in analysing the costs/benefits of project research.

Crop	Current pre-harvest price	Assumed current yield	Increased costs from new practices	Increased yield from new practices	Amount of adoption in 5 years
Beans	$586/t	5.0 t/ha	$150/ha	25%	30%
Beetroot	$110/t	40.0 t/ha	-$25/ha	12%	80%
Sweet corn	$275/t	15.0 t/ha	$30/ha	10%	50%

Using these values, the net benefit of this research to bean and beetroot growers is around $550/ha, and to sweet corn growers $380/ha. The net present value of adoption of the research (in Queensland alone) is about $2,400,000, and the return on research funds about 50:1. This analysis ignores the marketing, resource use and environmental benefits referred to earlier.

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Appendix 1. Experiment BEAN1 October-December 1993

Green bean sowing depth and seed dressings effects under different irrigation regimes

by Craig Henderson and Mick Webber
QDPI Gatton Research Station

Summary

The experiment was conducted at Gatton Research Station, October-December 1993. Green bean cultivar, Labrador was grown in an experiment consisting of a split-plot design with 3 fungicide seed dressing main plots (THIRAM®, THIRAM® + APRON®, THIRAM® + APRON® + RIZOLEX®) and sowing depth sub-plots (2.5 cm or 7 cm). This sequence was repeated in 3 irrigation regimes; dry, moderately dry and wet prior to flowering. Rainfall after flowering meant no irrigation was required during the pod-set and fill period.

Poor quality irrigation water and a heat wave at flowering severely affected bean growth and yields, with almost total flower and pod abortion. Bean yields increased with increasing irrigation. There was no advantage from stressing bean plants to promote smaller bush size and increase flowering.

Because of the dry conditions and absence of disease in this experiment there was no agronomic advantage from applying the fungicidal seed dressings.

Shallow sowing gave better bean plant growth and higher yields than deep sowing. Maximum yields, although still relatively low (about 3.4 t/ha), were obtained in the wettest treatments where the beans were sown at 2.5 cm.

This experiment reinforced the idea that tensiometers should only be used as a guide for irrigation scheduling, not absolute indicators. The experiment also emphasised in my mind the inherent dangers of stressing beans prior to flowering in order to suppress bush development. I believe this policy could inhibit root system development and hence the capacity of the plant to cope with extreme weather during the flowering and pod-set period.

Introduction

In Queensland, green beans are grown on about 4300 ha per annum (circa 45% of Australian production), with a gross return of approximately $17 million. The cost-price squeeze is adversely affecting the profitability of this industry. To remain viable, producers must reduce their costs per unit product, or develop new value-added products.

This experiment was a component of a project developing agronomic packages to reduce growers per unit costs. Previous research suggests that bean yields of 12 t/ha (compared to current averages of 6 t/ha) are achievable, given favourable weather conditions and effective pest management. This is possible through improved irrigation and crop nutrition, cultivar selection and pest management. Costs can also be reduced by more reliable stand establishment, less expensive weed control and more effective disease management.

Objectives

This experiment investigated how planting depth and fungicide application affected disease incidence, seedling establishment, plant growth and yield of spring-grown green beans, under several irrigation regimes, on black earth soils.

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 split-plot, with 3 fungicide treatments as main plots, and 2 sowing depth treatments as sub-plots. These were replicated 4 times in blocks.

The fungicide treatments were:

1. Control seed dressings, THIRAM® (800 g/kg thiram) as coated on purchased seed
2. Addition of APRON® (metalaxyl 350 g/kg) applied at 2 g/kg seed to Treatment 1
3. Spraying RIZOLEX® (tolclofos methyl 500 g/kg) at 1 kg/ha in the sowing furrow, using seed from Treatment 2. The RIZOLEX® was applied at a pressure of 220 kPa, in 250 L/ha of water.

The sowing depth sub-treatments involved seed placement at 2.5 cm or 7 cm below the soil surface.

This experimental design was repeated in 4 separate irrigation blocks, each containing 24 plots. These blocks were irrigated according to schedules determined from tensiometers placed in the plots treated with RIZOLEX® and sown 2.5 cm deep. Tensiometers installed 15 cm below ground level were used to determine when the crop needed irrigating; tensiometers at 60 cm indicated drainage below the effective root zone. Each block was irrigated using lines of solid-set sprinklers running down the edges of the block. Irrigation blocks were separated by 15 m of fallow ground, to prevent irrigation interference. The 4 blocks were irrigated according to the following pre-determined schedule:

Block 1. This block was watered at shallow tensiometer values of 50 kPa before flowering and 40 kPa after flowering. This was considered 'optimum' irrigation.

Block 2. This block was irrigated at shallow tensiometer values of 70-80 kPa before flowering and 40 kPa after flowering. This was noted as the 'dry' treatment.

Block 3. The third area was allocated as a 'wet' treatment, with irrigation at tensiometer values of 15 kPa prior to flowering, and optimum watering after flowering (40 kPa).

Block 4. This block was initially to have 'optimum' irrigation prior to flowering and 'wet' conditions after flowering. However, due to rainfall after flowering, it received the same irrigation as Block 1 for the entire experiment. Thus it was not considered a separate treatment. It was used as a replicate of the 'optimum' irrigation regime.

Hence, rather than 4 irrigation regimes, results for this experiment are interpreted according to 3 regimes; 'dry' (Block 2); 'optimum' (Blocks 1 and 4) and 'wet' (Block 3). Because of the experimental design, results for each regime were statistically analysed separately. Some comparisons between regimes are made. Replication of blocks for the 'optimum' treatment were taken into account in the analyses. Each plot was 1 bed (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 13 October 1993, with 0.85 m between the rows and 0.05 m intra-row spacing.

A total of 60 kg/ha of N (in urea form) were broadcast and irrigated in, 5 days before planting. A further 60 kg/haN was broadcast by hand, 34 days after sowing (DAS). A foliar spray containing 1 kg/ha urea and 1 kg/ha zinc sulphate was applied 35 DAS. Weed control was achieved by spraying 4 L/ha STOMP® (330 g/L pendimethalin) 1 DAS; 1 L/ha FUSILADE® (212 g/L fluazifop-p, butyl) 15 DAS; 2 L/ha BASAGRAN® (480 g/L bentazone) 27 DAS; mechanically cultivating 34 DAS; and hand-chipping any remaining weeds 41 DAS. An insecticidal spray comprising 2 L/ha of LANNATE® (225 g/L methomyl) and 2.1 L/ha THIODAN® (350 g/L endosulfan) was applied 14 DAS. Further applications of 2 L/ha of LANNATE® were sprayed 35 and 47 DAS.

LOCTRONIC® tensiometers were used in this experiment, 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. 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 establishment of bean plants was assessed by counting the number of healthy plants in 2 randomly selected 1 m lengths of row per plot. At the end of peak flowering, about 50 DAS, plants were destructively harvested from 1 m of row per plot. These whole plant tops were dried at 50 °C for 10 days, then weighed. Green beans were mechanically harvested from the northern row of each plot on 13 December 1994, 61 DAS. The fresh weights of the harvested material was determined; a sub-sample of approximately 2-3 kg was taken from each plot harvest. This sub-sample was sorted into marketable pods, trash (dirt, stems, broken pods), and, along with 20 marketable beans, were weighed.

Results

During the first 3 weeks after sowing, there was sufficient rainfall (Fig. 1) to enable successful bean plant establishment in even the least frequently irrigated block. Between 21 and 53 DAS, there was no effective rain. During the pod-filling period between flowering and harvest, sufficient rain meant no irrigation was required, even in the most frequently irrigated treatment (Fig. 1c). During the growing period, the bean crop received a total of 100 mm rain.

All blocks received 49 mm irrigation in the first few days after planting, to establish a full soil moisture profile. They were irrigated with about 30 mm of water twice during flowering (46-52 DAS), with no further irrigations until harvest. The only period of substantial irrigation differentiation was between 10-45 DAS; during the vegetative and early flowering growth stages (Fig. 1). Over the whole growing period, the 'dry' irrigation block received 157 mm of irrigation, the 'optimum' treatment 189 mm, and the 'wet' block 267 mm.

Values for shallow tensiometers in the 'dry' and 'optimum' blocks rose steadily to 60 kPa between 20-35 DAS (Figs. 1a,b), indicating a drying soil profile. In the 'dry' block, tensiometer values remained around 60 kPa until the second flowering irrigation, after which values fell to 5 kPa and stayed low prior to harvest (Fig. 1a). Shallow tensiometer readings in 'optimum' irrigation areas fluctuated between 5 and 40-50 kPa during the late vegetative and flowering period (Fig. 1b). During the vegetative phase, shallow tensiometers in the most frequently irrigated block peaked above 20 kPa on only 1 occasion (Fig. 1c), then cycled between 5 and 45 kPa during the flowering stage. As with all other treatments, the whole soil profile was wet during the post-flowering rainfall.

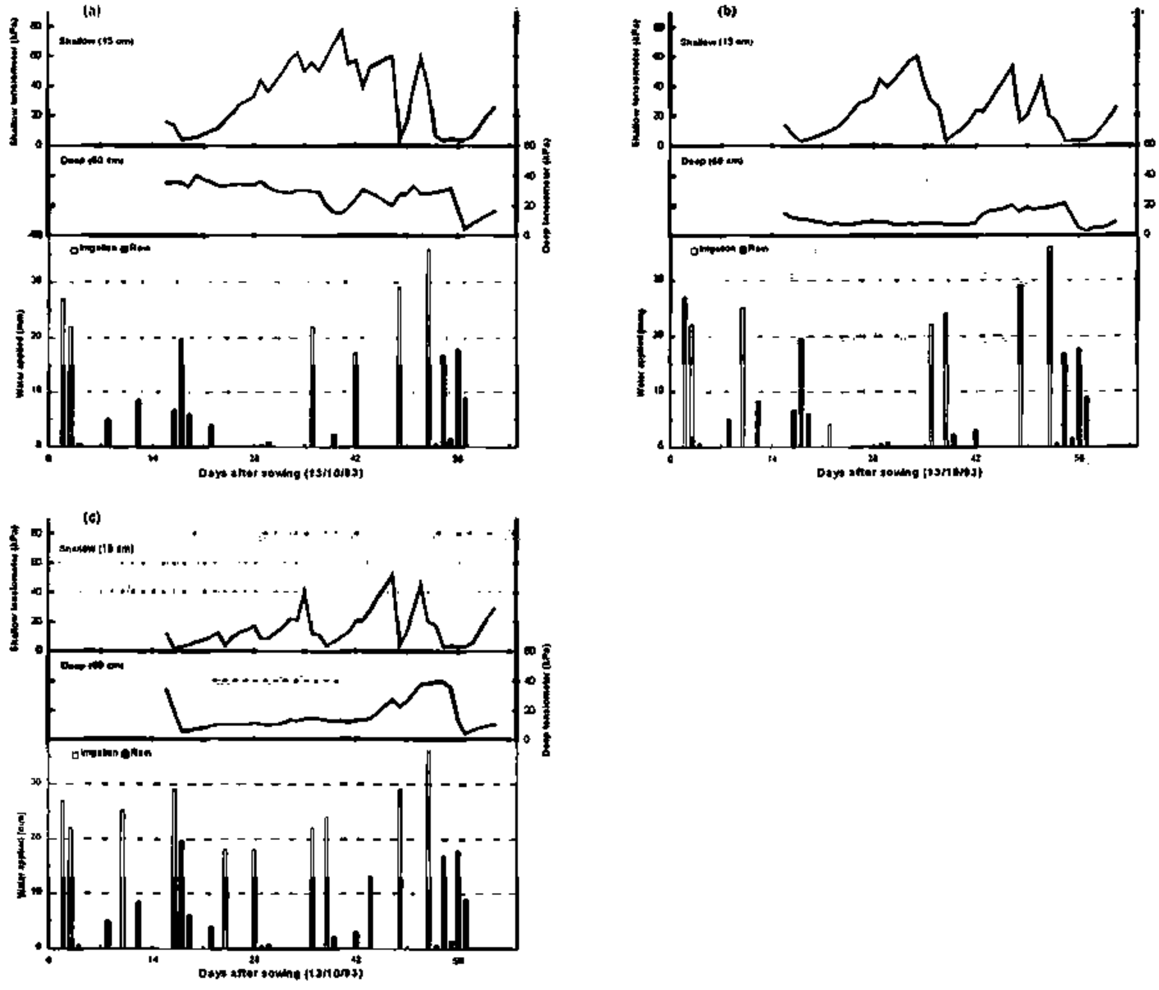


Figure 1. Fluctuations in soil matric suctions at 15 and 60 cm below ground level, where green beans were irrigated under (a) 'dry', (b) 'optimum' and (c) 'wet' irrigation regimes.

Values for deeper tensiometers in all blocks indicated little drainage of irrigation or rainfall below the root zone, until the heavy rain during the final fortnight before harvesting (note the consistent dips in Fig. 1). Also interesting to observe is the rise in deep tensiometer values at flowering for the 'wet' irrigation block. In my view, this indicates greater water uptake / root activity in the deeper soil zones, compared to the drier irrigation blocks. Due to the long drought, supply and quality of irrigation water at Gatton Research Station is of increasing concern. During this experiment, we used irrigation water of 280 mS/m and a chloride concentration of 620 mg/L. Significant leaf necrosis was notable after each irrigation, particularly during the early vegetative growth stages.

There were no significant effects of fungicide treatment nor sowing depth on the numbers of bean plants established. There were 16.1 plants/m row in the ‘dry’ irrigation block, 13.8 plants/m row in the ‘optimum’ block, and 14.8 plants/m row in the most frequently irrigated beans. These differences were not substantial, nor attributable to any obvious agronomic factors. The overall average establishment of 75% of seeds sown was poorer than the 85-90% achieved with cv. *Bronco and New Pioneer* in a neighbouring experiment.

There was very little evidence of any form of root rot in this experiment In no treatment was the mean severity greater than a Rating 1 (on a scale where 0 is no disease and 5 indicates death). There was a slight increase in root disease as irrigation frequency increased; likewise there were minor reductions in disease where APRON® or APRON® + RIZOLEX® were used (Fig. 2). In both 'dry' and 'wet' irrigation blocks, there were significant reductions in root rot where seeds were sown deep; this was not the case under the 'optimum' irrigation regime.

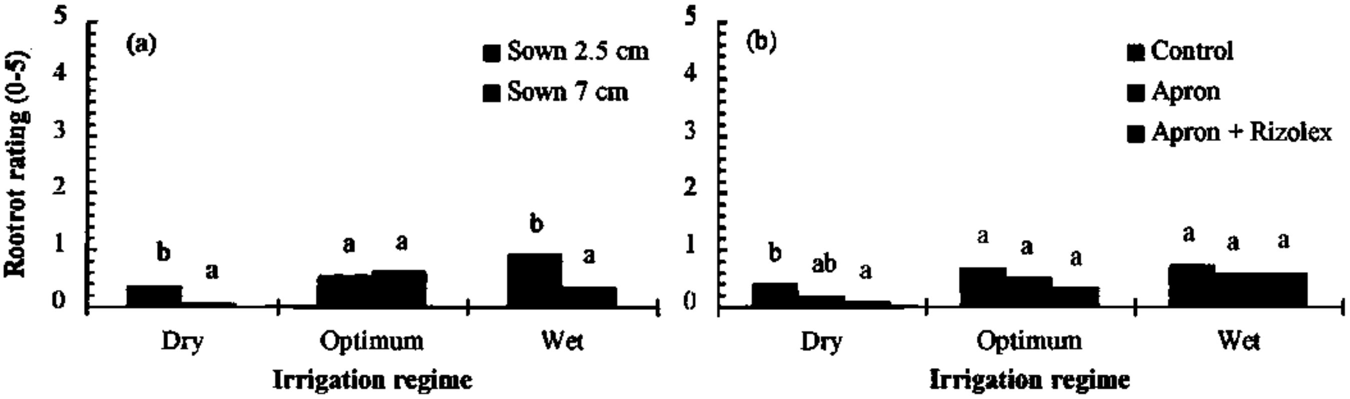


Figure 2. Neither (a) sowing depth nor (b) fungicidal seed treatment have agronomically significant impact on the severity of root rot in green bean seedlings under 3 irrigation regimes.

The fungicidal seed treatments did not affect any other growth nor yield measurement in the experiment. All biomass and yield results only refer to seed placement and irrigation effects.

Irrigation was the main factor affecting the size of bean plants at flowering, particularly the increase from the 'optimum' to 'wet' regimes (Fig. 3). There were slight declines in plant biomass with deep seed placement in the 'optimum' irrigation treatment.

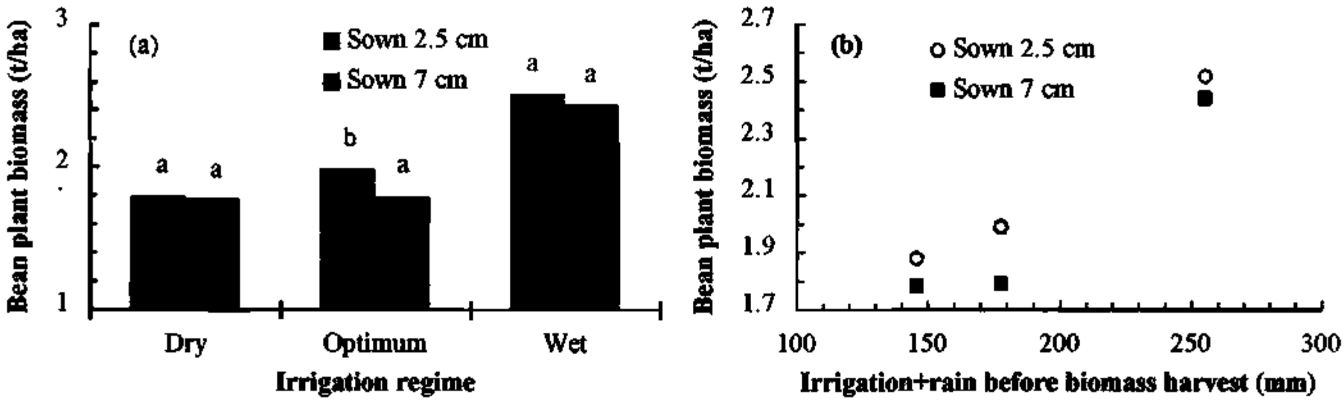


Figure 3. Biomass at flowering of the green bean cultivar *Labrador* increased with quantity of irrigation, but was only marginally affected by depth of sowing.

Whilst there were slight improvements in pod yields with the more frequent irrigation of the 'optimum' compared to 'dry' irrigation regimes, the gains were much more substantial in the most frequently irrigated blocks (Fig. 4). Under both the 'optimum' and 'wet' irrigation regimes, there were significant yield declines associated with deep sowing.

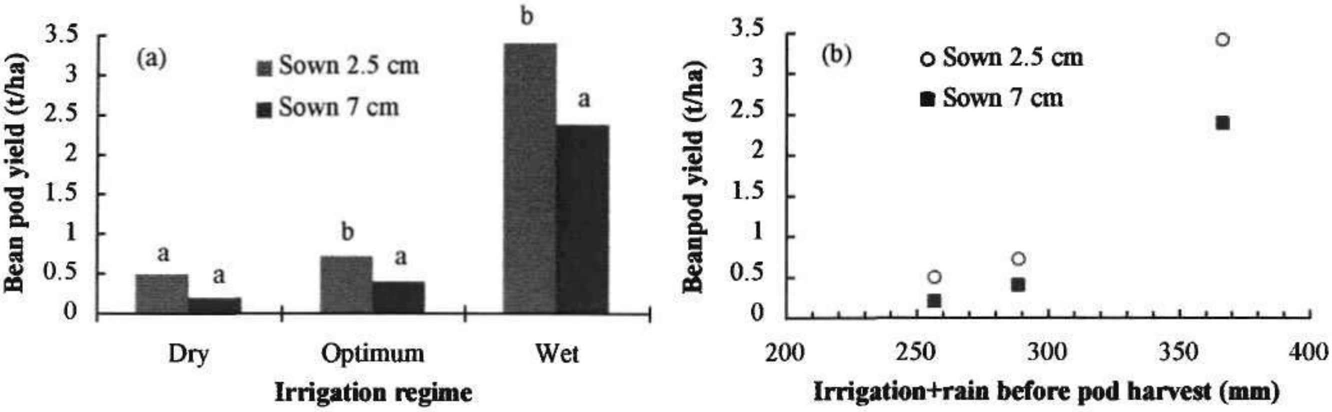


Figure 4. Marketable pod yields of the green bean cultivar *Labrador* were significantly increased by irrigation and reduced by deep sowing.

There were slight increases in the size of bean pods as irrigation frequency increased, however the greatest effects on yield were due to greater numbers of marketable pods (Fig. 5). Deeper sowing reduced bean pod size in both the drier irrigation regimes, but also reduced the number of pods harvested in the 'optimum' and 'wet' treatments.

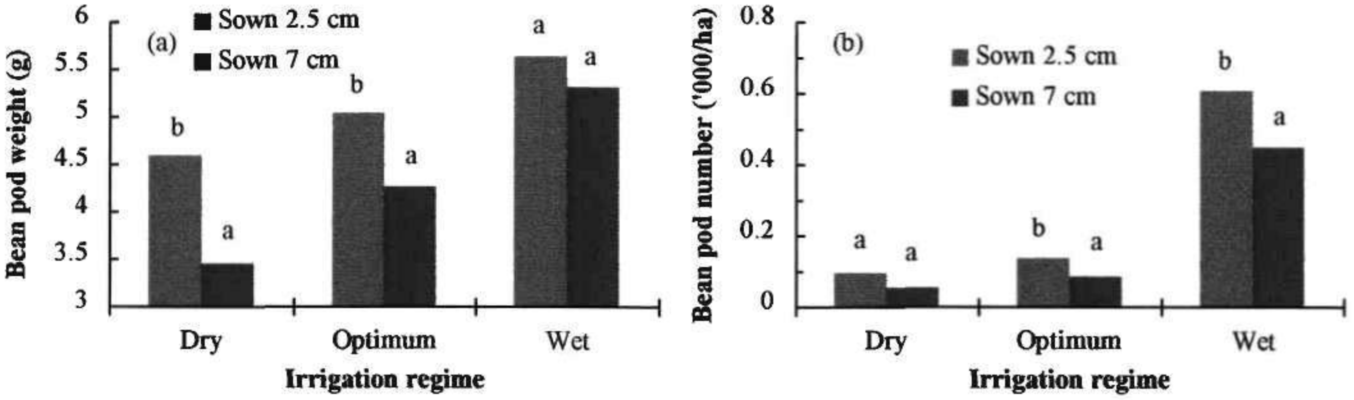


Figure 5. Increased irrigation frequency enhances bean pod size and number, while deep sowing reduces pod size in the 'dry' and optimum' treatments, and pod number in the 'optimum and 'wet' treatments.

Discussion

Poor water quality severely affected growth and yields of beans in this experiment. In addition, during flowering in late November - early December, there were several days of heatwave conditions, with maximum temperatures above 35°C. The combination of poor quality water and high temperatures were disastrous for bush growth and particularly pod-set. *Labrador* beans were particularly badly affected by the hot conditions, with almost total flower and pod abortion

Because of salinity and chloride concentrations in the irrigation water, I should probably have reduced the critical tensiometer values for triggering irrigation. In this experiment, the 'wet' irrigation regime was more appropriate, particularly during the vegetative stages of growth. This regime allowed more leaching of salts from around the seedling roots, with less osmotic influence on nutrient and water uptake.

Unusually high evaporative demand during the growing period, averaging 6.8 mm pan evaporation per day, meant the irrigation requirement was much higher than forecast from previous experimental outcomes. Normally we would look to apply 20 mm/week for the first 7 weeks after sowing, increasing to 25 mm/week until harvest. For the first 5 weeks after sowing we applied (including rainfall) an average of 25 mm/week to the 'optimum' blocks and 38 mm to the 'wet' block. To supply 0.8 of pan evaporation (a reasonable 'rule-of-thumb' for early growth stages of green beans), we needed to apply an average of 37 mm/week.

The tensiometer data (Fig. 1) suggests that the water stress period between 25-35 DAS in the 'optimum' irrigation blocks was the main determinant of their poorer biomass production and pod yields, compared to the most frequently irrigated beans. The increased vegetative growth in the 'wet' blocks may also have enabled the development of superior root systems, increasing access to nutrients and water availability. This may have been very important during the high evaporative demand period around flowering. The results suggest tensiometer values for triggering irrigation may need to be lowered to around 30-40 kPa under hot, dry conditions, or where poor quality irrigation water is used.

Not only did the amount of pre-flowering irrigation affect vegetative biomass of bean plants (Fig. 3), it also affected numbers of pods set for each kg of that biomass. For example, in the 'optimum' blocks, *Labrador* set an average of 59 pods for each kg dry weight of bean plant at flowering, while in the 'wet' block, the value was 213 pods/kg flowering biomass. It seems, increased irrigation prior to flowering increased pod-set. This may have been due to either increased total floral production, or reduced flower and/or pod abortion. I hypothesise that larger bushes (and by inference, more extensive root systems) allowed the plants to better cope with the hot weather at flowering.

Similarly, deep sowing also seemed to reduce the number of pods per kg of flowering biomass; by 42% in the 'dry' blocks, 30% in the 'optimum' blocks and 24% in the 'wet' blocks. It is possible that deep sowing also reduced root system development , with consequences similar to those described above.

This experiment reinforced the idea that tensiometers should only be used as a guide for irrigation scheduling, not absolute indicators. I should have been more conscious of the need for a substantial irrigation on the 'optimum' blocks during the peak evaporative demand period around 30 DAS.

The experiment emphasised in my mind the inherent dangers of stressing beans prior to flowering in order to suppress bush development. I believe this policy could inhibit root system development, and hence the capacity of the plant to cope with extreme weather during the flowering and pod-set period.

Because of the dry conditions and absence of disease in this experiment, there was no agronomic advantage in applying the fungicidal seed dressings. However, in situations where the risk of 'damping off' type diseases is significant, application of APRON® seed dressing (at a cost of approximately $15/ha) is relatively cheap insurance.

In examining green bean production practices in future experiments, we will endeavour to use sap testing to take a closer look at N balances, as well as make more intensive measurements of biomass, flower production and pod-set. We may have to use drip systems for irrigation, given the current water status at Gatton Research Station.

Appendix 2. Experiment BEAN2 October-December 1993

Green bean cultivar and nutrition interactions under different irrigation regimes

by Craig Henderson and Mick Webber
QDPI Gatton Research Station

Summary

The experiment was conducted at Gatton Research Station, October-December 1993. Green bean cultivars Bronco, Labrador and New Pioneer were grown in an experiment consisting of a split-split plot design with 2 nitrogen (N) nutrition main plots and 3 cultivar sub-plots. This sequence was repeated in 3 irrigation regimes; dry, moderately dry and wet prior to flowering. Rainfall after flowering meant no irrigation was required during the pod-set and fill period. N treatments were either 60 kgN/ha as a basal application, or the basal followed by 2 side-dressings of 25 kgN/ha.

Poor quality irrigation water and a heat wave at flowering severely affected bean growth and yields. The Labrador cultivar was particularly badly affected by the heat, with almost total flower and pod abortion. The yield of this cultivar in the most frequently irrigated, highest N treatment was only 3.2 t/ha, compared to 5.6 t/ha for Bronco and 6.0 t/ha for New Pioneer. Bean yields increased with increasing irrigation. There was no advantage from stressing bean plants to promote smaller bush size and increase flowering. Maximum yields, although still relatively low, were obtained in the wettest treatments with most applied nitrogen fertiliser. In the high N treatments, increasing irrigation frequency from moderate to high improved yields of Bronco by 58%, New Pioneer by 102%, and Labrador by 390%.

Increasing the amount of N applied increased yields of all cultivars in the wettest irrigation regime (Bronco by 32%, New Pioneer by 19%, Labrador by 10%), and decreased yields of all cultivars in the driest treatment. In the moderately irrigated treatments, additional N increased yields of Bronco (27%), but had no effect on New Pioneer nor Labrador. Although overall yields were low, nevertheless, the importance of getting all inputs correct was clearly demonstrated. For example, if we were looking to produce a beanette for processing, then by getting everything right in this experiment (frequent irrigation, split N applications, Bronco cultivar), we would have produced 5.6 t/ha of marketable pods. Getting just one thing wrong would have substantially reduced our yield; wrong cultivar - 43% reduction, insufficient irrigation - 63% reduction, insufficient nitrogen - 26% decline.

This experiment reinforced the idea that tensiometers should only be used as a guide for irrigation scheduling, not absolute indicators. The experiment also emphasised in my mind the inherent dangers of stressing beans prior to flowering in order to suppress bush development. I believe this policy could inhibit root system development, and hence the capacity of the plant to cope with extreme weather during the flowering and pod-set period.

Introduction

In Queensland, green beans are grown on about 4300 ha per annum (circa 45% of Australian production), with a gross return of approximately $17 million. The cost-price squeeze is adversely affecting the profitability of this industry. Producers must reduce their costs per unit product, or develop new value-added products, to remain viable.

This experiment was a component of a project developing agronomic packages to reduce growers per unit costs. Previous research suggests that bean yields of 12 t/ha (compared to current averages of 6 t/ha) are achievable, given favourable weather conditions and effective pest management. This is possible through improved irrigation and crop nutrition, cultivar selection and pest management. Costs can also be reduced by more reliable stand establishment, less expensive weed control and more effective disease management.

Objectives

This experiment investigated how cultivar selection and nitrogen nutrition affected foliar and pod diseases, plant growth and yield of spring-grown green beans, under several irrigation regimes, on black earth soils.

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 split-plot, with 2 nitrogen (N) nutrition treatments as main plots, and 3 green bean cultivars (*Labrador, Bronco* and *New Pioneer*) as sub-plots. These were replicated 4 times in blocks. The nitrogen treatments were: (i) 60 kgN/ha applied as urea prior to sowing; and (ii) 60 kgN/ha applied as urea prior to sowing, with 2 additional applications of 25 kgN/ha (urea) during the growing period.

This experimental design was repeated in 4 separate irrigation blocks, each containing 24 plots. These blocks were irrigated according to schedules determined from tensiometers placed in the *Bronco* - high N plots. Tensiometers installed 15 cm below ground level were used to determine when the crop needed irrigating; tensiometers at 60 cm indicated drainage below the effective root zone. Each block was irrigated using lines of solid-set sprinklers running down the edges of the block. Irrigation blocks were separated by 15 m of fallow ground, to prevent irrigation interference. The 4 blocks were irrigated according to the following pre-determined schedule:

Block 1. This block was watered at shallow tensiometer values of 50 kPa before flowering and 40 kPa after flowering. This was considered to be the 'optimum' irrigation treatment.

Block 2. This block was irrigated at shallow tensiometer values of 70-80 kPa before flowering and 40 kPa after flowering. This was noted as the 'dry' treatment.

Block 3. The third area was allocated as a 'wet' treatment, with irrigation at tensiometer values of 15 kPa prior to flowering, and optimum watering after flowering (40 kPa).

Block 4. This block was initially to have 'optimum' irrigation prior to flowering and 'wet' conditions after flowering. However, due to rainfall after flowering, it received the same irrigation as Block 1 for the entire experiment. Thus it was not considered a separate treatment. It was used as a replicate of the 'optimum' irrigation regime.

Hence, rather than 4 irrigation regimes, results for this experiment are interpreted according to 3 regimes; 'dry' (Block 2); 'optimum' (Blocks 1 and 4) and 'wet' (Block 3). Because of the experimental design, results for each regime were statistically analysed separately. Some comparisons between regimes are made. Replication of blocks for the 'optimum' treatment were taken into account in the analyses.

Each plot was 1 bed (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 were sown on 13 October 1993, with 0.85 m between the rows and 0.05 m intra-row spacing. Seed was treated with 2 g/kg of APRON® seed-dressing (350 g/kg metalaxyl) prior to sowing.

A total of 60 kg/ha of N (in the urea form) were broadcast and irrigated in, 5 days before planting. The 2 side dressings of N (for the high N treatments) were broadcast by hand, 20 and 34 days after sowing (DAS). A foliar spray containing 1 kg/ha urea and 1 kg/ha zinc sulphate was applied 35 DAS. Weed control was achieved by spraying 4 L/ha STOMP® (330 g/L pendimethalin) 1 DAS; 1 L/ha FUSILADE® (212 g/L fluazifop-p, butyl) 15 DAS; 2 L/ha BASAGRAN® (480 g/L bentazone) 27 DAS; mechanically cultivating 34 DAS; and hand-chipping any remaining weeds 41 DAS. An insecticidal spray comprising 2 L/ha of LANNATE® (225 g/L methomyl) and 2.1 L/ha THIODAN® (350 g/L endosulfan) was applied 14 DAS. Further applications of 2 L/ha of LANNATE® were sprayed 35 and 47 DAS.

LOCTRONIC® tensiometers were used in this experiment, 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. 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 establishment of bean plants was assessed by counting the number of healthy plants in 2 randomly selected 1 m lengths of row per plot. At the end of peak flowering, about 50 DAS, plants were destructively harvested from 1 m of row per plot. These whole plant tops were dried at 50 °C for 10 days, then weighed. Green beans were mechanically harvested from the northern row of each plot on 13 December 1994, 61 DAS. The fresh weights of the harvested material was determined; a sub-sample of approximately 2-3 kg was taken from each plot harvest. This sub-sample was sorted into marketable pods and trash (dirt, stems, broken pods). These components, along with 20 marketable beans, were weighed.

Results

During the first 3 weeks after sowing, there was sufficient rainfall (Fig. 1) to enable successful bean plant establishment in even the least frequently irrigated block. Between 21 and 53 DAS, there was no effective rain. During the pod-filling period between flowering and harvest, sufficient rain meant no irrigation was required, even in the most frequently irrigated treatment (Fig. 1c). During the growing period, the bean crop received a total of 100 mm rain.

All blocks received 49 mm irrigation in the first few days after planting, to establish a full soil moisture profile. They were irrigated with about 30 mm of water twice during flowering (46-52 DAS), with no further irrigations until harvest. The only period of substantial irrigation differentiation was between 10-45 DAS; during the vegetative and early flowering growth stages (Fig. 1). Over the whole growing period, the 'dry' irrigation block received 157 mm of irrigation, the 'optimum' treatment 189 mm, and the 'wet' block 267 mm.

Values for shallow tensiometers in the 'dry' and 'optimum' blocks rose steadily to 60 kPa between 20-35 DAS (Figs. 1a,b), indicating a drying soil profile. In the 'dry' block, tensiometer values remained around 60 kPa until the second flowering irrigation, after which values fell to 5 kPa and stayed low prior to harvest (Fig. 1a). Shallow tensiometer readings in 'optimum' irrigation areas fluctuated between 5 and 40-50 kPa during the late vegetative and flowering period (Fig. 1b). During the vegetative phase, shallow tensiometers in the most frequently irrigated block peaked above 20 kPa on only 1 occasion (Fig. 1c), then cycled between 5 and 45 kPa during the flowering stage. As with all other treatments, the whole soil profile was wet during the post-flowering rainfall.

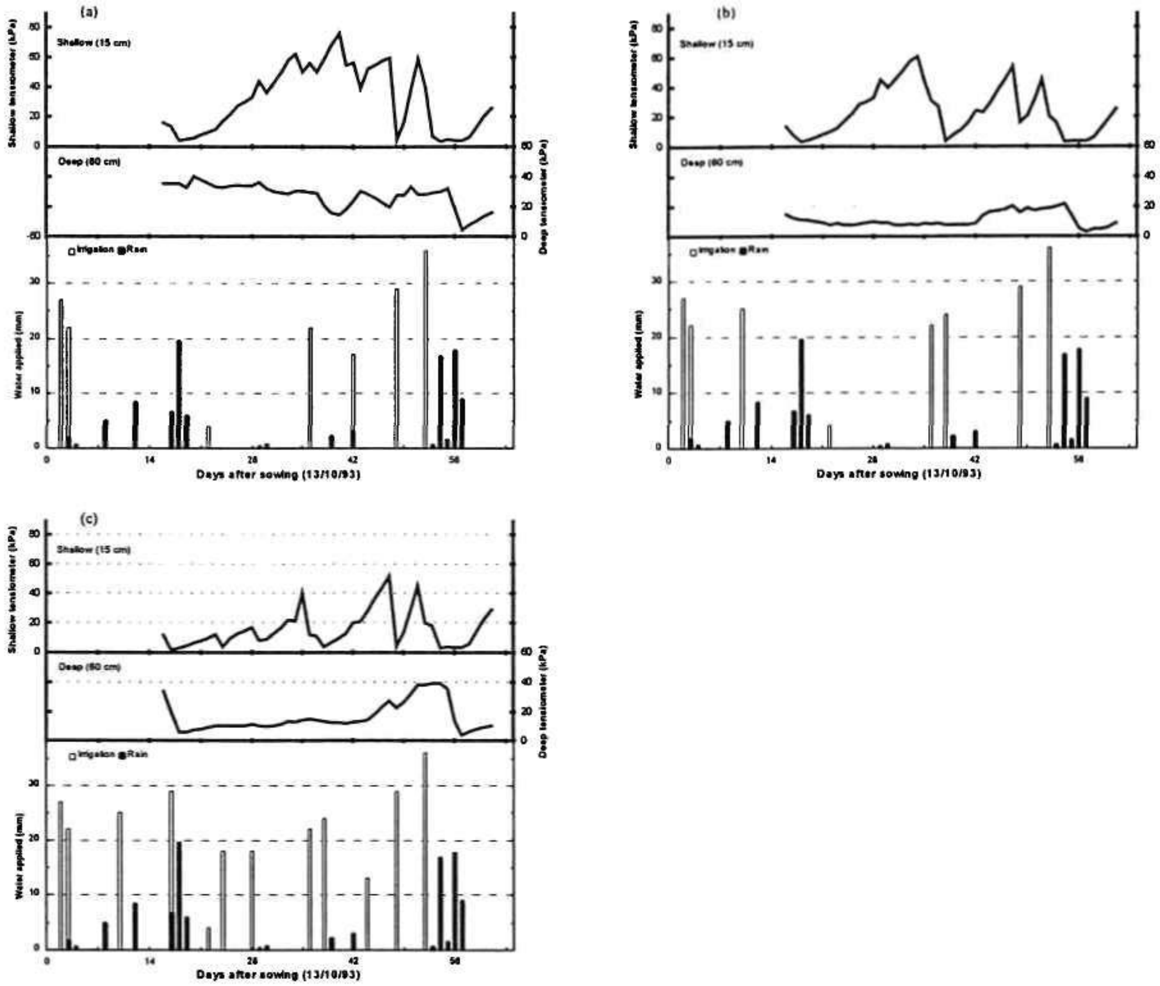


Figure 1. Fluctuations in soil matric suctions at 15 and 60 cm below ground level, where green beans were irrigated under (a) 'dry', (b) 'optimum' and (c) 'wet' irrigation regimes.

Values for deeper tensiometers in all blocks indicated little drainage of irrigation or rainfall below the root zone, until the heavy rain during the final fortnight before harvesting (note the consistent dips in Fig. 1). Also interesting to observe is the rise in deep tensiometer values at flowering for the 'wet' irrigation block. In my view, this indicates greater water uptake / root activity in the deeper soil zones, compared to the drier irrigation blocks.

Due to the long drought, supply and quality of irrigation water at Gatton Research Station is of increasing concern. During this experiment, we used irrigation water of 280 mS/m and a chloride concentration of 620 mg/L. Significant leaf necrosis was notable after each irrigation, particularly during the early vegetative growth stages.

Best bean plant establishment was achieved with the *Bronco* cultivar in the 'dry' irrigation block, with 18 plants/m row, or 90% of seeds sown (Fig. 2). Establishment of *New Pioneer* was slightly, but not significantly poorer. With both *Bronco* and *New Pioneer*, there was a minor, but consistent decline in plant establishment as the post-sowing irrigation frequency increased. In practical agronomic terms, this difference (circa 5%) was unimportant. In both 'dry' and optimum' irrigation blocks, *Labrador* establishment was significantly worse than the other 2 cultivars (Fig. 2). In contrast to *Bronco* and *New Pioneer*, establishment of *Labrador* was best in the most frequently irrigated block.

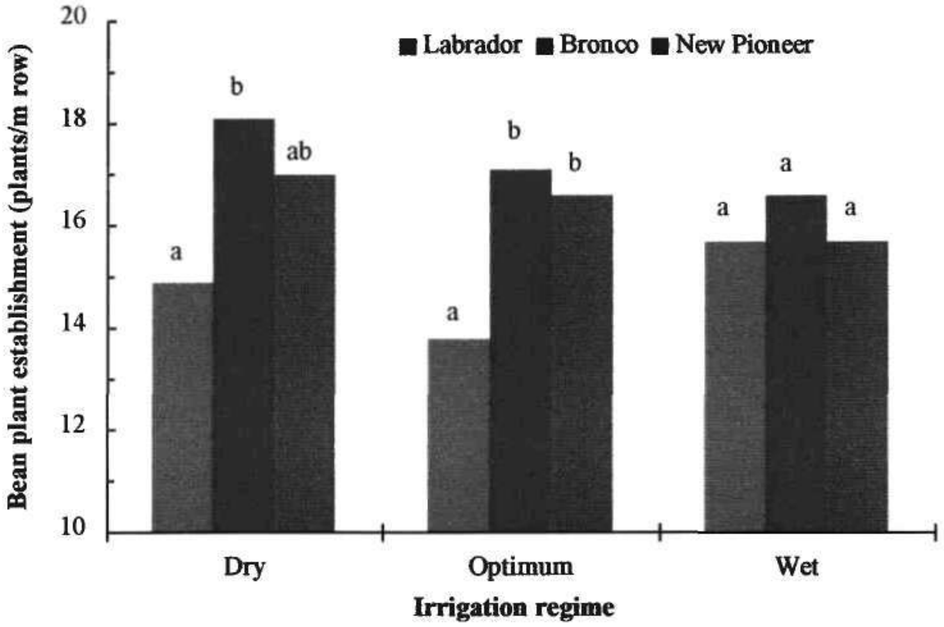


Figure 2. Cultivar and irrigation regime affect the establishment of green bean plants.

Interestingly, there were no significant effects of cultivar nor nitrogen nutrition on the biomass at flowering of the green bean plants (Fig. 3). In the 'dry' block, dry weight was 1.52 t/ha, in the 'optimum' blocks 1.91 t/ha, and in the 'wet' block 2.56 t/ha (averaged across cultivars and N treatments). There was a consistent and substantial bean plant biomass response to increased irrigation.

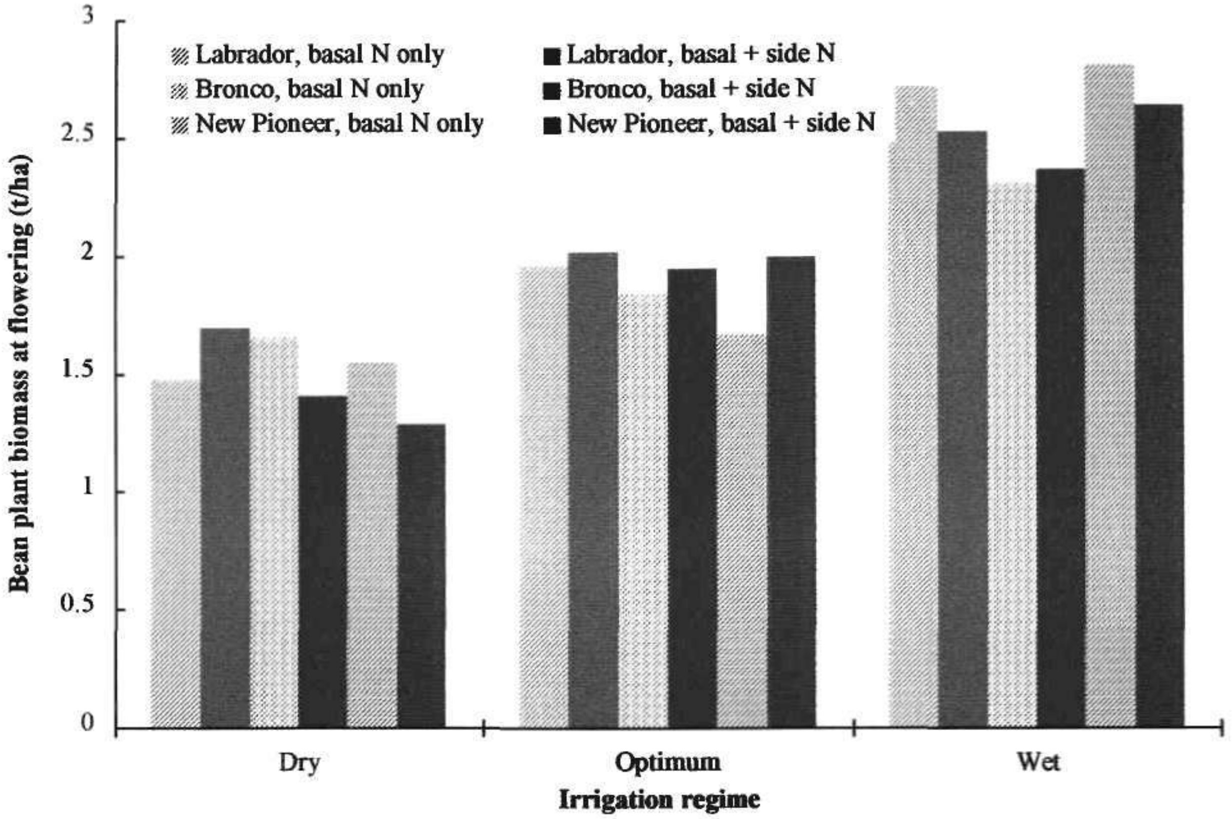


Figure 3. Bean plant biomass at flowering increased with quantity of irrigation, but was unaffected by cultivar selection or nitrogen nutrition.

There were no significant treatment effects on the amounts of trash in the samples; all yield data refers to marketable pods. Under both 'dry' and 'optimum' irrigation, marketable pod yields from *Labrador* were very poor; less than 0.7 t/ha fresh weight (Fig. 4). In the most frequently irrigated block, *Labrador* yielded around 3 t/ha. With *Labrador*, there were no significant responses to additional N fertiliser under any irrigation regime.

In the 'dry' block, *Bronco* appeared to outyield *New Pioneer* under both N regimes, although differences were neither substantial nor significant. With both cultivars in the least irrigated treatment, there seemed to be a small but consistent decline in yield associated with increased N fertiliser (Fig. 4). Under 'optimum' irrigation, both *Bronco* and *New Pioneer* produced similar pod yields (around 3 t/ha). *Bronco* was slightly responsive to additional N; *New Pioneer* was not.

In the wettest block, both *Bronco* and *New Pioneer* responded to additional N fertiliser (Fig. 4). Where only basal N was applied, *New Pioneer* outyielded *Bronco* by 1 t/ha; where additional N was supplied the yield advantage to *New Pioneer* was not significant, at 0.5 t/ha.

Average bean pod sizes in both *Bronco* (5.2 g) and *New Pioneer* (7.4 g) were unaffected by irrigation regime or N nutrition (Fig. 5). Yield differences within these cultivars, due to either irrigation or N nutrition, were associated with differences in total pod numbers (Fig. 6). *Labrador* yields were lower than *Bronco* because of fewer pods, although under the dry, high N treatment, *Labrador* pods were also significantly smaller. *Labrador* pods weighed 5.5 g where only basal N was applied, independent of irrigation regime. Where additional N was broadcast, pod weights fell from 6.0 g in the 'wet' block to 3.6 g in the driest treatment.

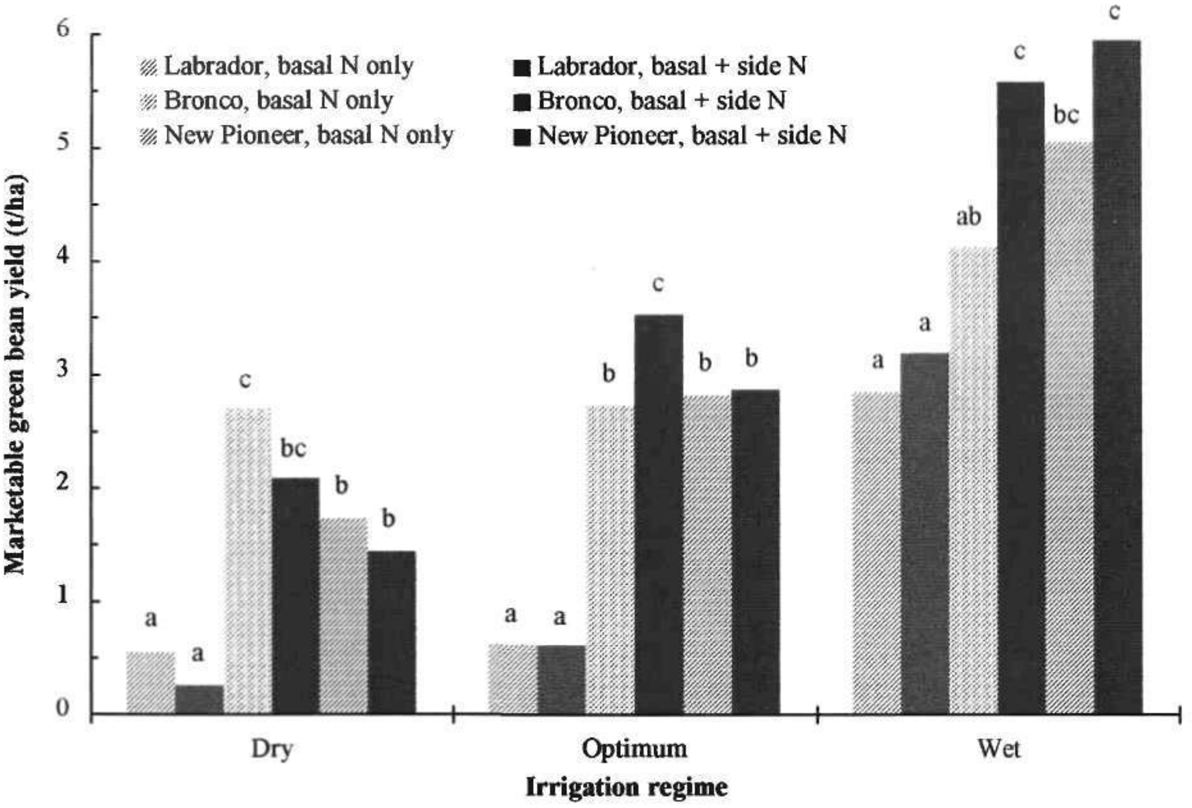


Figure 4. Marketable green bean pod yields are affected by cultivar selection and nitrogen nutrition under 3 irrigation regimes.

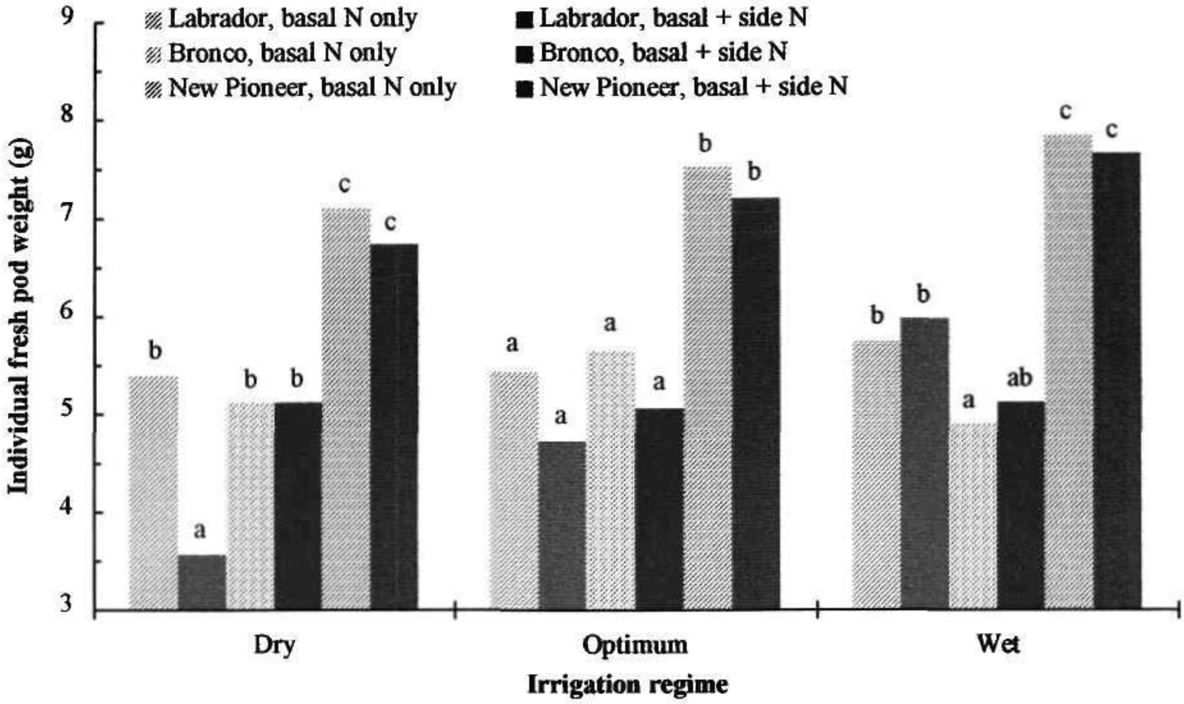


Figure 5. Green bean pod weights are affected by cultivar selection and nitrogen nutrition under 3 irrigation regimes.

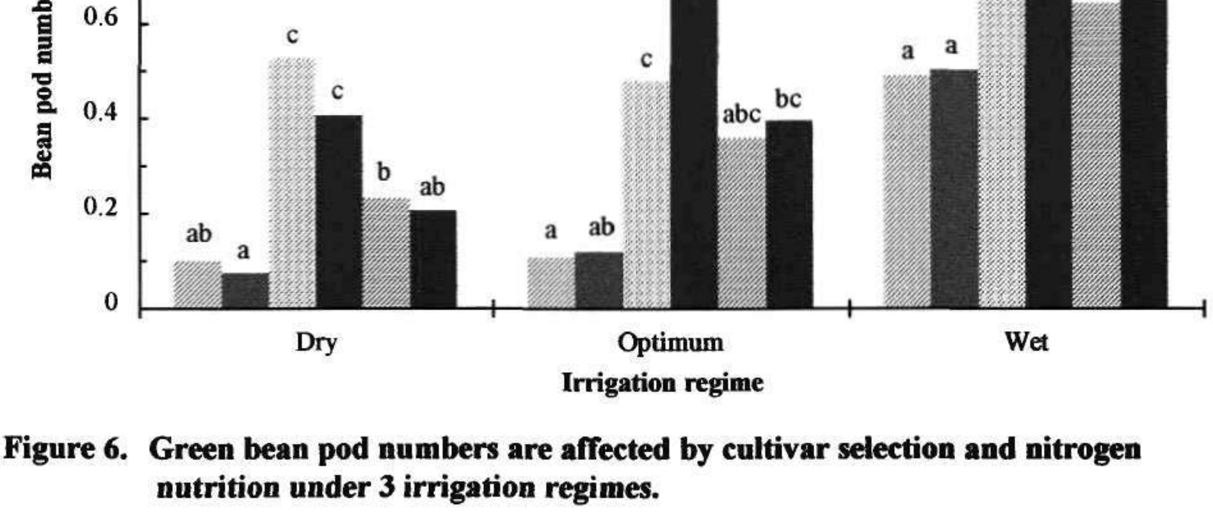


Figure 6. Green bean pod numbers are affected by cultivar selection and nitrogen nutrition under 3 irrigation regimes.

Marketable pod yields were highly linearly dependent on total water applied (Fig. 7). With the *Labrador* cultivar, this relationship was independent of N nutrition. Note this was from a very low yield base. With both *Bronco* and *New Pioneer*, responses to irrigation were greater under high N nutrition, compared to basal N regimes (Fig. 7).

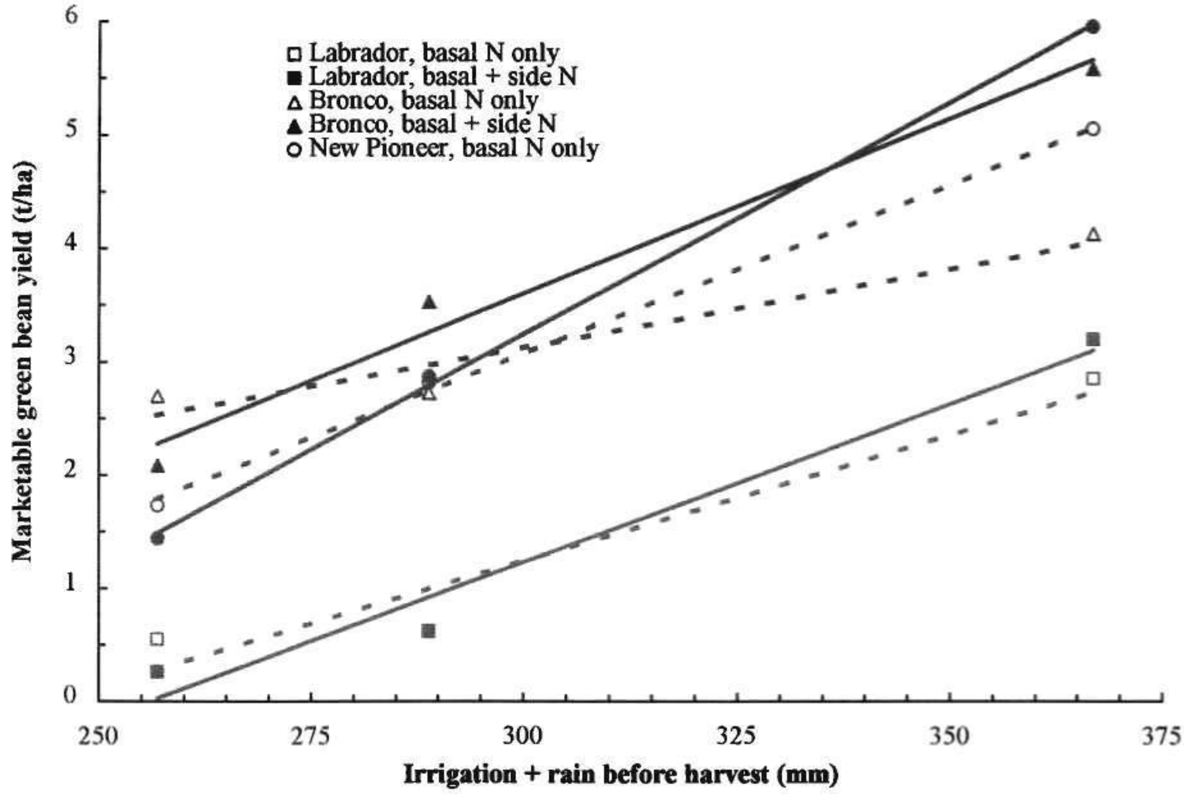


Figure 7. Green bean pod yields are linearly related to total water application prior to harvest, with responses affected by N nutrition in cultivars *Labrador*, *Bronco* and *New Pioneer*.

Discussion

Poor water quality severely affected growth and yields of beans in this experiment. In addition, during flowering in late November - early December, there were several days of heatwave conditions, with maximum temperatures above 35°C. The combination of poor quality water and high temperatures were disastrous for bush growth and particularly pod-set.

Because of salinity and chloride concentrations in the irrigation water, I should probably have reduced the critical tensiometer values for triggering irrigation. In this experiment, the 'wet' irrigation regime was more appropriate, particularly during the vegetative stages of growth. This regime allowed more leaching of salts from around the seedling roots, with less osmotic influence on nutrient and water uptake.

Unusually high evaporative demand during the growing period, averaging 6.8 mm pan evaporation per day, meant the irrigation requirement was much higher than forecast from previous experimental outcomess. Normally we would look to apply 20 mm/week for the first 7 weeks after sowing, increasing to 25 mm/week until harvest. For the first 5 weeks after sowing we applied (including rainfall) an average of 25 mm/week to the 'optimum' blocks and 38 mm to the 'wet' block. To supply 0.8 of pan evaporation (a reasonable 'rule-of-thumb' for early growth stages of green beans), we needed to apply an average of 37 mm/week.

Labrador beans were particularly badly affected by the hot conditions, with almost total flower and pod abortion. Note that this cultivar had similar biomass to the others at flowering (Fig. 3). This suggests a disadvantage in photosynthetic capacity for pod-set and pod-fill was not the reason for lower yields, compared to *Bronco* or *New Pioneer*. These lack of cultivar differences in biomass at flowering indicate the slightly poorer establishment of *Labrador* (Fig. 2) was also not a significant contributor to its lower yields.

The tensiometer data (Fig. 1) suggests that the water stress period between 25-35 DAS in the 'optimum' irrigation blocks was the main determinant of their poorer biomass production and pod yields, compared to the most frequently irrigated beans. The increased vegetative growth in the 'wet' blocks may also have enabled the development of superior root systems, increasing access to nutrients and water availability. This may have been very important during the high evaporative demand period around flowering. The results suggest tensiometer values for triggering irrigation may need to be lowered to around 30-40 kPa under hot, dry conditions, or where poor quality irrigation water is used.

Not only did the amount of pre-flowering irrigation affect vegetative biomass of bean plants (Fig. 3), it also affected numbers of pods set for each kg of that biomass. For example, in the 'optimum' blocks, *Labrador* set an average of 58 pods for each kg dry weight of bean plant at flowering, while *Bronco* set 347 pods/kg biomass. In the 'wet' block, these cultivars set 190 and 415 pods/kg flowering biomass respectively. It seems that in all cultivars, increased irrigation prior to flowering increased pod-set. This may have been due to either increased total floral production, or reduced flower and/or pod abortion. I hypothesise that larger bushes (and by inference, more extensive root systems) allowed the plants to better cope with the hot weather at flowering.

The deep tensiometer data (Fig. 1) suggests that leaching of nutrients should not have been a significant problem in this experiment. At 50 DAS, there were no biomass advantages from the additional N in the high N treatments (Fig. 3). With the *Labrador* cultivar, there was no yield response from additional N. There was a response in the other 2 cultivars, with the greatest benefit from additional N in *Bronco* . N responses were due to more pods (Fig. 6). These results indicate N demands by the bean plants (during flowering, pod-set and pod-fill) increased in the wetter irrigation regimes. Areas where urea was side-dressed were better able to service those demands.

Although overall yields were low, nevertheless, the importance of getting all inputs correct was clearly demonstrated. For example, if we were looking to produce a beanette for processing, then by getting everything right in this experiment (frequent irrigation, split N applications, *Bronco* cultivar), we would have produced 5.6 t/ha of marketable pods. Getting just one thing wrong would have substantially reduced our yield; wrong cultivar - 43% reduction, insufficient irrigation - 63% reduction, insufficient nitrogen - 26% decline.

This experiment also reinforced the idea that tensiometers should only be used as a guide for irrigation scheduling, not absolute indicators. I should have been more conscious of the need for a substantial irrigation on the 'optimum' blocks during the peak evaporative demand period around 30 DAS.

The experiment also emphasised in my mind the inherent dangers of stressing beans prior to flowering in order to suppress bush development. I believe this policy could inhibit root system development, and hence the capacity of the plant to cope with extreme weather during the flowering and pod-set period.

In examining green bean production practices in future experiments, we will endeavour to use sap testing to take a closer look at N balances, as well as make more intensive measurements of biomass, flower production and pod-set. We may have to use drip systems for irrigation, given the current water status at Gatton Research Station.

Appendix 3. Experiment CROP3 March-June 1996

Irrigation scheduling in green beans, beetroot and sweet corn

by Craig Henderson
QDPI Gatton Research Station

Summary

An experiment demonstrating the benefits of irrigation scheduling in 3 vegetable crops was conducted at Gatton Research Station during March-June 1996. Green beans (cv. Labrador), beetroot (cv. New Globe) and sweet corn (cv. Pacific H5) were grown using standard agronomy, with 2 irrigation scheduling strategies replicated twice. Plots were 4.5 m wide and 30 m long. All treatments were irrigated by drip tape; the ***regular*** *strategy irrigated with specific amounts on a semi-regular basis, while the* ***scheduled*** *strategy was watered once shallow tensiometer readings reached a set value. Tensiometer, irrigation and rainfall values were recorded, as were crop yields and produce quality.*

Due to 460 mm of rain falling over a fortnight in early May, there was little expression of differences between the 2 irrigation scheduling strategies. In all 3 test vegetables there was only 10-15 mm difference between the ***scheduled*** *and* ***regular*** *treatments in total quantities of irrigation applied. Although the patterns for the shallow tensiometers in the* ***scheduled*** *treatments were more even than the respective* ***regular*** *counterparts, in neither strategy were there any major periods of water stress. Under both strategies there was only minor deep drainage associated with excess irrigation.*

The inclement weather also adversely affected the overall performance of the green bean and sweet corn crops. Yields of these 2 vegetables were much lower than we would normally have expected, 3.6 t/ha and 7.5 t/ha respectively. Only the beetroot managed to overcome the 3 weeks of waterlogging and produce moderate-good yields (42 t/ha).

In previous experiments we showed that optimum yields and irrigation efficiencies were obtainable using shallow tensiometer values of 40-50 kPa as the point at which to start irrigating. Although the weather did not enable further testing of these hypotheses, the results from this experiment do not disprove that strategy. By using tensiometers, we were able to eliminate drainage due to excessive irrigation.

Relevance to industry

In many regions, including the Lockyer Valley, irrigation demands regularly exceed the reliable capacity of the water supply, resulting in scarcity or reliance on poorer quality water. In many vegetable enterprises, irrigation is a significant proportion of overall production costs, as well as a prime determinant of produce yields and quality. Until recently, the frequency and amount of irrigation were relatively ad-hoc, based on tradition and producer experience, combined with superficial observations of plant or soil conditions.

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

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

Objectives

This experiment was primarily to demonstrate the benefits of irrigation scheduling in green bean, beetroot and sweet corn crops.

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 experiment comprised 4 plots each of green beans, beetroot and sweet corn, with 2 replicates of either a ***regular*** or ***scheduled*** irrigation treatment. Each plot was 6 rows (4.5 m) wide and 30 m long.

All plots were watered with lines of "T-Tape Row Crop®" drip tape, with emitters every 0.2 m and an output of about 7.3 L/m/hr at an operating pressure of 70 kPa. This corresponds to an overall application rate of ≅9 mm/hr on a total area basis. An electronic timing system was used to commence and control duration of each irrigation. The drip tape was oriented along the sowing row, approximately 5 cm away from the plants.

The ***regular*** irrigation treatment was watered with a specific amount of water on a semi-regular basis, irrespective of climatic conditions (apart from heavy rain). In contrast, the ***scheduled*** irrigation treatment was watered depending on readings from tensiometers installed in the crops, using information from previous research.

The soil was well prepared, with a fine sowing seedbed and shallow beds. All crops (green bean cultivar *Labrador*, beetroot cultivar *New Globe* and sweet corn cultivar *Pacific H5)* were sown on 7 March 1996 and immediately received 31 mm of irrigation via hand-shift sprinklers. The crops were irrigated with these sprinklers over the next 10 days, after which the drip system was installed. The intra-row spacings of the beans and beetroot were both 0.04 m, whilst the sweet corn plants were sown 0.18 m apart.

A compound fertiliser containing 13.1%N, 2.2%P, 13.3%K and 18.8%S was broadcast at 350 kg/ha immediately after sowing. Urea was applied at 30 kgN/ha via drip irrigation on 4 April and 30 April 1996. Zinc hepta-sulphate and urea, both at 1 kg/ha, were sprayed over the crops on 8 April 1996, 32 days after sowing (DAS). Weeds were managed by mechanical cultivation and hand-weeding as required.

ROGOR® (dimethoate) at 0.75 L/ha was sprayed on 8 April to control aphids. THIADAN® (endosulfan) insecticide was applied at 2 L/ha to all plots on 8 April and 14 April, and to the sweet corn only on 13 May and 25 May 1996. LANNATE® (methomyl) was sprayed at 2.1 L/ha over all plots on 14 April, and on the sweet corn on 13 May, 25 May, 5 June and 13 June 1996. The sweet corn was also sprayed with 0.625 kg/ha DIPEL® (*B. thuringiensis*) and 1 L/ha SUMI-ALPHA® (esfenvalerate) on 22 May, and 0.35 L/ha of PHOSDRIN® (mevinphos) on 5 June and 13 June 1996.

Tensiometers were installed 15 cm and 60 cm below the soil surface in each plot on 21 March 1996. LOCTRONIC® tensiometers were used, which consist of a standard ceramic tip and plastic tube, with a rubber septum sealing the top of the tube. A small air gap is left in the top of the tubes after filling with water. To obtain readings, a hollow syringe is forced through the rubber septum at the top of the tensiometer, while an electronic vacuum gauge attached to the syringe records the vacuum in the small air gap below the septum. Tensiometer readings were recorded around 8-9 am daily. 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.

Green beans were hand-harvested from 6 m^{-2} of plot on 16 May 1996 (70 DAS). Sub-samples of harvested pods (about 0.7 kg) were weighed and the pods counted. Pods were rated for colour and maturity.

Beetroots were hand-harvested on 6 June 1996 (91 DAS) from 6 m^{-2} of plot, and graded into 4 categories; small, medium, large and over-size. The numbers and weights of beets in each category were recorded.

Sweet corn was hand-picked on 25 June 1996 (110 DAS) from 16 m of crop row. Cobs were counted, weighed and rated for insect damage, tip fill, bottom fill, degree of blanking and symmetry of kernel lines. Rating scales were from poor (1) to excellent (10).

We analysed all yield and quality parameters using standard analysis of variance.

Results and discussion

Irrigation

Between 7 and 9 weeks after sowing, over 460 mm of rain fell, causing substantial waterlogging and crop damage. Before and after this wet period, only 40 mm of rain was recorded, including just 2 events of more than 10 mm.

Because of the way the experiment was laid out, it was not possible to water the beans, beetroots and sweet corn separately. This meant that the crops were irrigated according to the species showing the greatest tensiometer readings. The green beans were probably watered more frequently than tensiometers in the ***scheduled*** treatment indicated was necessary.

Green beans

Although not scheduled, the pattern of irrigation in the ***regular*** green beans was effective, with no periods of obvious water stress (Fig. 1). Shallow tensiometer values peaked at less than 40 kPa before irrigations, with no extended periods of high values. There were no indications of deep drainage from excess irrigation (generally shown by sharp dips in deep tensiometer values). Interestingly, there was some water uptake from depth when the soil surface became very wet following consistent rain at 7 weeks after sowing. Once the heavy rain fell, the crop remained waterlogged until it was harvested (Fig. 1).

The pattern of irrigation in the ***scheduled*** treatment meant that shallow tensiometer values never rose above 20 kPa during the growing period (Fig. 2). The total soil profile remained moist at all times, with substantial waterlogging during the 2 weeks before the beans were harvested. There did not appear to be any deep drainage associated with excess irrigation.

During the period the 2 irrigation treatments were in operation (2-7 weeks after sowing), the ***regular*** strategy received 5 irrigations, averaging 12 mm every 7 days. The ***scheduled*** strategy was watered 7 times, averaging 13 mm every 5 days. The total amount of irrigation applied to the ***regular*** beans was 163 mm, compared to 173 mm for the ***scheduled*** beans.

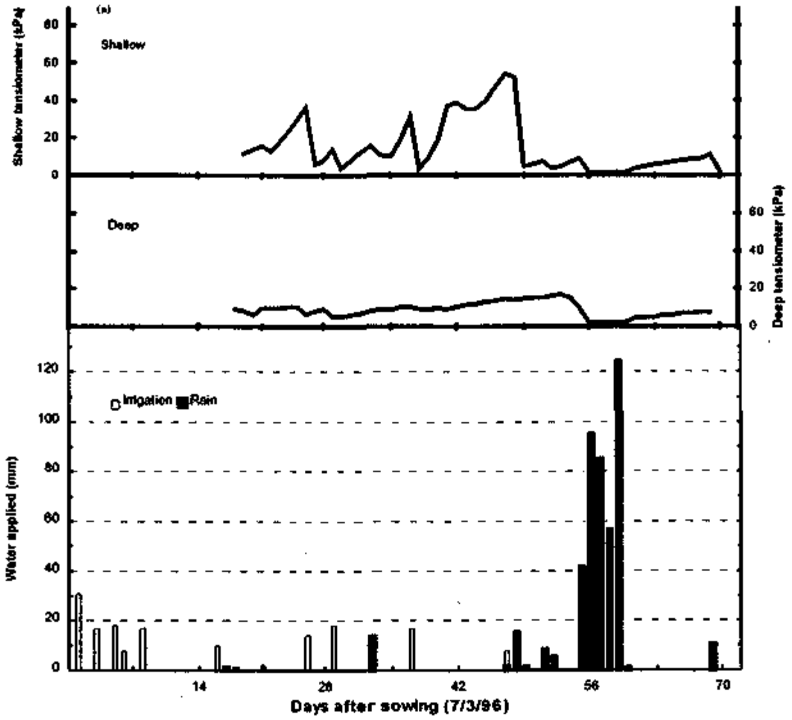


Figure 1. **Fluctuation in tensiometer values for a drip-irrigated green bean crop, watered on a regular basis.**

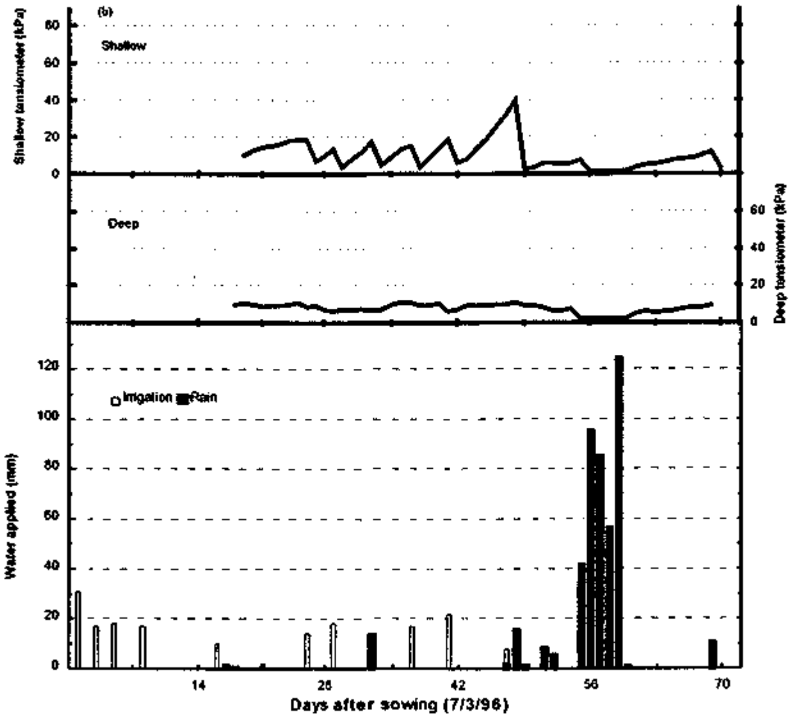


Figure 2. **Fluctuation in tensiometer values for a drip-irrigated green bean crop, watered according to shallow tensiometer values.**

Beetroot

Shallow tensiometers in beetroot watered on a ***regular*** basreached 50 kPa between irrigations in the first 7 weeks after sowing (Fig. 3). Deepnsiometer values remained around 30 kPa during this period, with no evidence of deeprainage. As with the green beans, this irrigation was effective, with no signs of wateress. The crop was waterlogged for at least 2 weeks after the heavy rain in early May. Thewas probably substantial deep drainage following the 48 mm irrigation just before the crwas harvested.

In the ***scheduled*** treatment, shallow tensiometer readings o reached 50 kPa between irrigations during the first 7 weeks after sowing (Fig. 4). ere was no excessive irrigation, although there may have been a little deep drainage from 23 mm of water applied 79 DAS. As with the ***regular*** beetroot, this crop was certaly waterlogged for an extended period after the heavy rain.

The early irrigation program was the same as for the greenans under both strategies. After the May rain, the ***regular*** treatment only received one irrigion of 48 mm, whilst the ***scheduled*** strategy was watered twice, averaging 18 mm ane. Total irrigations under the 2 strategies were nearly identical (211 mm and 216 mm reectively).

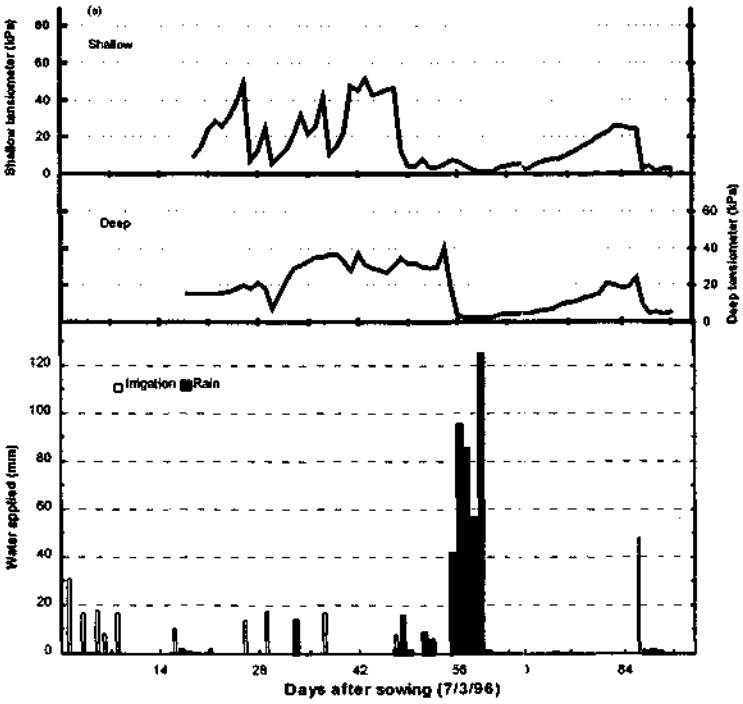


Figure 3. Fluctuation in tensiometer values for a driprigated beetroot crop, watered on a regular basis.

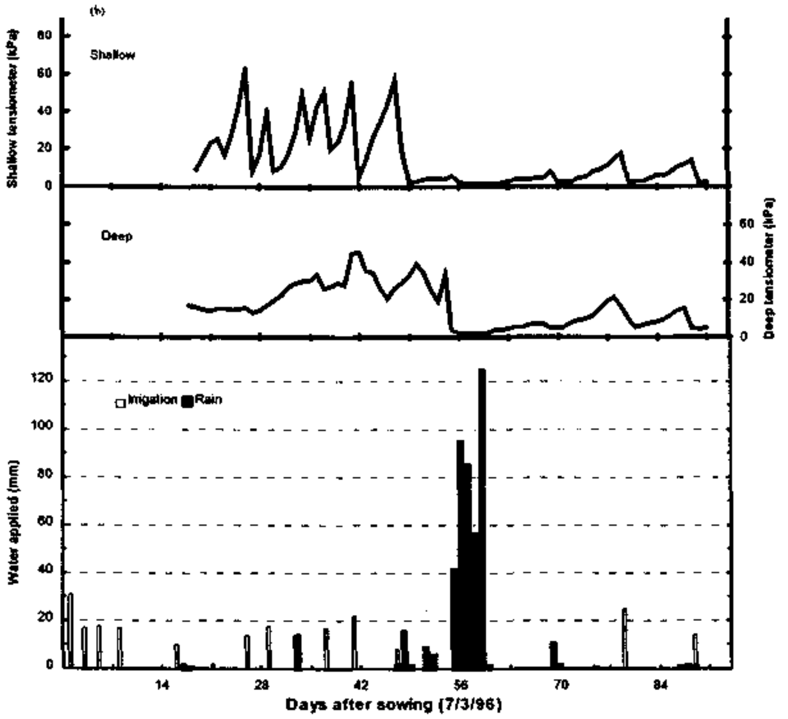


Figure 4. Fluctuation in tensiometer values for a drip-irrigated beetroot crop, watered according to shallow tensiometer values.

Sweet corn

Prior to the heavy May rain, shallow tensiometer values in the ***regular*** sweet corn did not peak at greater than 25 kPa. Although this crop was waterlogged during that rain, it appeared to recover more quickly than the beans or beetroot, with water uptake one week after the rain stopped (Fig. 5). The shallow tensiometer values reached 50 kPa before the 48 mm irrigation 85 DAS, with lesser peaks before the cobs were harvested. During the growing period there was no evidence of excessive irrigation, although there was probably a little deep drainage following the 48 mm irrigation. There may have been a few days of minor water stress just before that irrigation.

The sweet corn in the ***scheduled*** plots had shallow tensiometer readings that reached 40 kPa between irrigations before the heavy rain. In the 6 weeks before harvesting, the shallow tensiometers peaked at 40-50 kPa between irrigations, however there were no extended periods of these moderate values (Fig. 6). The deep tensiometer readings stayed very steady at around 15 kPa, apart from the saturated period in early May. The tensiometer patterns in these plots were close to an ideal, with no extended periods of water stress, nor examples of excessive irrigation.

The irrigation patterns for the sweet corn were the same as those for the beans and beetroot before the May rain. In the final 5 weeks before the cobs were harvested, the ***regular*** strategy was only watered twice, averaging 32 mm every 18 days. The ***scheduled*** strategy was irrigated on 3 occasions, averaging 18 mm every 11 days. The long intervals between irrigations reflect low evaporative demand in early June. Irrigation applications for the whole growing period were 226 mm for the ***regular*** plots and 239 mm for the ***scheduled*** plots.

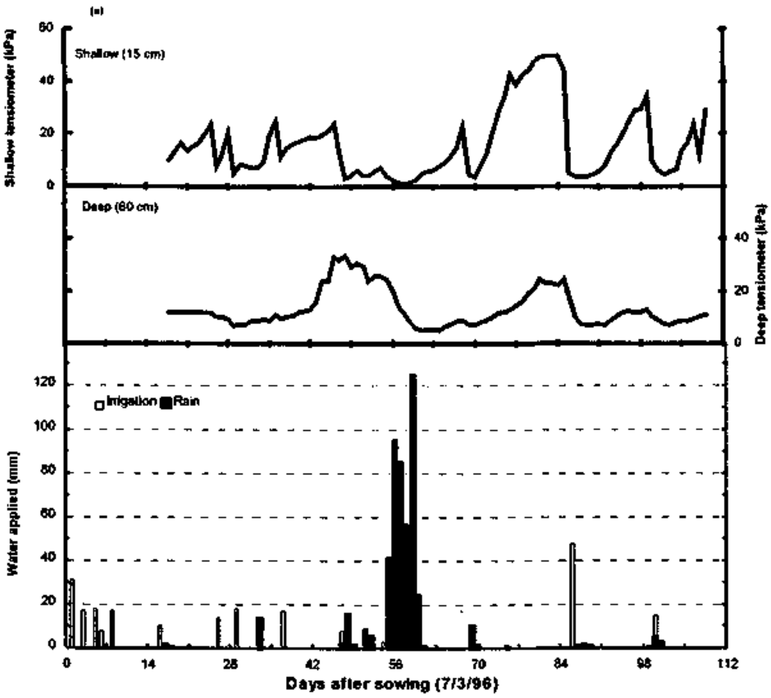


Figure 5. Fluctuation in tensiometer values for a drip-irrigated sweet corn crop, watered on a regular basis.

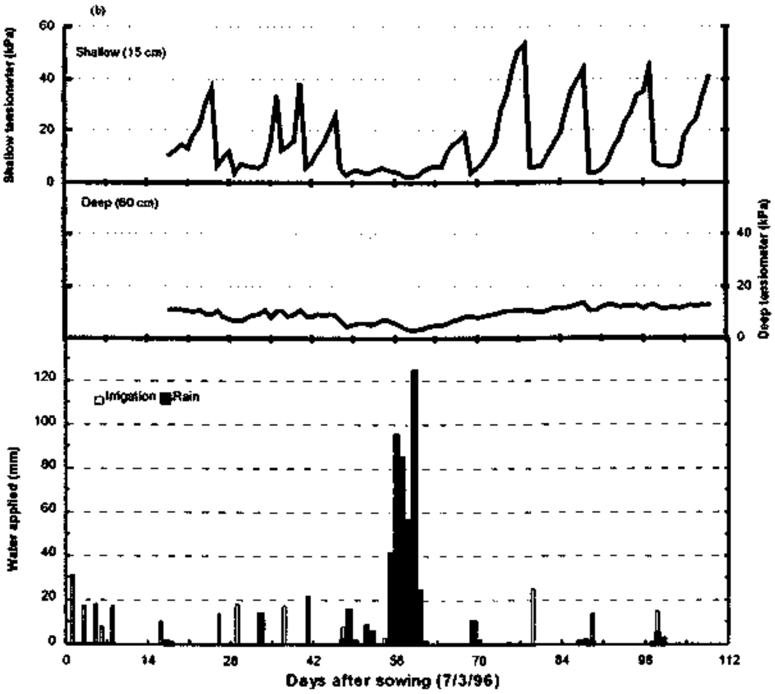


Figure 6. Fluctuation in tensiometer values for a drip-irrigated sweet corn crop, watered according to shallow tensiometer values.

Crop yields and quality

Green bean yields in this experiment were very low, probably because of the heavy rain and waterlogged conditions from flowering until harvest. There were no significant effects of irrigation scheduling strategy on bean yields nor pod quality (Table 1). There were many fewer pods than we normally produce, and average pod size was about 30% smaller than usually found in the *Labrador* cultivar.

Table 1. Bean yields and pod quality were unaffected by irrigation strategy.

	Regular strategy	***Scheduled*** strategy
Bean yield (t/ha)	3.86	3.46
Bean number ('000/ha)	968	927
Individual pod size (g)	4.0	3.7
Pod colour	moderate green	moderate green
Pod maturity	slightly over-mature	slightly over-mature

Despite adverse weather, beetroot yields were moderate-good in this experiment, averaging 42 t/ha. There were no significant effects of irrigation management on total beet yields, although there was a trend for slightly smaller beets in the ***scheduled*** treatments (Fig. 7).

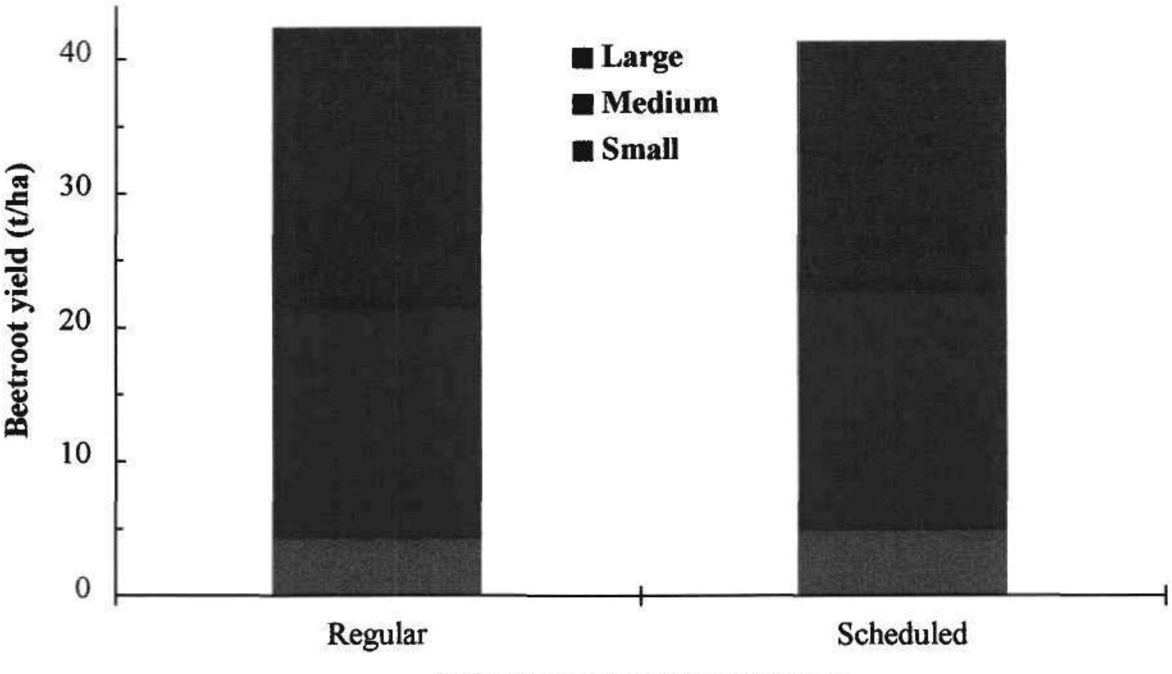


Figure 7. Beetroot yields were unaffected by irrigation strategy.

Sweet corn yields were very poor in this experiment, mainly due to the late planting date and terrible weather in early May. At an average of 7.5 t/ha, unhusked yields were around 35% of what we would normally expect from *H5* sweet corn. The cobs matured under very cold conditions; were slow to develop and lacked size. As a consequence, very few were actually harvested as marketable cobs. As with the other 2 crops, there were no significant effects of irrigation scheduling strategy on cob yields nor quality (Table 2). Insect damage was minimal (probably due in part to the cold weather), and cob appearance was moderate-good, although tip fill was only moderate.

Table 2. Sweet corn yields and cob quality were unaffected by irrigation strategy.

	Regular strategy	***Scheduled*** strategy
Sweet corn yield (t/ha)	7.15	7.74
Cob number ('000/ha)	23.4	25.2
Individual unhusked cob size (g)	305	307
Insect damage (1-3)	0.32	0.26
Tip fill (1-10)	6.8	7.0
Bottom fill (1-10)	7.3	7.4
Blanking (1-10)	7.4	7.2
Kernel symmetry (1-10)	7.1	7.2

Conclusions

The heavy rain in early May prevented any substantial expression of differences between the irrigation scheduling strategies. In all 3 test vegetables there was only 10-15 mm difference in total quantities of irrigation applied. Although the patterns for the shallow tensiometers in the ***scheduled*** treatments were more even than the respective ***regular*** counterparts, in neither strategy were there any major periods of water stress. Under both strategies there was only minor deep drainage associated with excess irrigation.

The inclement weather also adversely affected the overall performance of the green bean and sweet corn crops. Yields of these 2 vegetables were much lower than we would normally have expected. Only the beetroot managed to overcome the 3 weeks of waterlogging and produce moderate-good yields.

In previous experiments we showed that optimum yields and irrigation efficiencies were obtainable using shallow tensiometer values of 40-50 kPa as the point at which to start irrigating. Although the weather did not enable further testing of these hypotheses, the results from this experiment do not disprove that strategy. By using tensiometers, we were able to eliminate drainage due to excessive irrigation.

Appendix 4. Experiment BEET1 April-September 1994

Weed management, irrigation scheduling and fungicidal seed treatment of beetroot sown at 2 planting times.

by Craig Henderson and Mick Webber
QDPI Gatton Research Station

Summary

An experiment investigating the impacts of weed management, irrigation scheduling and fungicidal seed treatments was conducted at Gatton Research Station during April-September 1994. The experiment comprised 2 sowing times; irrigating according to tensiometer values or on a regular schedule; comparing seed treated with APRON® (metalaxyl) with controls; and spraying plots with various combinations of RAMROD® (propachlor), PYRAMIN® (chloridazon), BETANAL® (phenmedipham) and TRAMAT® (ethofumesate) herbicides. The emergence, growth and yields of both weeds and beetroots were measured, as were the amounts of irrigation and pesticides used.

Due to dry climatic conditions, there were no disease control nor beetroot yield benefits from treating seed with APRON® fungicide. Compared to regular irrigations, scheduling irrigation using tensiometers improved beetroot yields in both plantings. In Planting 1, the scheduled block required less irrigation, whilst in Planting 2 the scheduled block had slightly more irrigation. In both plantings, irrigation scheduling improved crop profitability.

The standard commercial practice involving one application of 5 L/ha of BETANAL® between 3-6 weeks after sowing slightly reduced beetroot yields in Planting 1, but had no deleterious effects in Planting 2. Neither PYRAMIN® nor RAMROD® adversely affected beetroot production, slightly improving weed control in Planting 2. Of all the herbicide treatments, low-rate post-emergence spraying of 2.5-3.5 L/ha of BETANAL® caused least damage to the beetroot. The 2.5 L/ha rate did not give commercially acceptable weed control, whilst 3.5 L/ha was sufficiently efficacious. Addition of TRAMAT® to these early post-emergence sprays caused beetroot damage in Planting 1, but not Planting 2. The low-rate BETANAL® treatments were the most profitable herbicide practices. Compared to standard commercial practice, they improved returns by $260/ha (averaging results over both plantings).

Potential benefits from irrigation scheduling and low-rate herbicide strategies will be further investigated in future experiments.

Relevance to industry

The cost-price squeeze has adversely affected profitability of fresh and processing beetroot production. Weed management in beetroot is costly; current herbicide strategies are expensive, do not provide reliable control and can occasionally cause significant crop damage. Beetroot producers are concerned about long-term residues from some herbicides.

In many regions, including the Lockyer Valley (where 90% of Australia's beetroots are produced), irrigation demands regularly exceed the reliable capacity of the water supply. This results in water scarcity, or reliance on poorer quality resources. Irrigation can be a substantial component of production costs. Matching irrigation to crop requirements maximises production by minimising plant water stress, nutrient deficiencies and some diseases. More efficient water use helps minimise salinity, as well as potential leaching of pesticides and nutrients into groundwater.

Beetroot establishment, yields and quality can be adversely affected by seedling diseases. Treatment of seed with protective fungicides is one method of reducing this risk.

Objectives

This experiment investigated and demonstrated different weed management, irrigation scheduling and seed treatment strategies. Effects of treatments on weeds, irrigation requirements, water movement, beetroot establishment, growth, yield and quality were measured. Information gained was used to develop strategies for further evaluation and extension to commercial producers.

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 split-split-plot, with irrigation, weed management and seed dressing treatments as main, sub and sub-sub plots respectively. Two replicates of the main plots were arranged in blocks. The initial experiment was sown on 21 April 1994, while a second experiment was sown on 12 May 1994.

The soil was prepared as per standard practice for a beetroot crop. Beetroots (cv. *New Globe*) were sown in rows 0.75 m apart. Intra-row spacings were 0.05 m, giving a total sown population of 267,000 plants/ha. Because of inherent soil fertility, no fertilisers were applied to the crop. Apart from the specific treatments detailed below, no pesticides were applied to the beetroot.

Irrigation treatments

The beetroots were generally irrigated with solid-set spray-lines, although initial irrigations were by hand-shift lines of sprinklers.

1. The first irrigation treatment was irrigated on a regular basis; 20 mm every week for the first 3 weeks, changing to 50 mm every fortnight until harvesting. This was designated as the ***regular*** treatment.

2. The second treatment was irrigated when readings from shallow tensiometers reached 50 kPa. This was designated as the ***scheduled*** treatment.

Tensiometers were installed 15 cm and 45 cm below ground level in hand-weeded plots in each block. LOCTRONIC® tensiometers were used, which consist of a standard ceramic tip and tube, but no vacuum gauge. To obtain readings, a hollow syringe is forced through the rubber septum at the top of the tensiometer, and an electronic vacuum gauge senses the vacuum in the small air gap below the septum. Tensiometer readings were recorded around 8-9 am daily.

Weed management treatments

The following herbicides were used in this experiment.

1. RAMROD® (propachlor 480 g/L SC) - registered for pre-emergence use in beetroot at a maximum rate of 3.8 L/ha. This is specifically for control of yellow weed (*Galinsoga parviflora)*. At higher application rates, it will also control a range of grasses and broadleaf weeds. It would require use with other herbicides, as there are several important weeds tolerant of propachlor.

2. PYRAMIN® (chloridazon 650 g/kg WP) - registered for post-sowing, pre-emergence application on beetroot. This herbicide is active on broadleaf weeds, with most grasses tolerant. PYRAMIN® may have potential for a split application strategy, with a second spraying after beetroot emergence.

3. BETANAL® (phenmedipham 157 g/L EC) - registered for post-emergence spraying when beetroot has 2-4 true leaves and weeds are correspondingly small. It is known to cause crop damage where temperatures exceed 32°C. BETANAL® is mainly used for broadleaf weed control, and is not active against most grasses. It is frequently used in combination with TRAMAT®.

4. TRAMAT® (ethofumesate 200 g/L EC) - registered for pre and post-emergence use in beetroot, controlling both grass and broadleaf weeds. In recent times there has been concern that this herbicide has been causing crop damage at registered rates, as well as having adverse effects on following crops.

All herbicides were applied with a motorised knapsack sprayer. The 1.5 m wide hand-held boom had 110° flat-fan nozzles spaced 0.30 m apart. It was operated at 200 kPa and sprayed 250 L/ha. The weed management treatments in this experiment are detailed below.

1. **(P/BT)**. PYRAMIN® applied at 5.5 kg/ha one day after sowing (DAS), followed by a mixture of 5 L/ha BETANAL® and 5 L/ha TRAMAT® sprayed post-emergence, when the oldest weeds had 3-4 true leaves. In the case of Planting 1, this post-emergence spraying was on 16 May 1994, 25 days after sowing. The post-emergence application in Planting 2 occurred on 15 June 1994, 34 DAS.

2. **(R/BT)**. RAMROD® applied at 4 L/ha immediately after sowing, followed by a mixture of 5 L/ha BETANAL® and 5 L/ha TRAMAT® sprayed post-emergence, as per Treatment 1.

3. **(R/B)**. RAMROD® applied at 6 L/ha immediately after sowing, followed by 5 L/ha BETANAL® sprayed post-emergence, when the oldest weeds had 3-4 true leaves. The post emergence spraying was conducted at the same times as the BETANAL®/TRAMAT® mixtures were applied in Treatment 1.

4. **(BT)**. A mixture of 5 L/ha BETANAL® and 5 L/ha TRAMAT® sprayed post-emergence at the same times as BETANAL®/TRAMAT® mixtures were applied in Treatment 1.

5. **(BR)**. A mixture of 5 L/ha BETANAL® and 7 L/ha RAMROD® sprayed post-emergence at the same times as BETANAL®/TRAMAT® mixtures were applied in Treatment 1.

6. **(B3.5)**. An application of 3.5 L/ha BETANAL® sprayed post-emergence, when the oldest weeds had 1-2 true leaves. In Planting 1, this was sprayed on 3 May 1994 (12 DAS), when the beetroot had fully expanded cotyledons. In Planting 2, this treatment was sprayed on 3 June 1994 (22 DAS), and repeated to control a second weed flush on 23 June 1994 (42 DAS).

7. **(B2.5)**. An application of 2.5 L/ha BETANAL® sprayed post-emergence, when the oldest weeds had 1-2 true leaves. Spray timings were the same as for Treatment 6.

8. **(BHTL)**. A mixture of 3.5 L/ha BETANAL® and 1.5 L/ha TRAMAT® sprayed post-emergence, when the oldest weeds had 1-2 true leaves. Spray timings were the same as for Treatment 6.

9. **(BLTH)**. A mixture of 2.5 L/ha BETANAL® and 2 L/ha TRAMAT® sprayed post-emergence, when the oldest weeds had 1-2 true leaves. Spray timings were the same as for Treatment 6.

10. **(HW)**. This treatment was hand weeded at fortnightly intervals once weeds had emerged.

Table 1. **Weather conditions at each spray application**

Date	DAS	Treatment	Temperature (°C)	Relative humidity (%)	Wind speed (km/hr)	Wind direction
22/4/94	1	Pre-em., Planting 1	18	75	3	NE
3/5/94	12	Post-em. 1, Planting 1	17	95	5	W
13/5/94	1	Pre-em., Planting 2	12	85	8	W
16/5/94	25	Post-em. 2, Planting 1	11	80	5	W
3/6/94	22	Post-em. 1, Planting 2	10	90	10	W
15/6/94	34	Post-em. 2, Planting 2	13	65	5	SW
23/6/94	42	Post-em. 3, Planting 2	23	85	8	ENE

Seed treatments

In the control seed treatment, beetroot seeds were purchased already coated with THIRAM® seed dressing. The fungicide APRON® (metalaxyl 350 kg) was applied to the second treatment at the rate of 2 g/kg beetroot seed prior to sowing. APRON® is mainly used for control of *Pythium* seedling diseases; it will not affect *Rhizoctonia* or *Fusarium* fungi.

Measurements

The growth of beetroot plants and weeds were monitored throughout the growing period. Emerged beetroot plants were counted in two randomly chosen metre lengths of row in each plot. Heights of 5 randomly selected beetroot plants from each plot were measured on 2 occasions in Planting 1 and once in Planting 2. A 1 m row of plants was removed from each plot when the beetroots had reached baby beet size. The number and fresh weights of these plants were recorded. A total 9 m of beetroot row was hand-harvested for yield from each plot. The beetroot were graded into small, medium and large beets, counted and weighed.

Weeds found in 2 randomly placed 0.2 m quadrats in each plot were counted during the growing period. Immediately before the beetroot were harvested, weeds from the central 9*0.75 m of each plot were harvested, sorted into separate species, counted and weighed.

The days on which each of the crop and weed assessments was made are shown in Table 2.

Table 2. Date and days after sowing (DAS) of crop and weed assessments.

Assessment	Planting 1 - 21/4/94		Planting 2 - 12/5/94	
	Date	DAS	Date	DAS
Beetroot emergence counts	8/6/94	48	18/7/94	67
Beetroot plant heights	15/6/94	55	26/7/94	75
	13/7/94	83		
Baby beet plant fresh weights	8/7/94	78	17/8/94	96
Beetroot harvest	27/7/94	97	5/9/94	115
Initial weed counts	16/6/94	56	15/7/94	64
Final weed harvests	21/7/94	91	26/8/94	105

Data analyses

All beetroot growth and yield variables were analysed using standard analysis of variance. Comparisons between irrigation treatments were not statistically analysed, because these treatments were unreplicated. Other results were pooled over irrigation blocks, as there were no evident interactions between irrigation and other imposed treatments.

Owing to the nature of their distributions, weed counts and weights were log-transformed prior to analysis. The transformed data were converted back to normal values prior to presentation in tables and figures.

Results and discussion

Seed treatments

In Planting 1, seed treatment with APRON® significantly increased the number of beetroot plants emerged per metre of crop row (Fig. 1). By the time the beetroot were baby beet size (78 DAS), the number of plants surviving had declined, however there were still more beetroots in plots sown with APRON®-treated seed. When the beetroot were finally harvested, there was no difference in the number of plants in the control and APRON® treatments. In Planting 2, seed treatment did not affect the number of beetroot plants at any time of assessment (Fig. 1).

Application of APRON® to the seed did not significantly affect beetroot height, biomass production nor yields in either planting (Table 3). Dry conditions throughout the growing period probably prevented any dramatic impact of seedling diseases on beetroot growth or yield. The mortality of plants between emergence and harvest, particularly in Planting 1 (Fig. 1), is difficult to explain. It may have been due to disease, plant competition, or insect predation. Whatever the reason, seed treatment with APRON® did not prevent this decline.

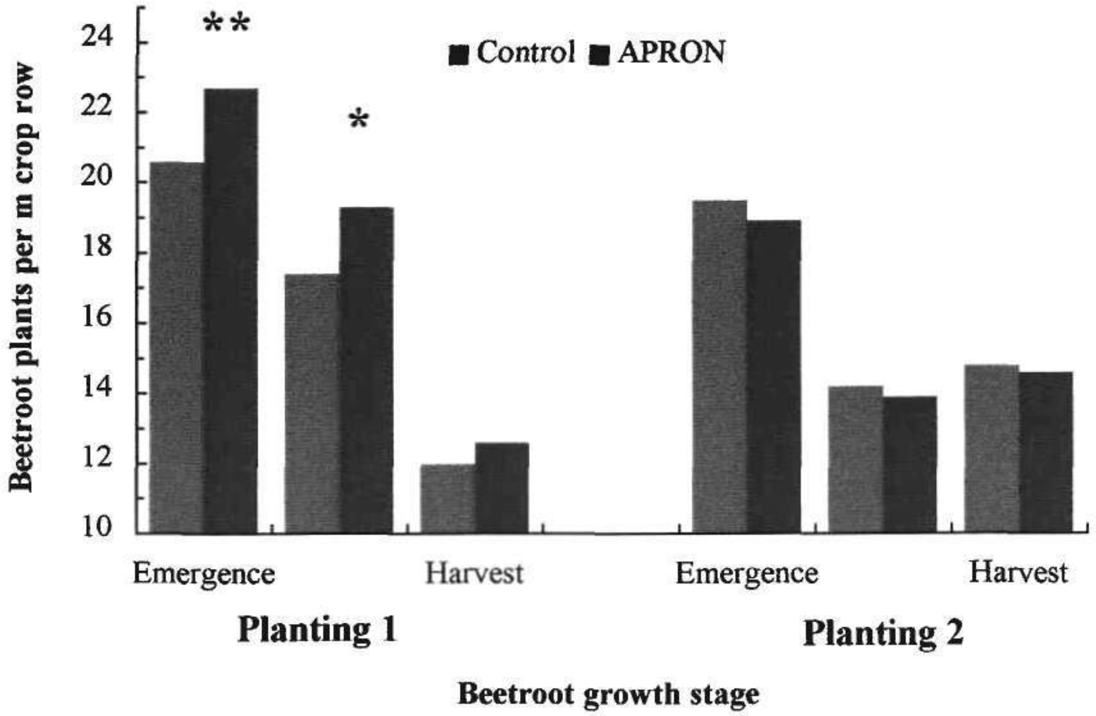


Figure 1. **APRON® seed treatment affects beetroot plant numbers at Planting 1 but not Planting 2.**

Table 3. **APRON® seed treatment has no effect on beetroot growth nor yield.**

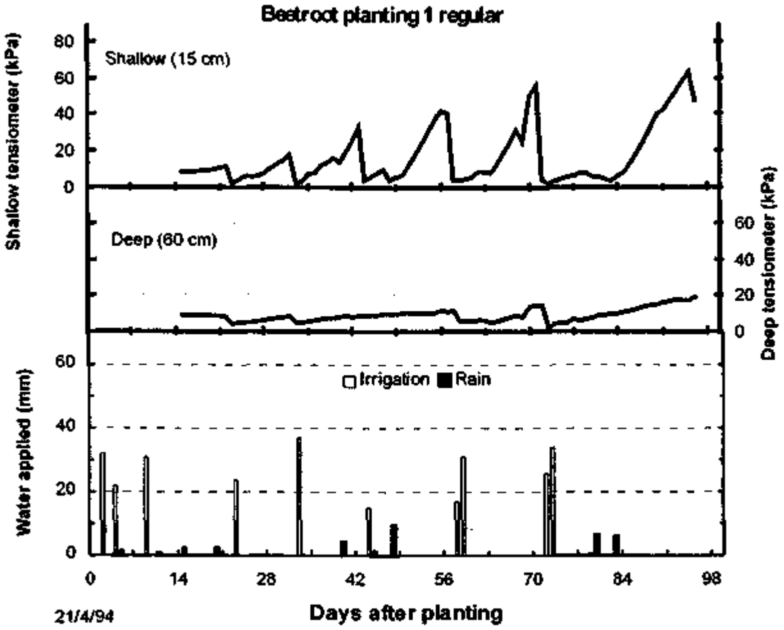
	Planting 1		Planting 2	
	Control	APRON®	Control	APRON®
Beetroot plant height (cm)	28.0	28.4	32.5	32.2
Beetroot plant biomass at baby beet stage (t/ha)	33.3	35.1	34.0	32.7
Total beetroot yield (t/ha)	18.4	17.9	25.1	24.3

Irrigation

There was minimal rainfall during the experiment; Planting 1 receiving 34 mm and Planting 2 29 mm during their respective growing periods. In both beetroot plantings there were only slight differences in quantities and frequencies of irrigation applied between ***regular*** and ***scheduled*** programs. The ***regular*** block in Planting 1 received an additional 34 mm of irrigation at about 73 DAS, compared to the ***scheduled*** block (Fig. 2). Total irrigations were 269 mm and 235 mm respectively. With Planting 2, irrigations in the 2 blocks were identical for the first 90 DAS (Fig. 3). Between then and final harvest, the ***regular*** block only received one large irrigation, whilst the *scheduled* block was irrigated on 2 occasions. The total amounts of irrigation received were 311 mm and 328 mm respectively.

Shallow tensiometer values in the Planting 1 ***regular*** block generally stayed below 40 kPa, except for immediately before harvesting (Fig. 2). There was an indication (by the dip in deep tensiometer readings) of some deep drainage following the major irrigation 73 DAS. There was also a suggestion of slightly waterlogged conditions at the same time, demonstrated by continuous low values for the shallow tensiometers. In contrast, tensiometers in the ***scheduled*** block showed no excessively dry nor waterlogged conditions during the growing period. Nor did deep tensiometer values suggest any deep drainage (Fig. 2).

In Planting 2, shallow tensiometers in both blocks showed no values greater than 45 kPa for the first 80 DAS (Fig. 3). For the week around 90 DAS, the ***regular*** block had shallow tensiometer values 50-60 kPa, whilst the ***scheduled*** block tensiometer values fell, due to the additional irrigation. Water stress in the ***regular*** block is indicated by the rise in deep tensiometer values during that period. In both blocks, there appeared to be slight drainage following the irrigation at 44 DAS, shown by the fall in deep tensiometer values (Fig. 3). The major irrigation at 83 DAS may have caused additional drainage in the ***scheduled*** block.



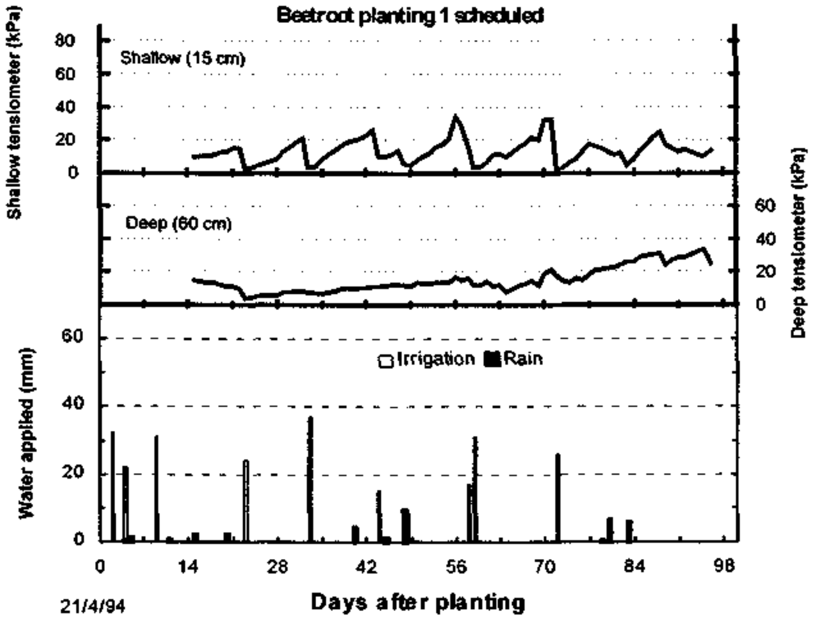
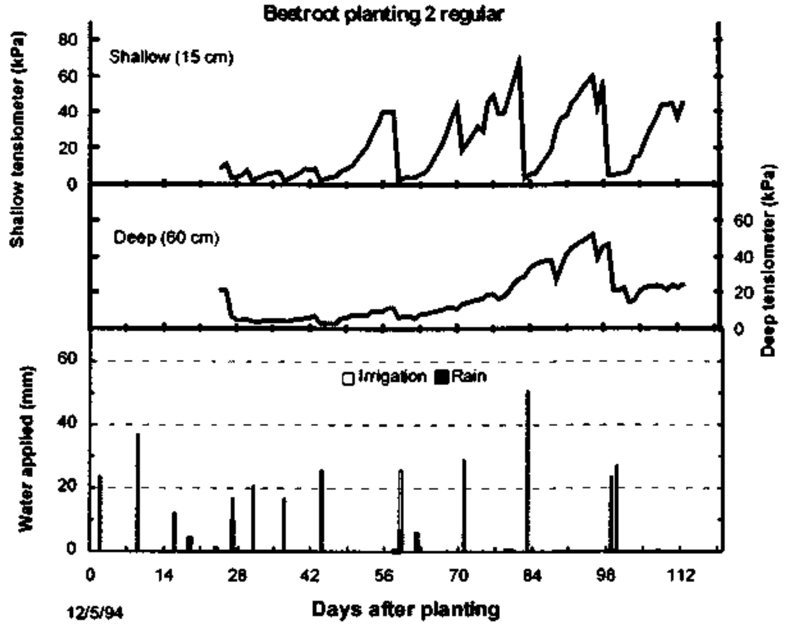


Figure 2. **Fluctuations in tensiometer values with rainfall and irrigation during the growing period of beetroot Planting 1.**



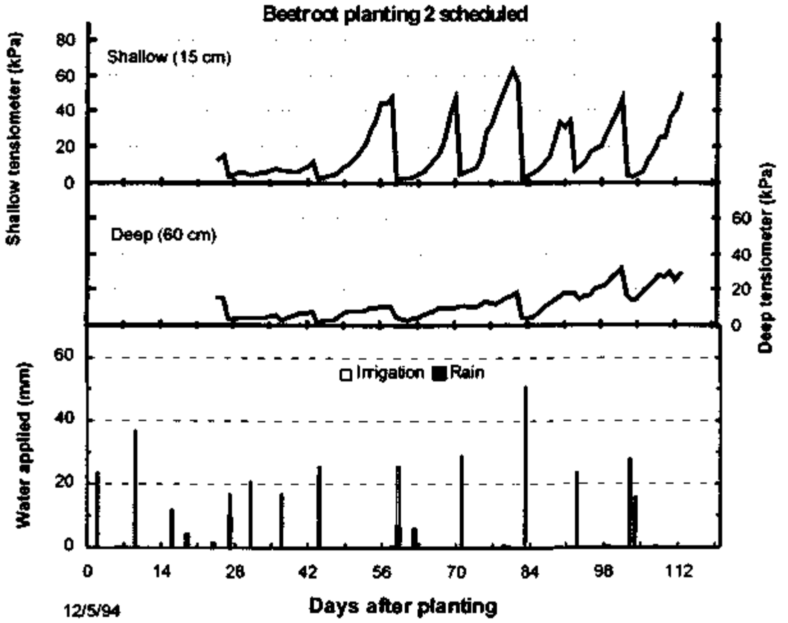


Figure 3. **Fluctuations in tensiometer values with rainfall and irrigation during the growing period of beetroot Planting 2.**

Due to the identical nature of ***regular*** and ***scheduled*** irrigation regimes (up until 10 weeks after sowing), there were no differences in beetroot growth during that growing period (Table 4).

Table 4. Irrigation strategy has no effect on beetroot growth at 2 planting times.

	Planting 1		Planting 2	
	Regular	Scheduled	Regular	Scheduled
Established plants/m row	20.4	23.0	19.8	18.6
Beetroot plant height (cm)	28.0	28.4	32.7	32.0
Beetroot plants/m row at baby beet stage	17.8	18.9	14.7	13.4
Beetroot plant biomass at baby beet stage (t/ha)	33.1	35.3	32.9	33.7

Interestingly, despite only minor changes in irrigation during the latter parts of the growing periods, in both plantings there were consistently higher yields in the ***scheduled*** compared to ***regular*** blocks (Fig. 4). Differences were due to more and heavier medium and large beetroots in the higher yielding blocks (Fig. 5, Table 5). The yield differences between irrigation treatments were not statistically tested, and thus any conclusions must be made with caution. Yields from the ***regular*** block in Planting 1 may have been suppressed by waterlogging between 73-84 DAS. Conversely, yields from the same treatment in the second planting may have slightly suppressed by dry conditions between 85-100 DAS.

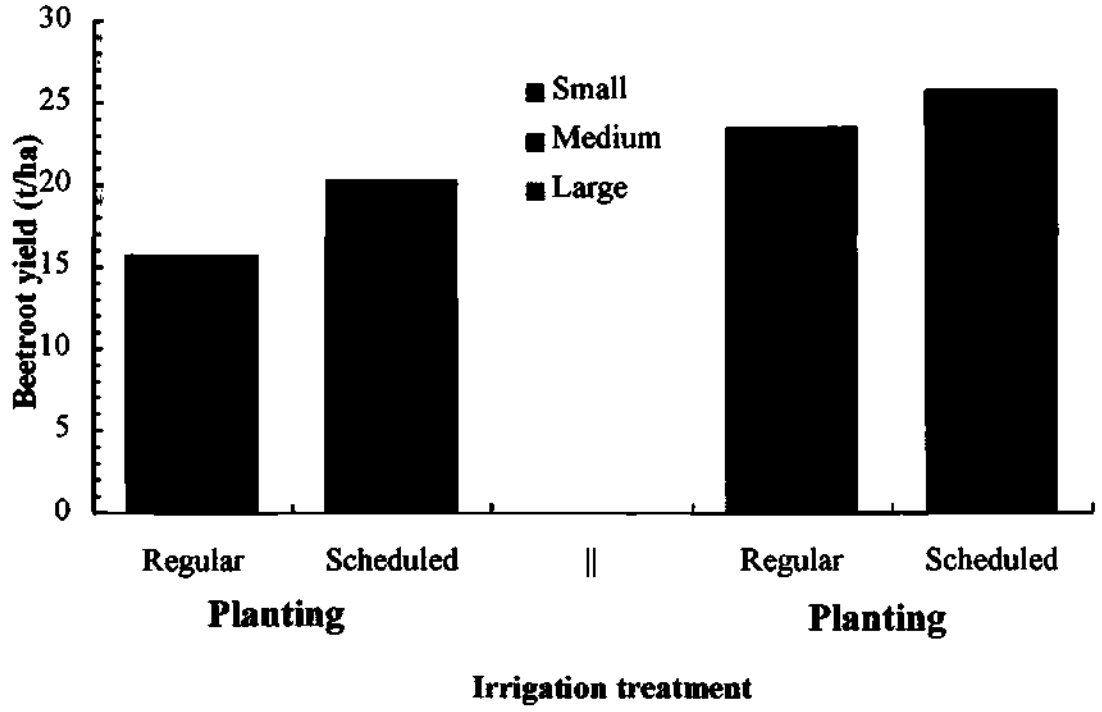


Figure 4. Irrigation scheduling increases total beetroot yields in 2 plantings.

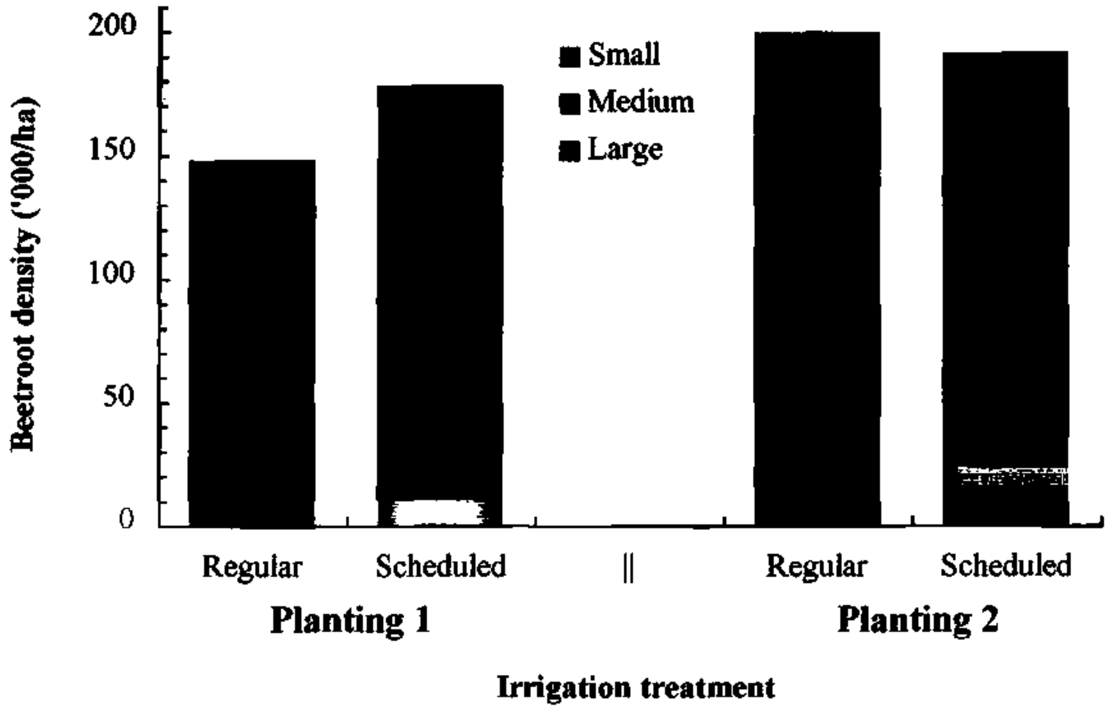


Figure 5. **Irrigation scheduling increases the numbers of large and medium sized beetroot in 2 plantings.**

Table 5. **Scheduling irrigation increases the mean size of individual beetroot within grade classes.**

	Planting 1		Planting 2	
	Regular	Scheduled	Regular	Scheduled
Mean weight of small beetroot (g)	64.2	62.6	62.0	63.0
Mean weight of medium beetroot (g)	125.1	138.7	137.8	147.4
Mean weight of large beetroot (g)	223.8	250.8	271.9	286.2

Weed management strategies

Beetroot growth and yield

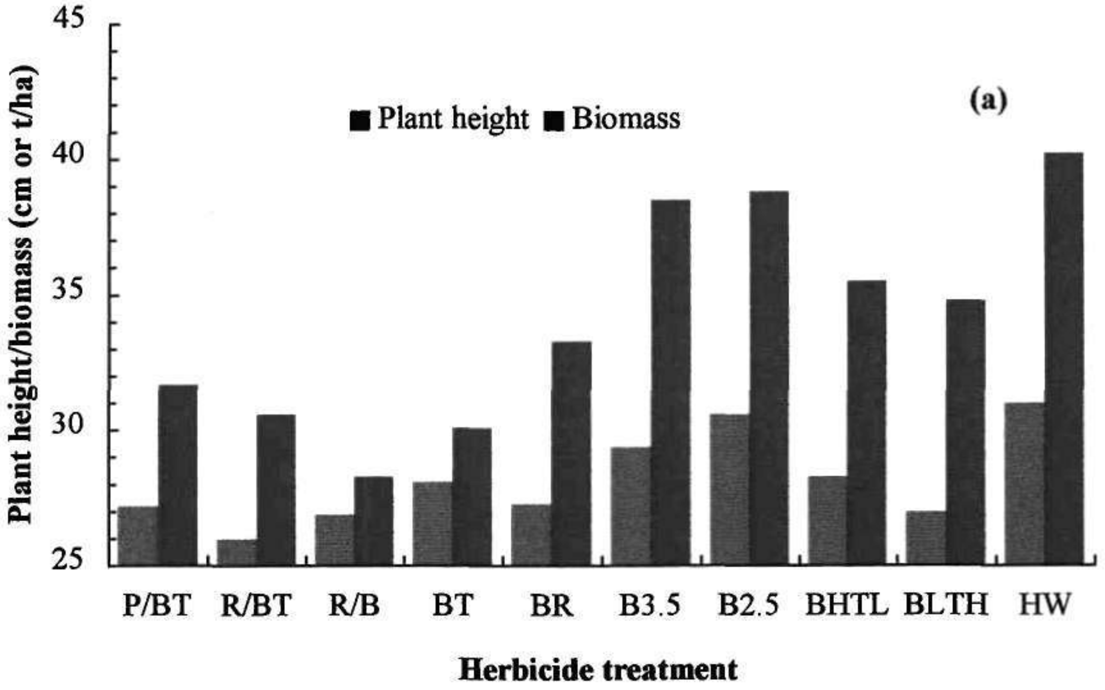
As will be shown by later weed data, the only treatment where sufficient weeds were present to affect beetroot growth and yields was where BETANAL® was sprayed once at 2.5 L/ha (**B2.5**) in Planting 1. In all other instances, differences in beetroot growth or yields were due to phytotoxic effects from the herbicide treatments.

None of the herbicide treatments affected the numbers of beetroot plants present at any time of assessment in either planting.

In Planting 1, beetroot sprayed with 2.5-3.5 L/ha of BETANAL® at 12 DAS were not significantly shorter than hand-weeded beetroot (Fig. 6a). Addition of TRAMAT® to the herbicide solutions at this time of spraying reduced beetroot height; more severely at 2 L/ha compared to 1.5 L/ha. All beetroot sprayed with 5 L/ha of BETANAL® at 25 DAS were significantly shorter than beetroot from the hand-weeded areas, irrespective of any additional pre or post-emergence herbicides.

When the fresh weights of beetroot plants were determined at their baby beet growth stage, only plots sprayed with 2.5-3.5 L/ha of BETANAL® produced the same biomass as the hand-weeded areas. Treatments where TRAMAT® was applied early were slightly less productive, while areas sprayed with 5 L/ha BETANAL® produced the least biomass (Fig. 6a).

In contrast to Planting 1, there were minimal effects of herbicide treatments on beetroot plant heights in Planting 2 (Fig. 6b). There may have been a slight trend for shorter plants in areas sprayed with TRAMAT® or the 5 L/ha rate of BETANAL®. This trend may have continued through to the biomass harvest at the baby beet growth stage, although these measurements were relatively variable and inconsistent (Fig. 6b).



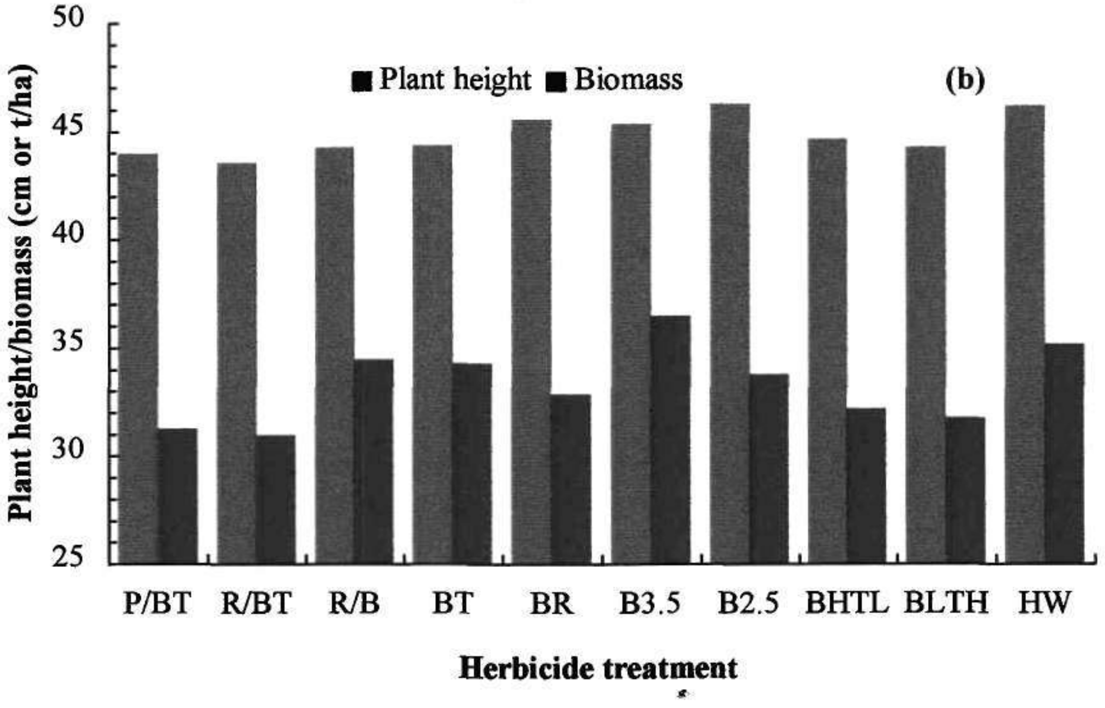
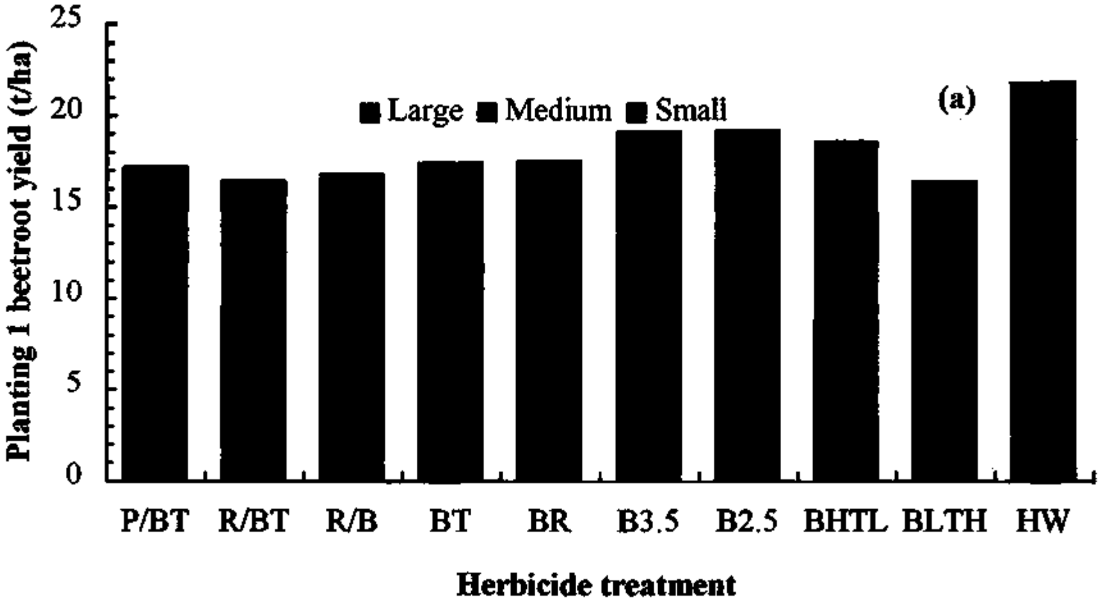


Figure 6. Herbicide application strategies affect the heights and biomass production of beetroot plants in (a) Planting 1 and (b) Planting 2.

Total yields of all the herbicide treated plots in Planting 1 were significantly less than yields from the hand weeded areas (Fig. 7a). The highest yielding of the sprayed beetroot were those treated at 12 DAS with 2.5-3.5 L/ha of BETANAL®, and no more than 1.5 L/ha of TRAMAT®. Areas sprayed with 2 L/ha of TRAMAT® at that time, or with 5 L/ha of BETANAL® at 25 DAS, yielded slightly less beetroot than the former treatments (Fig. 7a).

In contrast to Planting 1, there were no significant effects of any of the herbicide treatments on beetroot yields in Planting 2 (Fig. 7b). Yields in Planting 2 were also consistently higher than yields from the earlier planting.



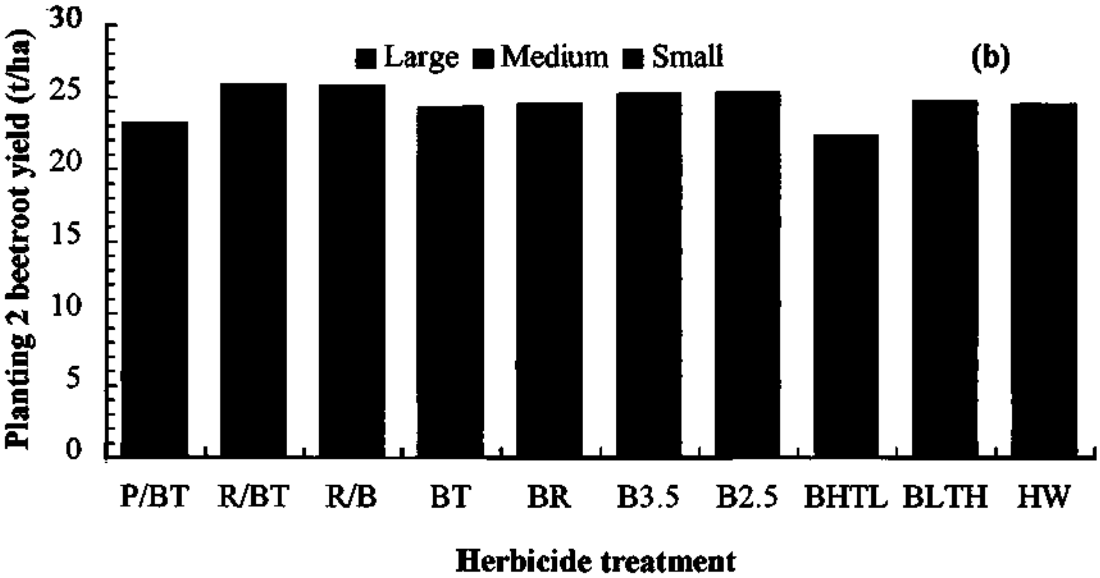
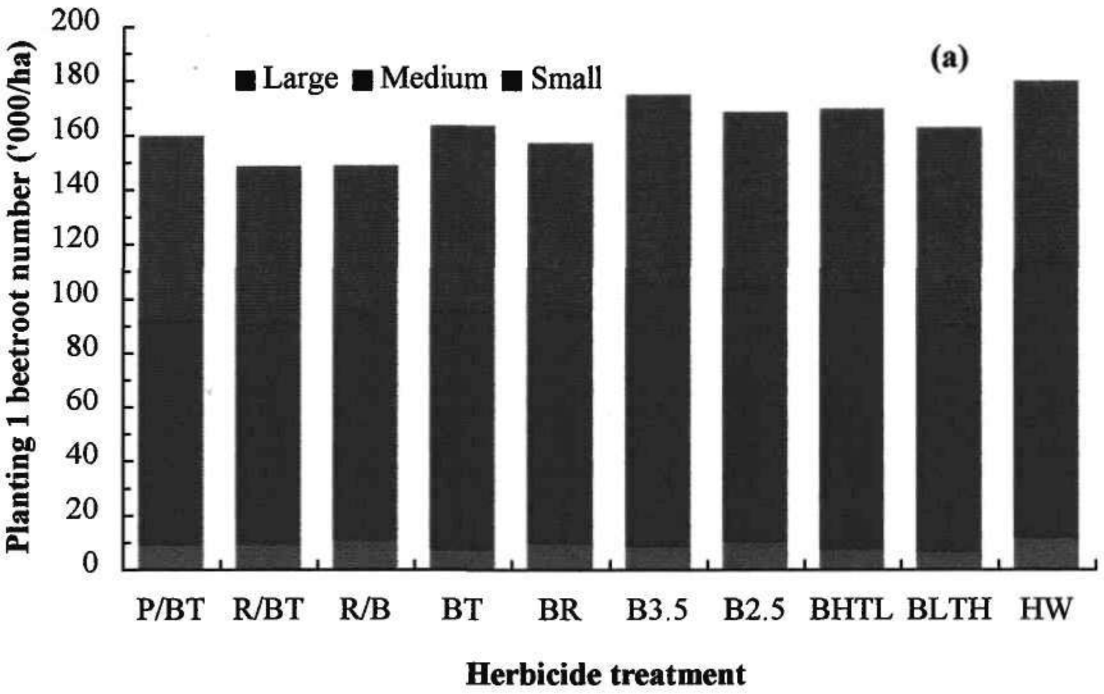


Figure 7. Herbicide treatments (a) reduce yields of beetroot in Planting 1, but (b) have no consistent effect on yields in Planting 2.

Differences in yields in Planting 1 were associated with changes in both the numbers and mean individual weights of medium-large sized beetroot (Fig. 8a,b).



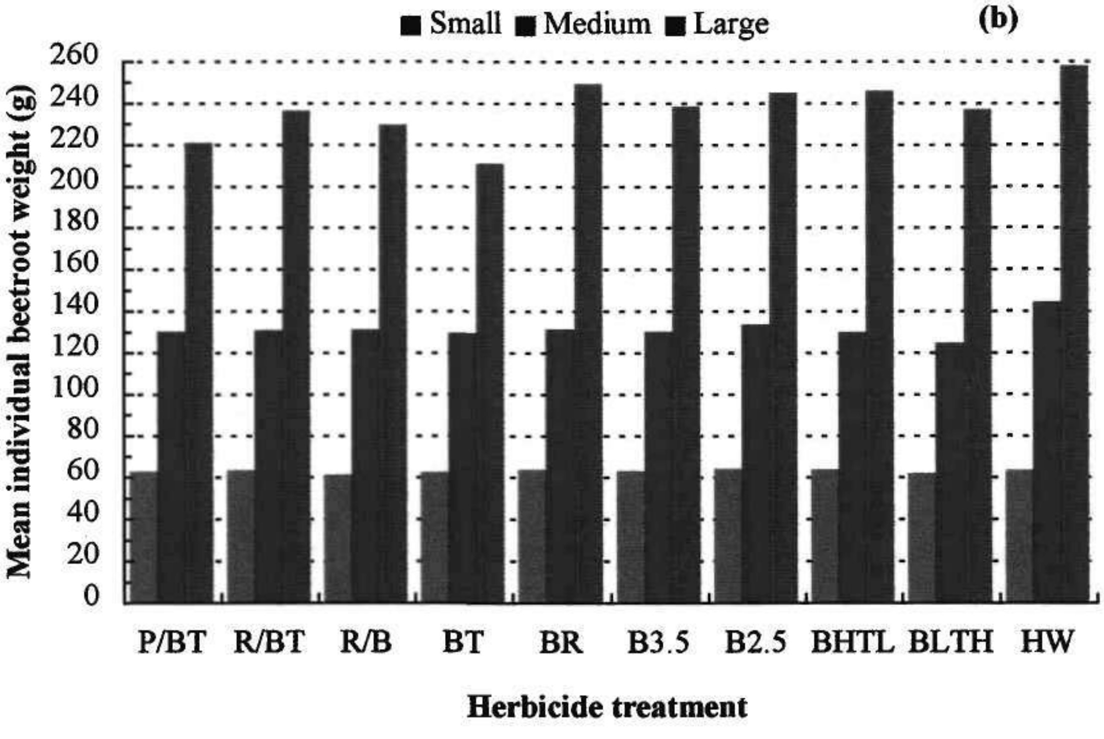


Figure 8. Applications of some herbicides in Planting 1 reduced (a) the number of medium-large beetroot and (b) the mean individual size of medium-large beetroot.

Weed control

Burr medic *Medicago polymorpha*

In Planting 1, there were significant numbers of burr medic plants in plots not sprayed with a pre-emergence herbicide, or sprayed post-emergence with less than 2 L/ha of TRAMAT® (Fig. 9a). In Planting 2, the only plots with any significant numbers of burr medic were those sprayed only with 2.5-3.5 L/ha of BETANAL® (Fig. 9b). By the time beetroot were harvested, significant biomass of burr medic was only found in plots sprayed with 2.5 L/ha of BETANAL®, with a small population in areas sprayed with 3.5 L/ha of this herbicide (Fig. 10a,b).

Sowthistle *Sonchus oleraceus*

Significant early populations of sowthistle occurred in areas sprayed with 2.5-3.5 L/ha of BETANAL® in both plantings (Fig.9a,b). The sowthistle biomass present in these treatments when the beetroot were harvested was relatively minor; particularly in plots sprayed at the higher rate (Fig. 10a,b). Although sowthistles were present in other treatments at the early assessments, in Planting 1 they were not apparent in any significant biomass when the beetroot were harvested (Fig. 10a). In Planting 2, there were small populations of this species in the treatments only sprayed post-emergence at 34 DAS (Fig. 10b).

Deadnettle *Lamium amplexicaule*

This species was the most prevalent weed in this experiment. In Planting 1, early counts showed significant numbers present in all treatments, except those sprayed with PYRAMIN® post-sowing, pre-emergence, or RAMROD® post-sowing, pre-emergence, followed by a full-rate BETANAL®/TRAMAT® mixture post-emergence (Fig. 9a). The greatest populations were in those areas only sprayed with 2.5-3.5 L/ha of BETANAL®, with higher numbers in the lower rate plots. At the time beetroot were harvested, significant biomass of deadnettle occurred in plots only sprayed post-emergence 12 DAS, with the worst infestation in the treatment involving a single application of 2.5 L/ha BETANAL® (Fig. 10a).

In Planting 2, early deadnettle counts showed substantial populations in the low rate BETANAL® treatments, as well as treatments sprayed with; RAMROD® pre-emergence and BETANAL® post-emergence; or BETANAL® and TRAMAT® at maximum rates post-emergence and no pre-emergence herbicides (Fig. 9b). These early counts were reflected in deadnettle biomass at the time of beetroot harvest (Fig. 10b).

Fat hen *Chenopodium album*

Early weed counts in Planting 1 indicated significant numbers of fat hen in the treatments sprayed with low rates of BETANAL® and BETANAL®/TRAMAT® mixtures 12 DAS, as well as plots sprayed with maximum rate BETANAL®/TRAMAT® and no post-sowing, pre-emergence herbicides (Fig. 9a). These early counts were confirmed by fat hen biomass collected immediately prior to harvesting the beetroot (Fig. 10a). In Planting 2, early counts and later biomass harvests showed significant fat hen populations only in plots sprayed with 2.5 L/ha of BETANAL®, and to a lesser extent those areas sprayed with 3.5 L/ha of the same herbicide (Fig. 9b, 10b).

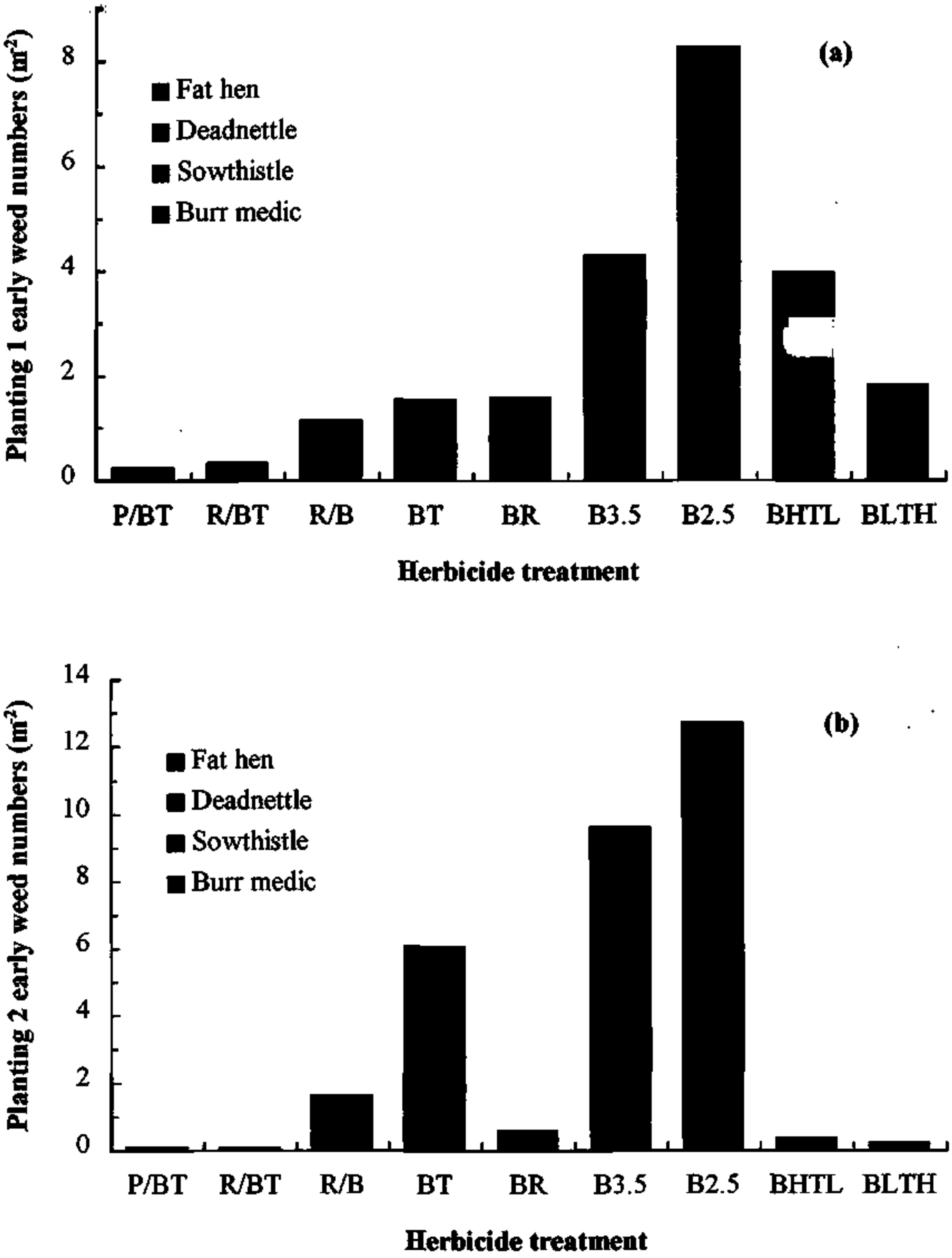


Figure 9. Herbicide treatments affect the early abundance of 4 weed species in (a) Planting 1 and (b) Planting 2.

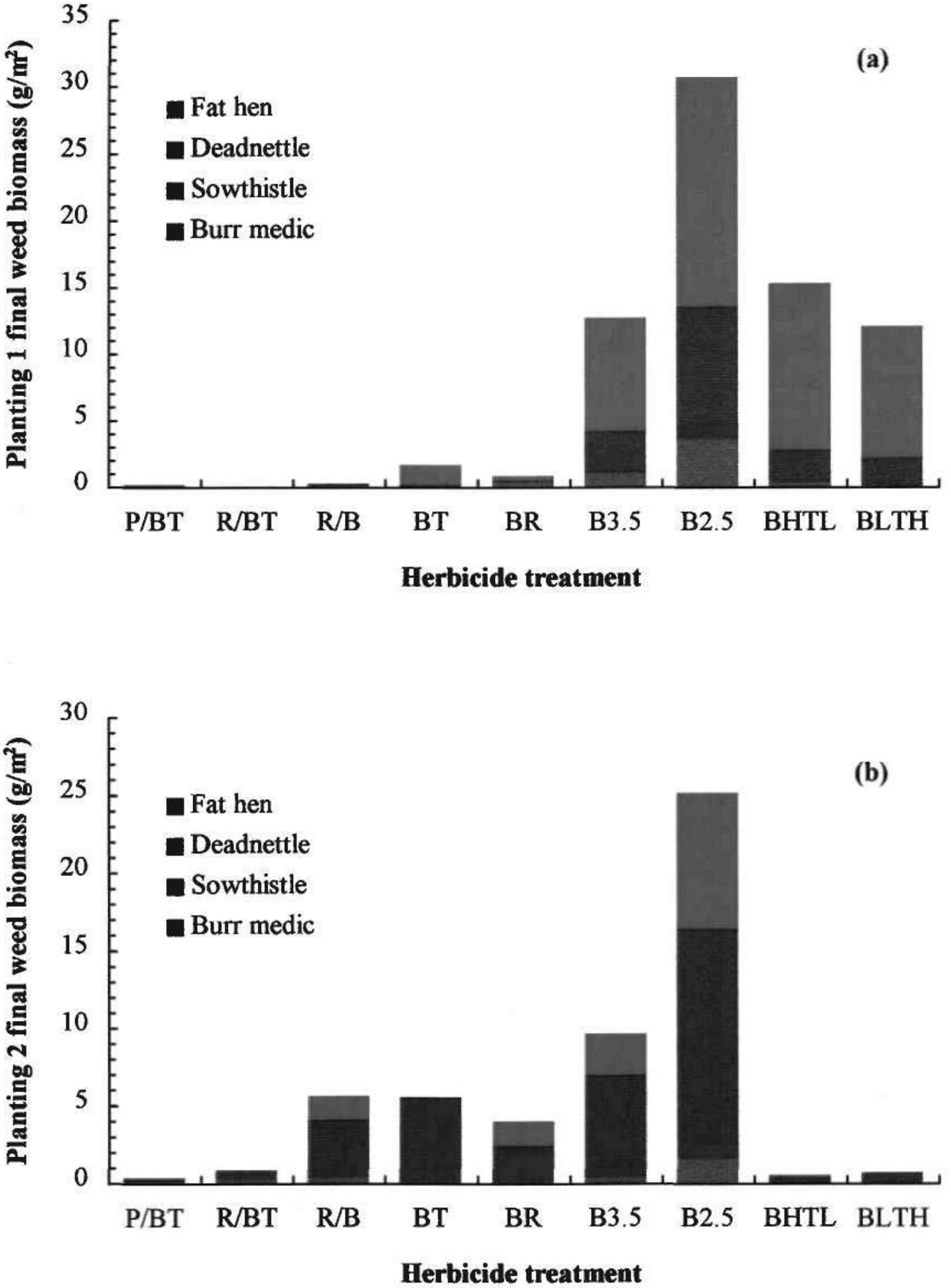


Figure 10. Herbicide treatments affect the final biomass of 4 weed species in (a) Planting 1 and (b) Planting 2.

Total weed component

Apart from the previously mentioned weeds, there were also minor occurrences of small-flowered mallow (*Malva parviflora*), shepherd's purse (*Capsella bursapastoris*) and stinging nettle (*Urtica urens*).

In Planting 1, areas sprayed with 5 L/ha of BETANAL®, mixed with either TRAMAT® or RAMROD®, or following a post-sowing, pre-emergence herbicide application, had minimal weed populations (Fig. 11). Plots sprayed once with 3.5 L/ha of BETANAL® 12 DAS had 40 gm^{-2} of weeds immediately prior to beetroot harvest, whilst adding 1.5 L/ha of TRAMAT® to the spray mixture did not improve efficacy. Spraying once with 2.5 L/ha of BETANAL® at 12 DAS gave the worst weed control (circa 100 gm^{-2} of fresh weed biomass). Combining 2 L/ha of TRAMAT® with 2.5 L/ha of BETANAL® significantly improved weed control to a level equivalent to that achieved in the other post-emergence treatments sprayed at the same time (Fig. 11).

In Planting 2, areas sprayed with the 5 L/ha rate of BETANAL® in all combinations also gave good weed control. Efficacy was better in those treatments combining a full-rate mixture of BETANAL®/TRAMAT® with a post-sowing, pre-emergence herbicide (Fig. 11). The plots sprayed with 2.5-3.5 L/ha of BETANAL® 22 and 42 DAS contained 40-50 gm^{-2} of weeds immediately prior to harvesting the beetroots. Interestingly, addition of low rates of TRAMAT® to these post-emergence applications dramatically improved efficacy, in contrast to Planting 1 (Fig. 11).

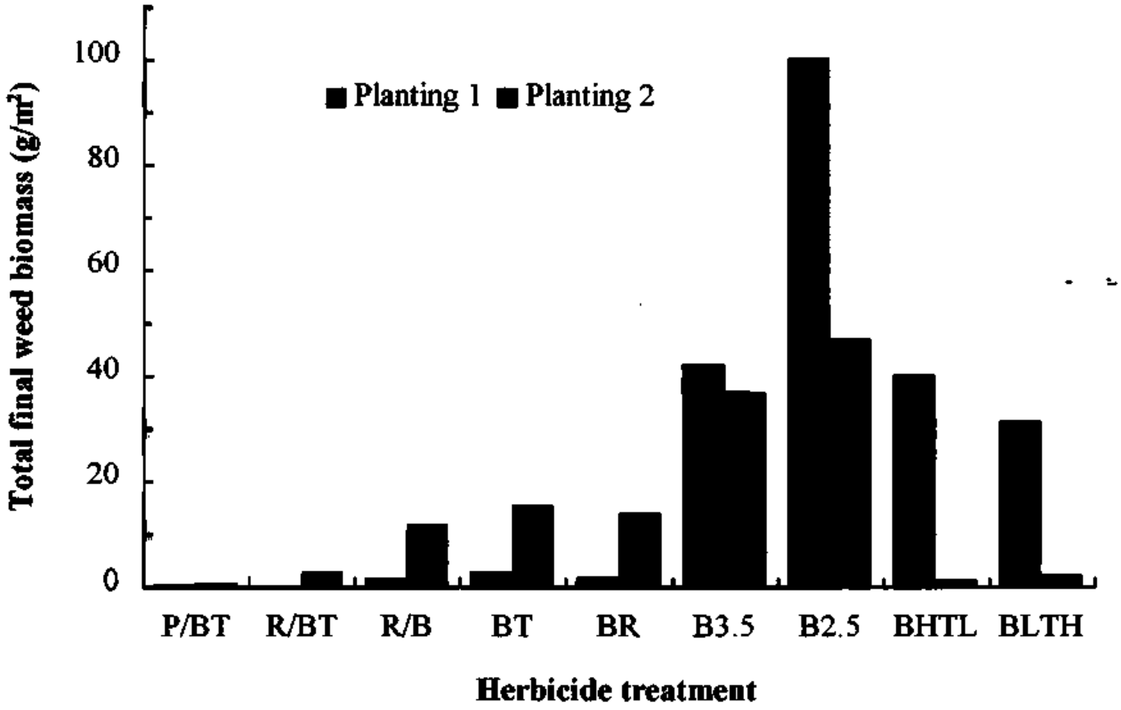


Figure 11. The effects of herbicide regimes on total weed biomass produced during the growing period of 2 beetroot plantings.

In Planting 1, post-emergence applications of treatments containing 5 L/ha BETANAL® at 25 DAS appears to have been at a sufficiently early weed growth stage to effectively control the weed species present. In Planting 2, the same treatments applied 34 DAS were not as effective, although the level of weed control achieved was still sufficient to prevent weed competition. Whether reduced efficacy was due to older weeds, or environmental conditions (eg. lower relative humidities, as shown in Table 1) is not clear. The main escape species appeared to have been deadnettle, with a few fat hen and sowthistle (Fig. 10b).

Spraying 2.5 L/ha of BETANAL® gave only moderate weed control, particularly of deadnettle, fat hen, and to a lesser extent burr medic. Making 2 applications during the growing period improved control in the second planting. Increasing the application rate to 3.5 L/ha certainly increased the efficacy, although significant numbers of deadnettle and fat hen still survived in both beetroot Plantings (Fig. 9b, 10b). In Planting 1, addition of TRAMAT® to these low-rate BETANAL® applications did not improve efficacy, however it dramatically improved weed control in Planting 2. The reasons for this are unclear. In Planting 2, applications were made at an earlier stage, but were followed up by a second spraying. Overseas investigations suggest that due to slow metabolism of herbicides by weeds, effects of sequential sprayings can be cumulative, providing superior weed control.

Conclusions

In dry climatic conditions, there is no economic benefit from additional fungicide seed dressings. If beetroot is being sown into a paddock with a history of seedling disease problems, or weather is such that wet soil conditions are likely, then an insurance seed dressing is probably warranted. In terms of overall production, the costs associated with this treatment (≅\$3/ha) are relatively minor.

In both beetroot plantings, scheduling irrigation with tensiometers was more profitable than irrigating according to a calendar regime. Assume that tensiometer scheduling costs \$40/ha, irrigation \$50/ML, and beetroot has a net value (price less post-harvest costs) of \$110/t on-farm. In Planting 1, scheduling saved on irrigation and increased yield, improving total profit by about \$390/ha. In Planting 2, scheduling resulted in slightly more water being applied, with yield increased and profits greater by \$280/ha. In both circumstances, increased profits were primarily due to better yields, not savings in water used. In conditions where there is more significant rainfall during the growing period, it is likely that profits from irrigation scheduling may be even greater. This is because predicting plant water needs in such circumstances, without some objective methodology, is even more difficult.

Spraying beetroot with 5 L/ha of BETANAL® at 25-34 DAS noticeably reduced beetroot growth, particularly in Planting 1. The effect was less apparent in Planting 2, and in both plantings the relative phytotoxic effects declined as the beetroot got older. Spraying 5 L/ha of BETANAL® slightly reduced yields in Planting 1, however it had no deleterious impacts on yields in Planting 2. Interestingly, the application in Planting 1 was about 9 days earlier than the corresponding treatment in Planting 2, and gave slightly more effective weed control. More humid conditions at the time of spraying in Planting 1 may have improved uptake and efficacy of BETANAL® in both weeds and beetroot. Spraying 5 L/ha of BETANAL® 3-6 weeks after beetroot sowing is a standard post-emergence herbicide application in commercial beetroot. Weather conditions in neither planting were sufficiently hot to promote the type of damage from BETANAL® mentioned on the product label.

Use of pre-emergence herbicides such as PYRAMIN® or RAMROD® may have slightly improved weed control in Planting 2, where BETANAL® by itself did not give a complete kill. These pre-emergence herbicides did not adversely affect beetroot growth nor yield.

Low-rate post-emergence spraying of BETANAL® at 2.5-3.5 L/ha were the treatments least phytotoxic to beetroot in Planting 1, and to a lesser extent in Planting 2. Although 3.5 L/ha of BETANAL® at 12 DAS in Planting 1 did reduce initial beetroot heights, the plants had recovered by 78 DAS. These beetroot gave the highest yields of areas sprayed with herbicides in Planting 1, and equal highest yields in Planting 2. Although beetroot yields in plots sprayed with 2.5 L/ha of BETANAL® were reasonable, the levels of control of fat hen and deadnettle, and to a lesser extent burr medic, were probably unacceptable in a commercial situation, particularly in the light of long-term weed management. At 3.5 L/ha, weed control was probably just acceptable; roguing of large fat hen late in the growing period may have been a justifiable additional weed management strategy.

Addition of 1.5-2 L/ha of TRAMAT® to the low-rate BETANAL® treatments adversely affected the beetroot in Planting 1, whilst providing minimal improvement in weed control compared to 3.5 L/ha of BETANAL® on its own. In contrast, delaying spraying of these BETANAL®/TRAMAT® mixtures in Planting 2, combined with a second application 20 days later, improved weed control and negated adverse effects on beetroot growth and yield.

Assume the pre-emergence and early post-emergence applications are only sprayed over the central third of each beetroot row, and the later post-emergence applications over the central half of each beetroot row, and that inter-row weeds are controlled by cultivation. Further assume that post-emergence spraying with 5 L/ha of BETANAL® mixed with 5 L/ha of TRAMAT® is the standard commercial practice. Taking into account relative herbicide costs and yield differences, results over both plantings show:

1. Inclusion of PYRAMIN® as a pre-emergence treatment reduced profit by $175/ha.

2. Inclusion of RAMROD® as a pre-emergence treatment, or as a substitute for post-emergence TRAMAT® increased profit by $85/ha.

3. Spraying BETANAL® at low-rates early post-emergence increased profits by $370/ha in Planting 1, and $140/ha in Planting 2 (2 applications were required).

4. Addition of TRAMAT® to the early post-emergence sprayings mentioned in 3 reduced their profits consistently and considerably.

The results of this experiment demonstrate the gains to be made by scheduling irrigation in beetroot. They also indicate significant reductions in herbicide use and risks of crop damage, and increases in overall profit, are potentially available from low-rate, early application of beetroot herbicides. These ideas will be further tested in future experiments.

Appendix 5. Experiment BEET2 March-June 1995

Low-rate herbicide strategies for beetroot

by Craig Henderson and Mick Webber
QDPI Gatton Research Station

Summary

An experiment investigating efficacy and phytotoxicity of low-rate herbicide sequences in beetroot production was conducted at Gatton Research Station during March-June 1995. The experiment compared 8 herbicide treatments with a hand-weeded control. Herbicides BETANAL® (phenmedipham) and TRAMAT® (ethofumesate) were sprayed in sequences between the cotyledon and 4 leaf stages of a beetroot crop. Growth and yields of weeds and beetroots were measured, as were the amounts of irrigation and pesticides used.

Water restrictions and delays in tensiometer installation reduced the efficiency of irrigation scheduling. Poor quality water, combined with at least one period of water stress, probably restricted beetroot yields. In previous experiments, irrigation scheduling has led to higher beetroot yields, more efficient water use, and greater profitability.

The commercial strategy of applying 5 L/ha of both BETANAL® and TRAMAT® when beetroots have 4 true leaves significantly reduced growth and yields of beetroot. When only 5 L/ha of BETANAL® was sprayed, the phytotoxic effect largely disappeared.

Low-rate sequences of BETANAL®, whether applied at the cotyledon or 2 true leaf stages, caused slight growth and yield depressions (compared to hand-weeded areas). The best herbicide treatment, with least damage to beetroot and effective weed control, was where low rates of BETANAL® and TRAMAT® were sprayed at the 2 and 4 leaf stages of the crop. Apart from the lowest rate BETANAL® spraying, all other herbicide treatments gave weed control equivalent to hand-weeding.

Low rate herbicide sequences reduced weed control costs by 50-60%. Each of the treatments where BETANAL® alone was sprayed (when the beetroots had up to 2 true leaves) increased profitability (compared to the commercial standard) by $250-420/ha. Addition of 0.5 L/ha of TRAMAT® to early post-emergence sprayings increased profits by $485/ha compared to the commercial standard. Increases in profitability were largely due to less crop damage from low-rate herbicide treatments, although reduced weed control costs provided around $60/ha.

Commercial applications of these weed control strategies need to be tested over larger areas, in producers' crops, and in situations with greater weed burdens. These ideas will be further examined in future experiments and demonstrations.

Relevance to industry

The cost-price squeeze has adversely affected profitability of fresh and processing beetroot production. Weed management in beetroot is costly; current herbicide strategies are expensive, do not provide reliable control and occasionally cause significant crop damage. Beetroot producers are concerned about long-term residues from some herbicides. Previous experiments have shown potential for low rates of beetroot herbicides applied sequentially. These strategies enable earlier weed control, with less risk of crop damage at lower costs. Such methods are already used commercially in sugarbeet in both the USA and Europe.

Objectives

This experiment investigated and demonstrated low application rates on efficacy and phytotoxicity of post-emergence herbicides in beetroot production. Effects of treatments on weeds, beetroot growth, yield and quality were measured. Information gained was used to develop strategies for further evaluation and extension to commercial producers.

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 replicates of 9 weed management treatments arranged in blocks. The experiment was sown on 30 March 1995.

The soil was prepared as per standard practice for a beetroot crop. Beetroots (cv. *Early Wonder Tall Top*) were sown in rows 0.75 m apart. Intra-row spacings were 0.05 m, giving a total sown population of 267,000 plants/ha. Because of inherent soil fertility, no fertilisers were applied to the crop. Apart from the specific treatments detailed below, no pesticides were applied to the beetroot.

Irrigation

The beetroots were generally irrigated with solid-set spray-lines, although initial irrigations were by hand-shift lines of sprinklers. Irrigations were scheduled based on data from tensiometer stations installed in the crop about 5 weeks after sowing.

Tensiometers were installed 15 cm and 45 cm below ground level in hand-weeded plots in each block. LOCTRONIC® tensiometers were used, which consist of a standard ceramic tip and tube, but no vacuum gauge. To obtain readings, a hollow syringe is forced through the rubber septum at the top of the tensiometer, and an electronic vacuum gauge senses the vacuum in the small air gap below the septum. Tensiometer readings were recorded around 8-9 am daily.

Weed management treatments

The following herbicides were used in this experiment.

1. BETANAL® (phenmedipham 157 g/L EC) - registered for post-emergence spraying wh beetroot has 2-4 true leaves and weeds are correspondingly small. It is known to cause crop damage where temperatures exceed 32°C. BETANAL® is mainly used for broadle weed control, and is not active against most grasses. It is frequently used in combinatio with TRAMAT®.

2. TRAMAT® (ethofumesate 200 g/L EC) - registered for pre and post-emergence use in beetroot, controlling both grass and broadleaf weeds. In recent times there has been concern that this herbicide has been causing crop damage at registered rates, as well as having adverse effects on following crops.

All herbicides were applied with a motorised knapsack sprayer. The 1.5 m wide hand-held boom had 110° flat-fan nozzles spaced 0.30 m apart. It was operated at 200 kPa and spraye 250 L/ha. The weed management treatments in this experiment are detailed below. Weathe conditions at each spraying time are shown in Table 1.

1. **(BcL).** BETANAL® applied at 1.5 L/ha when the beetroots had fully expanded cotyledons, on 12 April 1995, 13 days after sowing (DAS). This was followed by an additional application of 1.5 L/ha 7 days later, when the beetroots had 2 true leaves.

2. **(BcM).** BETANAL® applied at 2.0 L/ha when the beetroots had fully expanded cotyledons, on 12 April 1995, 13 (DAS), followed by 2.0 L/ha 7 days later.

3. **(BcH).** BETANAL® applied at 2.5 L/ha when the beetroots had fully expanded cotyledons, on 12 April 1995, 13 (DAS), followed by 2.0 L/ha 7 days later.

4. **(B2L).** BETANAL® applied at 2.5 L/ha when the beetroots had 2 true leaves, on 19 April 1995, 20 (DAS), followed by 1.5 L/ha 7 days later, on 26 April 1995.

5. **(B2H).** BETANAL® applied at 2.5 L/ha when the beetroots had 2 true leaves, on 19 April 1995, 20 (DAS), followed by 2.5 L/ha 7 days later.

6. **(BTL).** BETANAL® at 2.5 L/ha mixed with TRAMAT® at 0.5 L/ha, sprayed when the beetroots had 2 true leaves, on 19 April 1995, 20 (DAS). This was followed by 1.5 L/ha of BETANAL® mixed with 0.5 L/ha of TRAMAT® sprayed 7 days later.

7. **(B5).** BETANAL® applied at 5 L/ha when the beetroots had 4 true leaves, on 26 April 1995, 27 (DAS).

8. **(BT5).** BETANAL® at 5 L/ha mixed with TRAMAT® at 5 L/ha, sprayed when the beetroots had 4 true leaves, on 26 April 1995, 27 (DAS). This is the standard post-emergence herbicide treatment in commercial beetroot production.

9. **(HW).** This treatment was hand weeded once only on 9 May 1995, 40 DAS.

Table 1. Weather conditions at each spray application

Date	DAS	Beetroot growth stage	Temperature (^{o}C)	Relative humidity (%)	Wind speed (km/hr)	Wind direction
12/4/95	13	Expanded cotyledons	11	70	8	W
19/4/95	20	2 true leaves	18	65	8	W
26/4/95	27	4 true leaves	20	85	8	NE

Measurements

The growth of beetroot plants and weeds were monitored throughout the growing period. Heights of 5 randomly selected beetroot plants from each plot were measured on 25 May 1995, 56 DAS. A total 9 m of beetroot row was hand-harvested for yield from each plot on 21 June 1995, 83 DAS. The beetroots were graded into small, medium and large beets, counted and weighed.

Weeds removed by hand weeding on 9 May were separated into species, counted and weighed. On 16 June, 5 days before the beetroot were harvested, weeds from the central 9*0.75 m of each plot were harvested, sorted into separate species, counted and weighed.

Data analyses

All beetroot growth and yield variables were analysed using standard analysis of variance. Owing to the nature of their distributions, weed counts and weights were log-transformed prior to analysis. The transformed data were converted back to normal values prior to presentation in tables and figures.

Results and discussion

Irrigation

A total of 59 mm of rain fell during the beetroot growing period; the bulk in a 30 mm event just prior to harvest (Fig. 1). The experiment received around 25 mm of irrigation every 5 days for the first 2-4 weeks after sowing. There was a major interval of 2 1/2 weeks between irrigation around 30 DAS, with only 9 mm of rain during that time. This interval, due to minimal water supplies at Gatton Research Station, probably resulted in substantial stress to the beetroot, and forced the development of deep root systems. From 40 DAS until harvest, the beetroots were regularly irrigated when values for the shallow tensiometers reached 40 kPa. Between irrigations, note that the deep tensiometer values rose substantially, indicating water uptake from layers normally below the beetroot crop root-zone (Fig. 1). After irrigations and the large rainfall event, significant dips in the deep tensiometers indicated soil water drainage. Because of the deeper beetroot roots, more of this would have been available for crop use than would normally have been the case.

Irrigation in this beetroot experiment was probably sub-optimal. A period of water stress at 5 weeks after sowing may have restricted leaf area and hence biomass development. There may have been some excess irrigation later in the growing period, although given the poor water quality, some leaching was desirable.

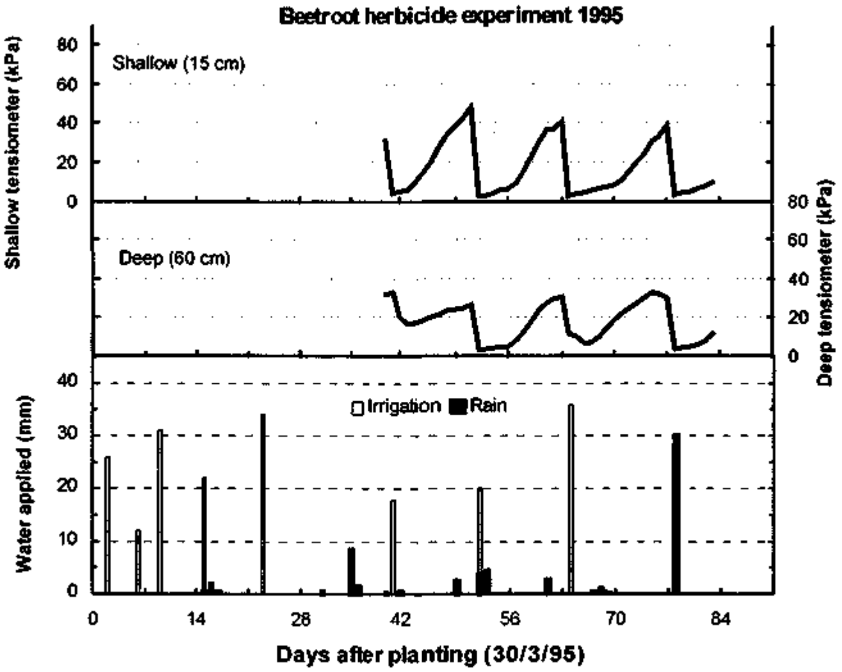


Figure 1. Fluctuation in tensiometer values with rainfall and irrigation during the growing period of beetroot.

Weed management strategies

Beetroot growth and yield

As will be shown by weed data, there were very few weeds in this experiment. Differences in beetroot growth or yields were due to phytotoxic effects from the herbicide treatments.

Only beetroots sprayed with the mixture of 5 L/ha of BETANAL® and 5 L/ha of TRAMAT® 27 DAS were significantly shorter than the hand weeded plants at 56 DAS (Fig. 2). There was however a consistent trend for all other plots sprayed with herbicides (apart from the low-rate BETANAL®/TRAMAT® mixture) to be 5% shorter than the hand-weeded beetroots.

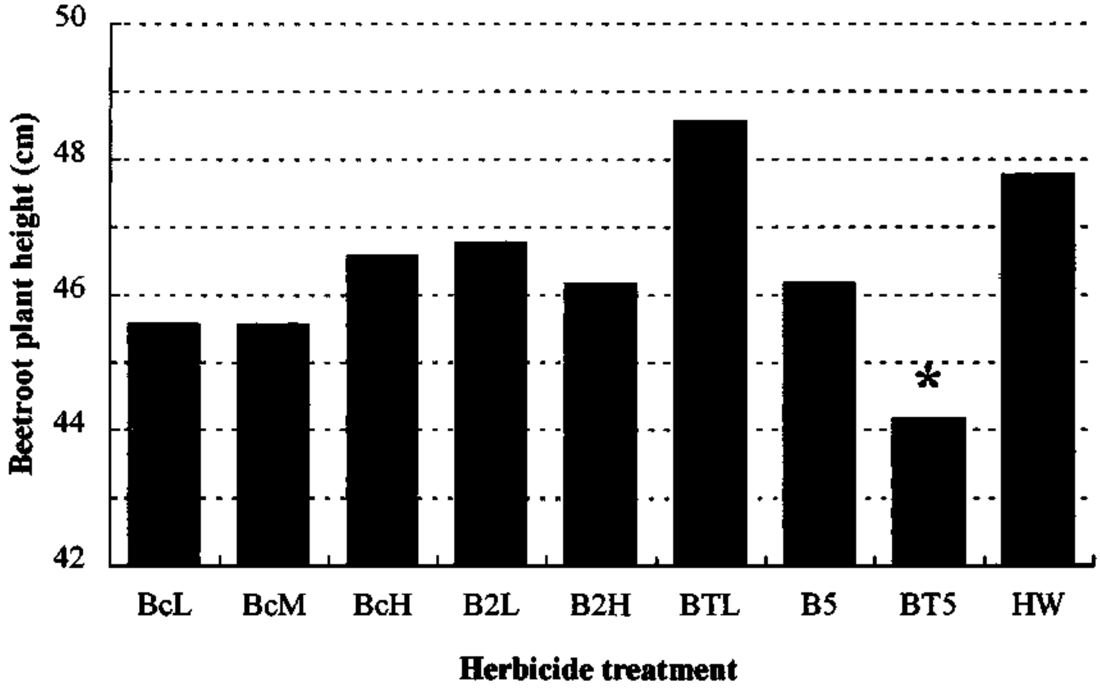


Figure 2. Herbicide application strategies affect the heights of beetroot plants. Treatments marked with an asterisk are significantly less than the hand-weeded controls.

The hand-weeded beetroots gave the highest total yields of all weed management strategies (Fig. 3). Areas sprayed with low-rate BETANAL®/TRAMAT® mixtures (when the beetroots had 2 true leaves), or 5 L/ha of BETANAL® (when the beetroots had 4 true leaves), yielded similarly to the hand-weeded crop. Treatments sprayed when the beetroots had expanded cotyledons, and beetroots sprayed with 2.5 L/ha of BETANAL® at 2 true leaves, followed by 1.5 L/ha of BETANAL® 7 days later, yielded about 2.3 t/ha less than the hand-weeded beetroots. The B2H treatment yielded slightly less (Fig. 3). The lowest yielding areas were those sprayed with the commercial treatment of 5 L/ha of both BETANAL® and TRAMAT®. This treatment produced 4.5 t/ha less beetroot than the hand-weeded plots (Fig. 3). Differences in yields were due to variation in the number of large and medium size beetroots (Fig. 4), not the mean weight of individual beetroots in each size class (Fig. 5).

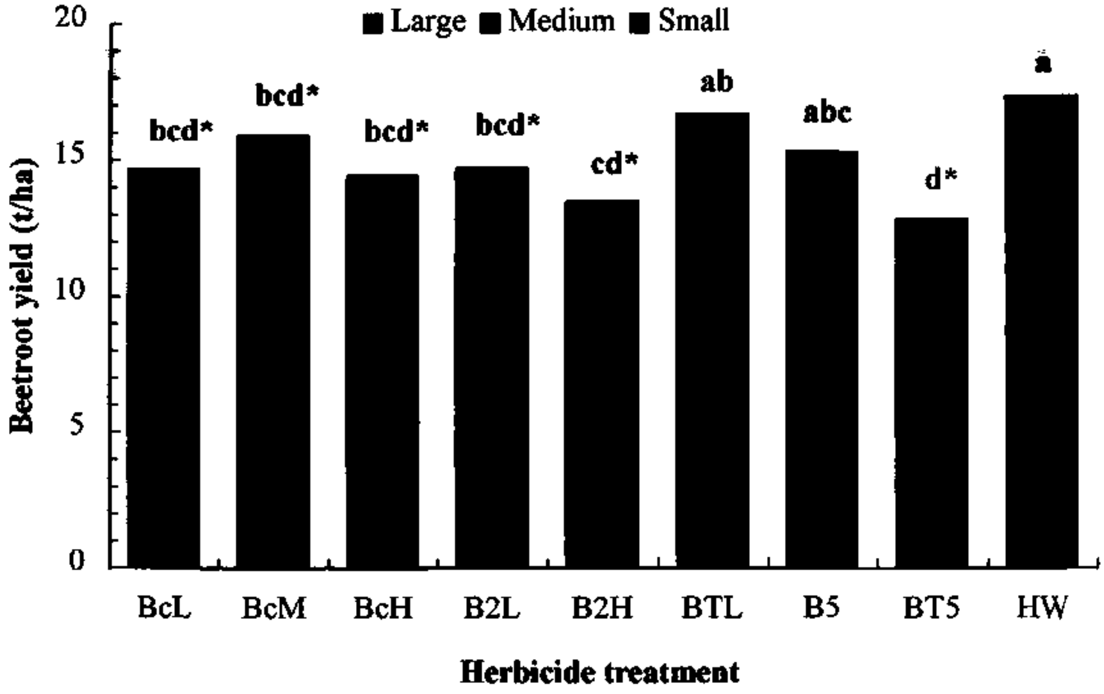


Figure 3. Herbicide treatments reduce yields of beetroot. Treatments with the same lettering are not significantly different; those followed by an asterisk are significantly less than the hand-weeded value.

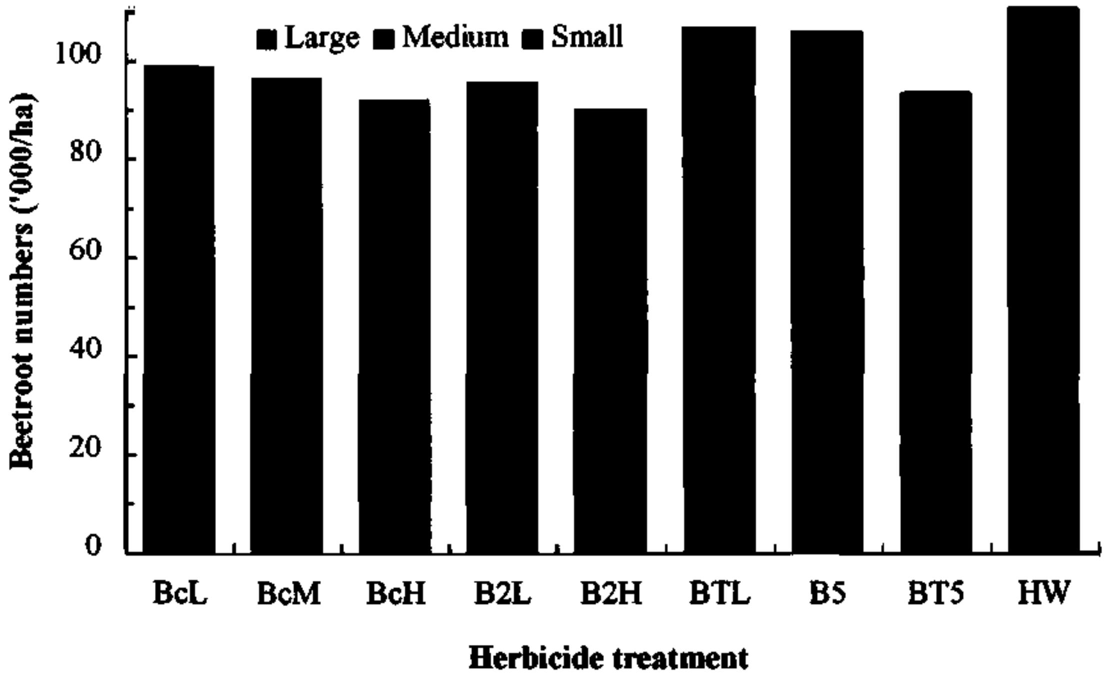


Figure 4. Herbicide treatments reduce the numbers of medium and large beetroots.

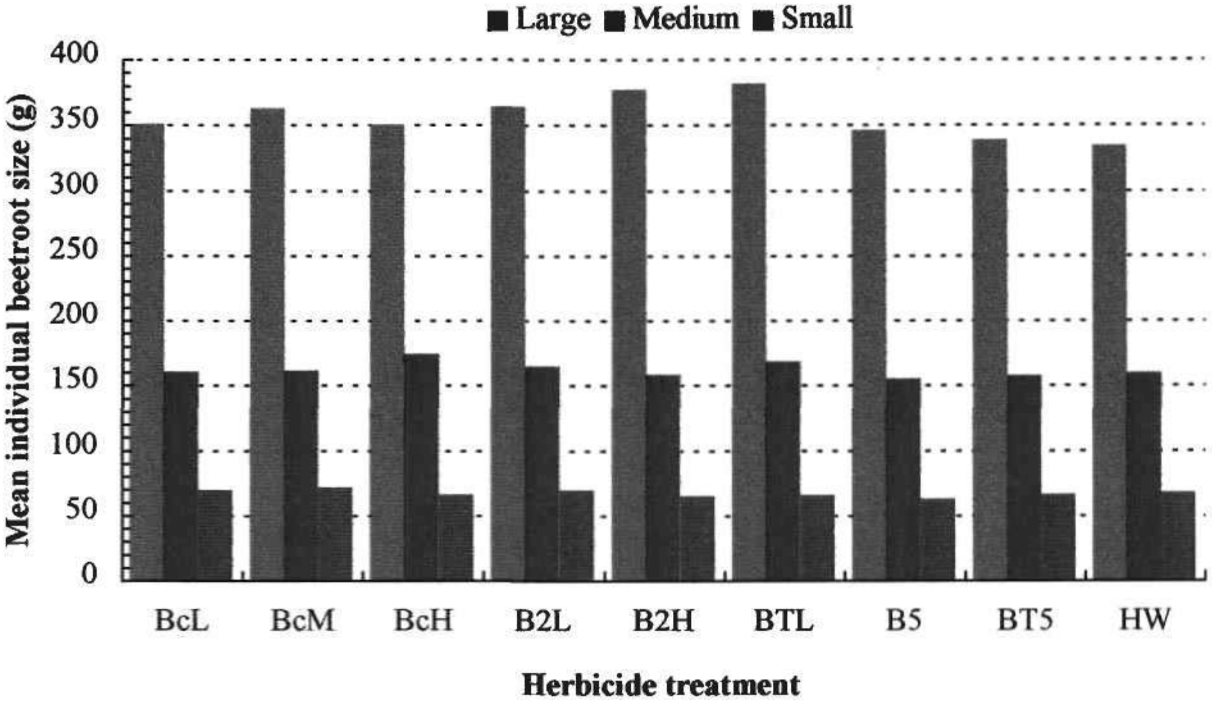


Figure 5. **Herbicide treatments did not affect the mean size of individual beetroots within grades.**

Weed control

Weed species present in the experimental area included burr medic (*Medicago polymorpha*), sowthistle (*Sonchus oleraceus*), deadnettle (*Lamium amplexicaule*), fat hen (*Chenopodium album*), bittercress (*Coronopus didymus*), amaranthus (*Amaranthus spp.*), common pigweed (*Portulaca oleracea*) and various grasses. Of these, only the first 4 species consistently occurred across the experiment. At the time of hand-weeding, there were few weeds present (Fig. 6a). Although burr medic, sowthistle, deadnettle and fat hen occurred in similar numbers, fat hen, and to a lesser extent sowthistle, produced most biomass (Fig. 6b).

At the time of beetroot harvest, the numbers and biomass of weeds were still very low; less than 1 weed/m^2 on average, producing about 2 g/m^2 of biomass (Fig. 7). The only plots where there were even minor weed occurrences were those sprayed with the lowest rates of BETANAL®, when beetroot was at the cotyledon stage. Because of low weed numbers, conclusions as to efficacy against each species are difficult to establish. All herbicide treatments gave commercially acceptable weed control, with weeds present at beetroot harvest small, non-competitive, and non-contributors to the weed seedbank. In situations of greater weed burdens, the **BcL** treatment may not provide sufficient weed suppression.

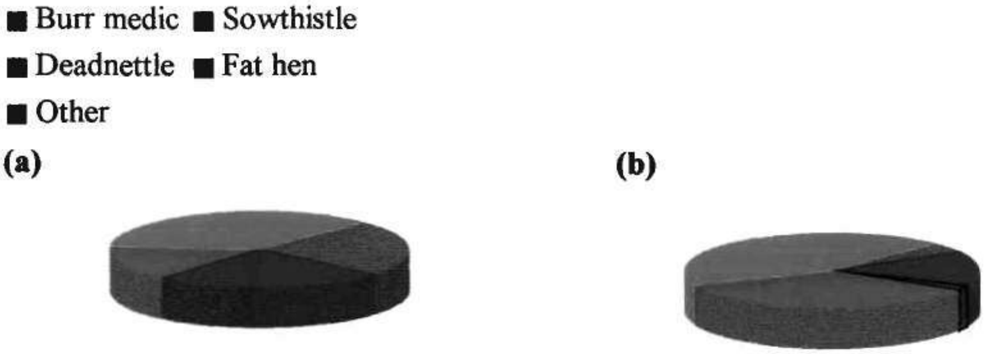


Figure 6. The proportions of (a) total weed numbers (1.3 weeds/m^2) and (b) total weed biomass (4.9 g/m^2) removed from hand weeded plots on 9 May 1995.

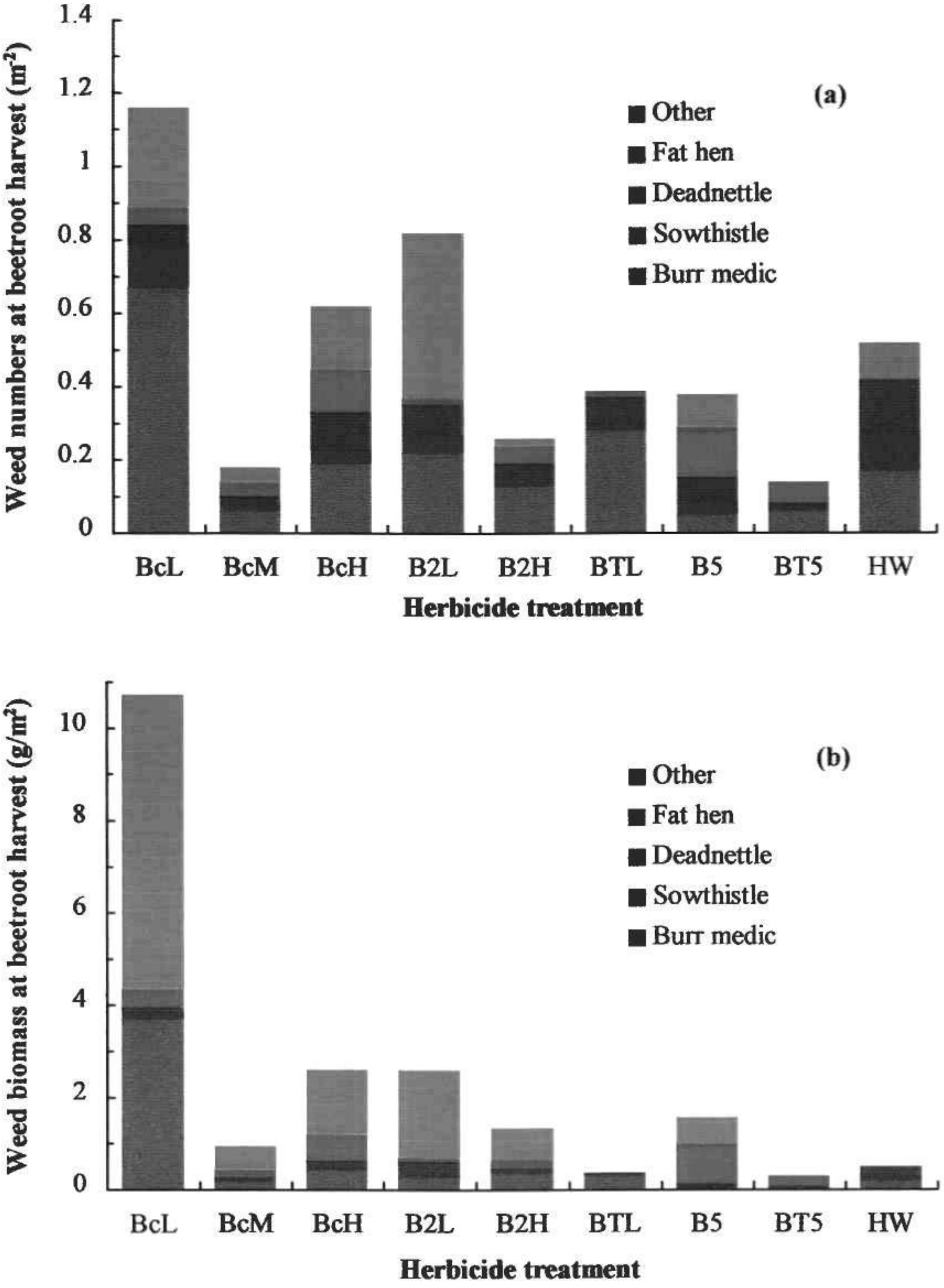


Figure 7. **Herbicide treatments affect (a) final numbers and (b) final biomass of weed species in a beetroot experiment.**

Conclusions

In this experiment, because of water limitations, and delays in tensiometer installation, best use was not made of irrigation scheduling strategies. Poor quality water, combined with at least one period of water stress, probably led to establishment and biomass production limitations that restricted beetroot yields. In previous experiments, irrigation scheduling has led to higher beetroot yields, more efficient water use, and greater profitability.

The commercial strategy of applying 5 L/ha of both BETANAL® and TRAMAT® when beetroots have 4 true leaves significantly reduced growth and yields of beetroot. In contrast to a previous experiment, when the TRAMAT® component was removed, the phytotoxic effect also largely disappeared.

Low-rate sequences of BETANAL®, whether applied at the cotyledon or 2 true leaf stages, all caused slight growth and yield depressions (compared to hand-weeded areas). Interestingly, the best performed herbicide treatment, with least beetroot damage and effective weed control, was where low rates of BETANAL® and TRAMAT® were sprayed at the 2 and 4 leaf stages of the crop (BTL).

Apart from where BETANAL® was sprayed at the lowest rate (BcL), all other herbicide treatments gave weed control equivalent to hand-weeding.

Assume the pre-emergence and early post-emergence applications are only sprayed over the central third of each beetroot row, and that inter-row weeds are controlled by cultivation. Further assume that post-emergence spraying with 5 L/ha of BETANAL® mixed with 5 L/ha of TRAMAT is the standard commercial practice. Taking into account relative herbicide costs and yield differences, results show:

1. Removal of TRAMAT® from the commercial treatment increased profit by $340/ha.

2. Low rate herbicide sequences reduced weed control costs by 50-60%.

3. Spraying BETANAL® sequences at low-rates when beetroot has up to 2 true leaves increased profitability by $250-420/ha.

4. Addition of 0.5 L/ha of TRAMAT® to the early post-emergence sprayings increased profits by $485/ha compared to the commercial standard.

Increases in profitability were largely due to less crop damage from the low-rate herbicide treatments, although there was about a $60/ha contribution from reduced weed control costs. Commercial applications of these weed control strategies need to be tested over larger areas, in producers' crops, and in situations with greater weed burdens. These ideas will be further tested in future experiments and demonstrations.

Appendix 6. Experiment BEET3 April-August 1996

Weed management strategies for beetroot production

by Craig Henderson and Dan Galligan
QDPI Gatton Research Station

Summary

An experiment investigating efficacy and phytotoxicity of low-rate herbicide sequences in beetroot production was conducted at Gatton Research Station during April-August 1996. The experiment compared 4 weed management strategies with a hand-weeded control. Herbicides BETANAL® (phenmedipham) and TRAMAT® (ethofumesate) were sprayed in sequences between the 4 leaf and 6 leaf stages of a beetroot crop. The treatments were sprayed later than the optimum times, due to wet conditions. Growth and yields of weeds and beetroots were measured, as were the amounts of irrigation and pesticides used.

Over 500 mm of rain fell during the second week after sowing, flooding the beetroot. Fortunately, mild weather during the following week enabled the beetroot plants to re-establish their root systems. Good yields (averaging 42 t/ha), particularly in the light of the terrible early weather, reflect sound agronomic management during the growing period.

*The commercial strategy of applying 5 L/ha of both BETANAL® and TRAMAT® **(COM)** when beetroots had 4-6 true leaves significantly reduced early growth of the beetroot. The plants recovered by harvest, to give yields equivalent to the other treatments. Each weed management strategy had similar numbers and weights of beets in the 3 size grades. Yields in the low-rate BETANAL® sequence treatment **(BS)** may have been marginally lower.*

*By the time the beetroot were harvested, areas sprayed with low-rate sequences of BETANAL®/TRAMAT® **(BTS)** had slightly more weeds, but less weed biomass, than the **COM** strategy. Both **BTS** and **COM** strategies effectivly controlled burr medic, bittercress, sowthistle, slender celery, and fat hen. **BTS** seemed to give better control of burr medic and sowthistle, but was not as effective as **COM** against bittercress nor small-flower mallow. This may have been due to application timing in relation to rain. Incorporating low rates of TRAMAT® (one tenth recommended) in the BETANAL® sequences (**BTS** vs **BS** strategies) improved control of burr medic, bittercress and slender celery. Even a single application of the low-rate BETANAL®/TRAMAT® mixture **(BT)** gave better burr medic control than 2 applications of BETANAL® alone **(BS)**. In contrast, an additional BETANAL® spray improved control of both bittercress and sowthistle. The optimum time of application for such sequences is still probably at the 2 and 4 leaf stages of the beetroot, rather than the 4 and 6 leaf stages investigated in this experiment.*

Low rate herbicide sequences reduced weed control costs by $65-110/ha. Apart from achieving equivalent or better weed control with low-rate sequences, there is also less chance of crop damage, or of herbicide residues adversely affecting following crops, compared to the standard commercial strategy.

Relevance to industry

The cost-price squeeze has adversely affected profitability of fresh and processing beetroot production. Weed management in beetroot is costly; current herbicide strategies are expensive, do not provide reliable control and occasionally cause significant crop damage. Beetroot producers are concerned about long-term residues from some herbicides. Previous experiments have shown potential for low rates of beetroot herbicides applied sequentially. These strategies enable earlier weed control, with less risk of crop damage at lower costs. Such methods are already used commercially in sugarbeet in both the USA and Europe.

Objectives

This experiment investigated and demonstrated low application rates on efficacy and phytotoxicity of post-emergence herbicides in beetroot production. Effects of treatments on weeds, beetroot growth, yield and quality were measured. Information gained was used to develop strategies for further evaluation and extension to commercial producers.

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 4 replicates of 5 weed management treatments arranged in blocks. The experiment was sown on 22 April 1996.

The soil was prepared as per standard practice for a beetroot crop. Beetroots (cv. *New Globe*) were sown in rows 0.75 m apart. Intra-row spacings were 0.05 m, giving a total sown population of 267,000 plants/ha. A compound fertiliser (Crop King CK77S) was applied at 350 kg/ha one week before sowing and incorporated with cultivation. A side-dressing of 60 kgN/ha as urea was applied on 24 May 1996, 32 days after sowing, and incorporated with irrigation. Apart from treatments detailed below, no other pesticides were applied.

Irrigation

Irrigations via solid set spray lines were scheduled based on data from tensiometer stations installed in the crop about 4 weeks after sowing.

Tensiometers were installed 15 cm and 60 cm below ground level in plots treated with the standard, commercial herbicide strategy. LOCTRONIC® tensiometers were used, which consist of a standard ceramic tip and tube, but no vacuum gauge. To obtain readings, a needle is forced through the rubber septum at the top of the tensiometer, and an electronic vacuum gauge senses the vacuum in the small air gap below the septum. Tensiometer readings were recorded around 8-9 am daily.

Weed management treatments

The following herbicides were used in this experiment.

1. BETANAL® (phenmedipham 157 g/L EC) - registered for post-emergence spraying when beetroot has 2-4 true leaves and weeds are correspondingly small. It is known to cause crop damage where temperatures exceed 32°C. BETANAL® is mainly used for broadleaf weed control, and is not active against most grasses. It is frequently used in combination with TRAMAT®.

2. TRAMAT® (ethofumesate 200 g/L EC) - registered for pre and post-emergence use in beetroot, controlling both grass and broadleaf weeds. In recent times there has been concern that this herbicide has been causing crop damage at registered rates, as well as having adverse effects on following crops.

All herbicides were applied with a motorised knapsack sprayer. The 1.5 m wide hand-held boom had 110° flat-fan nozzles spaced 0.30 m apart. It was operated at 200 kPa and sprayed 270 L/ha. The weed management treatments in this experiment are detailed below.

1. **(BT)**. BETANAL® applied at 2.5 L/ha plus TRAMAT® applied at 0.5 L/ha when the beetroots had 4 true leaves, on 14 May 1996, 22 days after sowing (DAS).

2. **(BS)**. BETANAL® applied at 2.5 L/ha when the beetroots had 4 true leaves, on 14 May 1996 (22 DAS), followed by 2.5 L/ha 7 days later.

3. **(BTS)**. BETANAL® applied at 2.5 L/ha plus TRAMAT® at 0.5 L/ha when the beetroots had 4 true leaves, on 14 May 1996 (22 DAS), followed by 2.5 L/ha of BETANAL® and 0.5 L/ha of TRAMAT® 7 days later.

4. **(COM)**. The commercial treatment of BETANAL® and TRAMAT® each applied at 5 L/ha, when the beetroots had 4-6 true leaves, on 21 May 1996 (29 DAS).

5. **(HW)**. This treatment was hand weeded as necessary.

There was 10 mm of rain within 4 hours of the first spray applications on the 14 May 1996. This would almost certainly have reduced the efficacy of the BETANAL® component of the spray mixtures.

Measurements

The growth of beetroot plants and weeds were monitored throughout the growing period. Widths of 5 randomly selected beetroot plants from each plot were measured on 3 June 1996, 42 DAS. Two m of beetroot row were hand-harvested from each of 4 beds per plot on 13 August 1996, 113 DAS. The beetroots were graded into small, medium and large beets, counted and weighed. Weeds in each plot were counted 37 DAS and 71 DAS. On 15 August, 2 days after the beetroot were harvested, weeds from the central 6 m of 4 randomly selected beds in each plot were harvested, sorted into species, counted and weighed.

Data analyses

All beetroot growth and yield variables were analysed using standard analysis of variance. Owing to the nature of their distributions, weed counts and weights were log-transformed prior to analysis. The transformed data were converted back to normal values prior to presentation in tables and figures.

Results and discussion

Irrigation

During the second week after sowing, nearly 500 mm of rain fell (Fig. 1). Fortunately, most of the excess water slowly ran off the experiment area. In addition, overcast weather during the following weeks allowed the beetroot plants to recover without being put under serious moisture or temperature stresses. In the remainder of the growing period, only another 30 mm of rain fell, around 97 DAS. For the bulk of the growing period, the beetroot crop was irrigated when average shallow tensiometer values reached 40 kPa. The crop received a total of 158 mm of irrigation, averaging 25-35 mm every 2 weeks (Fig. 1).

Fluctuations in both the shallow and deep tensiometer values suggest the beetroot root systems were effectively taking up water from a reasonable depth, and that there were no obvious times of water stress during the growing period. Similarly, there was no evidence of excess irrigation causing significant through-drainage of water. The coincident rainfall that accompanied the final irrigation at 97 DAS may have drained through the profile. Irrigation in this experiment was relatively optimal, particularly given the very wet start. We were very fortunate that the beetroot plants recovered from the waterlogged conditions at sowing, to grow and yield normally.

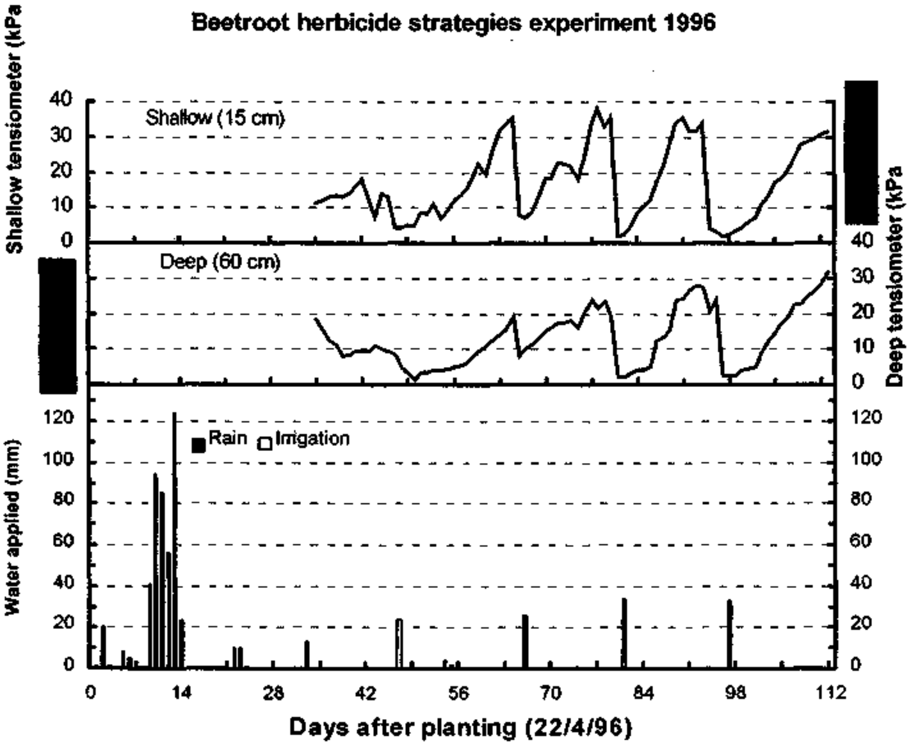


Figure 1. **Fluctuation in tensiometer values with rainfall and irrigation during the growing period of beetroot.**

Weed management strategies

Beetroot growth and yield

At 42 DAS, there was a significant trend for smaller beetroot plants in areas sprayed with the commercial mixture of 5 L/ha of BETANAL and 5 L/ha of TRAMAT (Fig. 2). There were no other symptoms of herbicide damage.

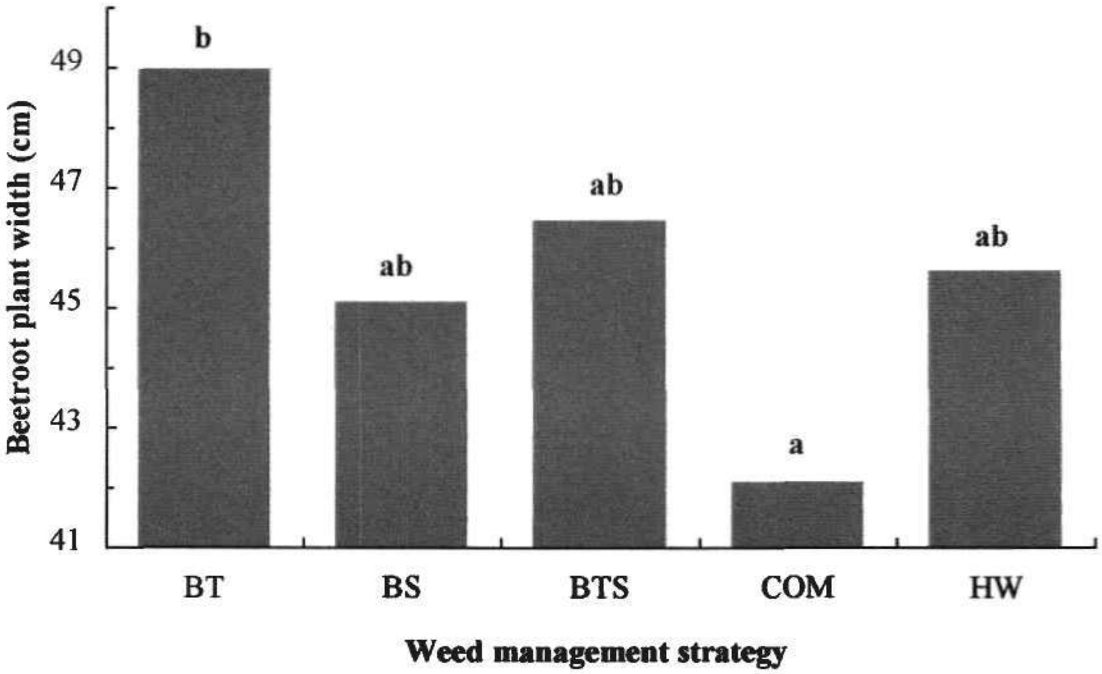


Figure 2. Weed management strategies affect the widths of beetroot plants on 3 June 1996. Treatments with the same lettering are not significantly different.

There were no significant differences in beetroot yields between the 5 weed management strategies. The average yield across the experiment was 42.1 t/ha, mostly medium and large size beets (Fig. 3). This yield was obtained from an average of 191,000 beets/ha (Fig. 4), meaning that harvestable beets were produced from 72% of sown seed. Given the extremely wet conditions just after planting, this was a very acceptable result. The mean individual weight of the small beets was 72 g, of the medium beets 206 g, and the large 411 g (Fig. 5).

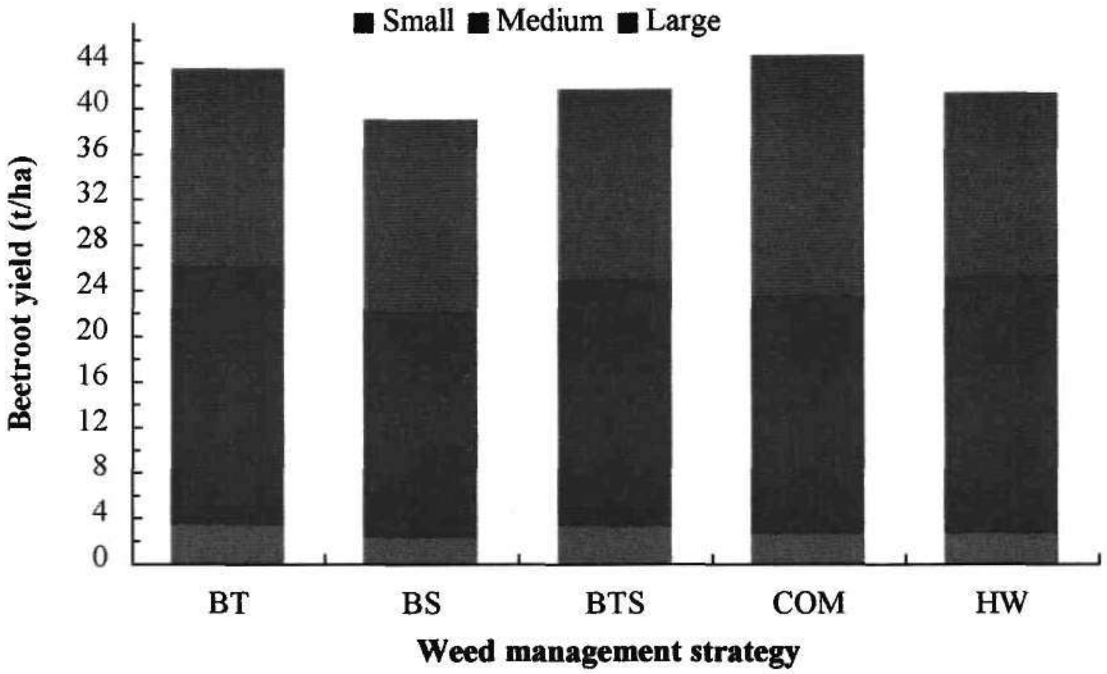


Figure 3. Weed management strategies did not significantly affect total beetroot yields, nor the proportion in each size grade.

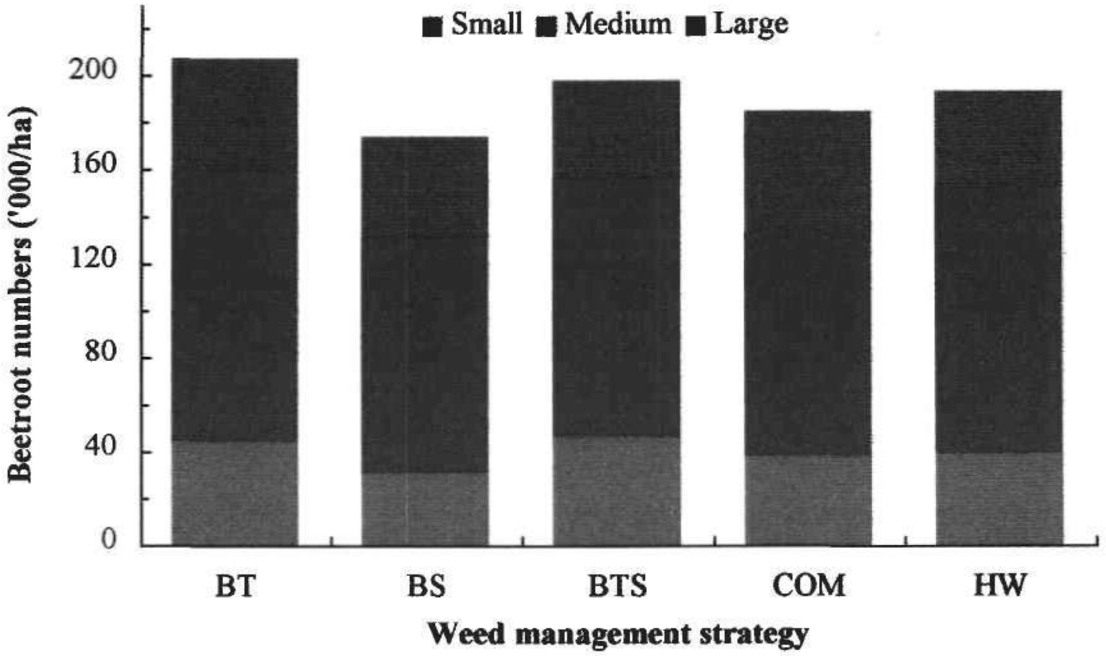


Figure 4. Weed management strategies did not significantly affect total beetroot numbers, nor the proportion in each size grade.

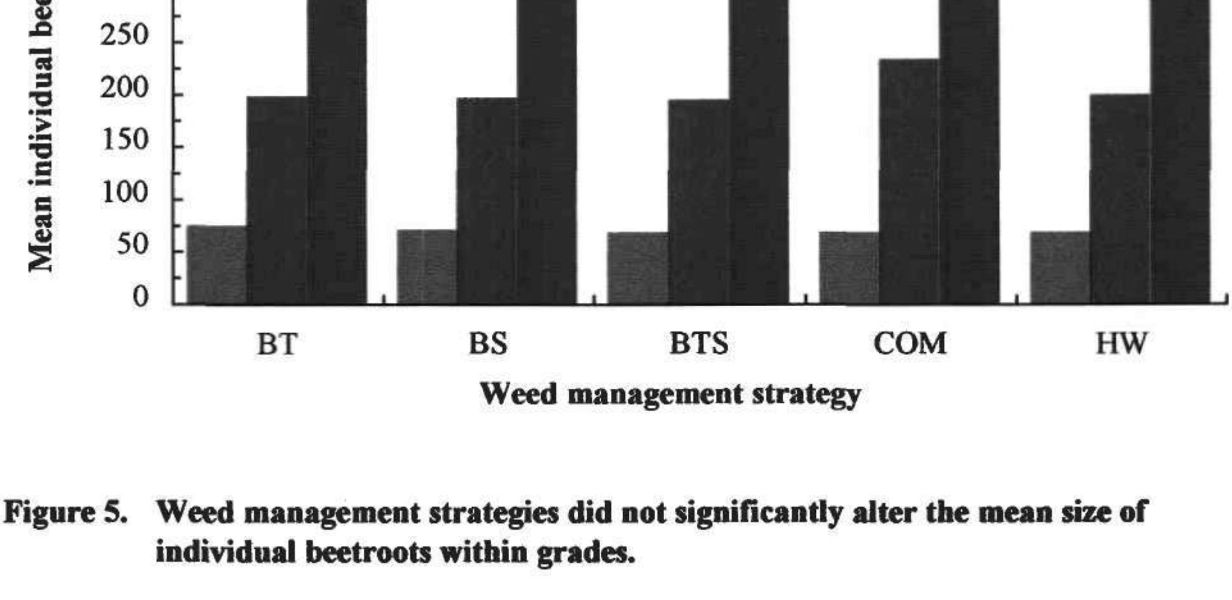


Figure 5. Weed management strategies did not significantly alter the mean size of individual beetroots within grades.

Weed control

Weed species consistently found were; burr medic (*Medicago polymorpha*), bittercress (*Coronopus didymus*), sowthistle (*Sonchus oleraceus*), fleabanes (*Conyza spp.*), slender celery (*Apium leptophyllum*), fat hen (*Chenopodium album*), and amaranthus (*Amaranthus viridus, Amaranthus macrocarpus).* Other weeds present in minor occurrences included bladder ketmia (*Hibiscus trionum*), bellvine (*Ipomoea plebia*), deadnettle (*Lamium amplexicaule*), giant pigweed (*Trianthema portulacastrum*), small-flower mallow (*Malva parviflora*), wireweed (*Polygonum aviculare*), and blackberry nightshade (*Solanum nigrum*).

The first weed count took place before the initial hand-weeding of the **HW** strategy, hence the relatively larger number of weeds in that treatment. Both the **BT** and **BS** strategies significantly reduced total weed numbers compared to the unweeded areas (Fig. 6). The **BTS** and **COM** strategies were even more effective. The commercial standard (**COM**) and BETANAL®/TRAMAT® sequence (**BTS**) gave superior control of bittercress, sowthistle, fat hen and amaranthus, compared to the **BT** and **BS** strategies, which gave significant suppression. All 4 herbicide strategies significantly suppressed slender celery and giant pigweed (the latter made up the bulk of the 'other' category) at this early stage (Fig. 6).

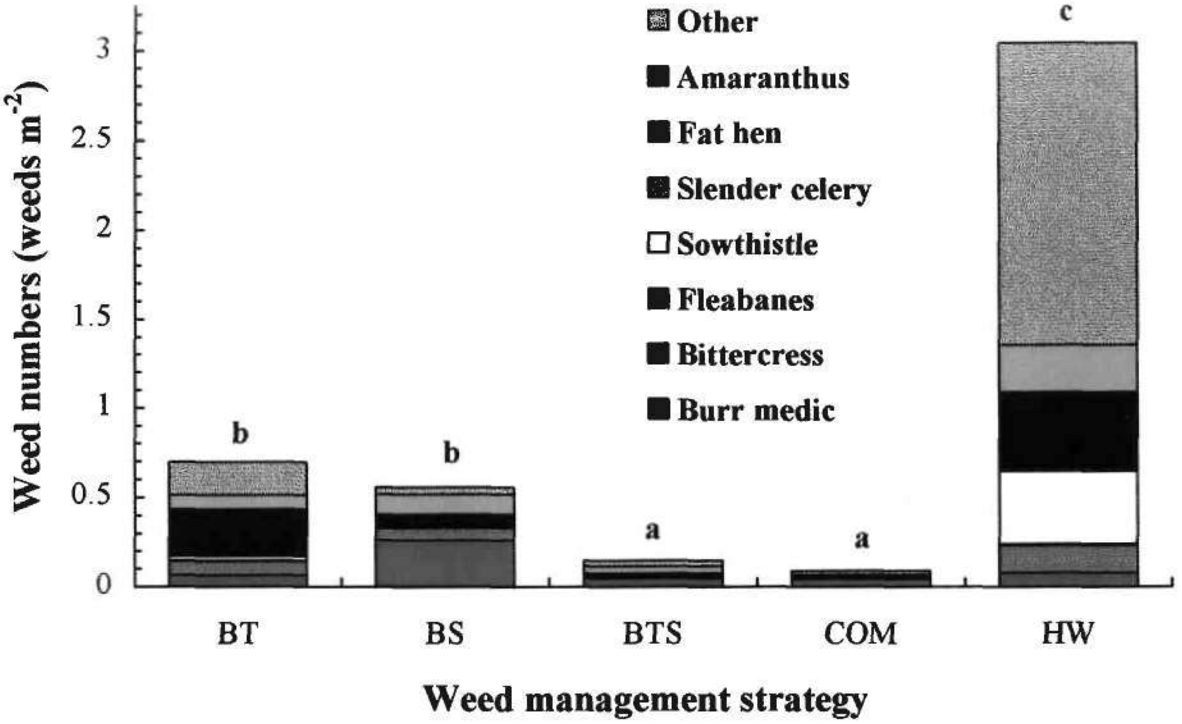


Figure 6. Weed management strategies affect the numbers of various weeds in a beetroot crop 37 DAS. Treatments with the same lettering do not have significantly different total weed numbers.

The hand-weeded treatment (**HW**) had very few weeds at the second weed count, 71 DAS. Amongst the herbicide treated plots, there was a significant trend for greater weed numbers as the total amount of herbicide applied declined; ie. the **COM** strategy had fewest and **BT** strategy most weeds (Fig. 7). Weed management strategy did not significantly alter the numbers of sowthistle, slender celery nor amaranthus weeds present across the experimental area. The single application of a low-rate BETANAL®/TRAMAT® mixture (**BT**) had significantly more fat hen than the other treatments. The hand-weeded treatment had significantly lower numbers of burr medic, bittercress and fleabanes, compared to herbicide strategies. The **COM** strategy had low burr medic and bittercress counts, but relatively high fleabane numbers (Fig. 7), whilst the **BTS** strategy gave reasonable control of all 3 of these species. The single application of BETANAL®/TRAMAT® gave good suppression of burr medic and fleabane, but was less effective (relatively) against bittercress.

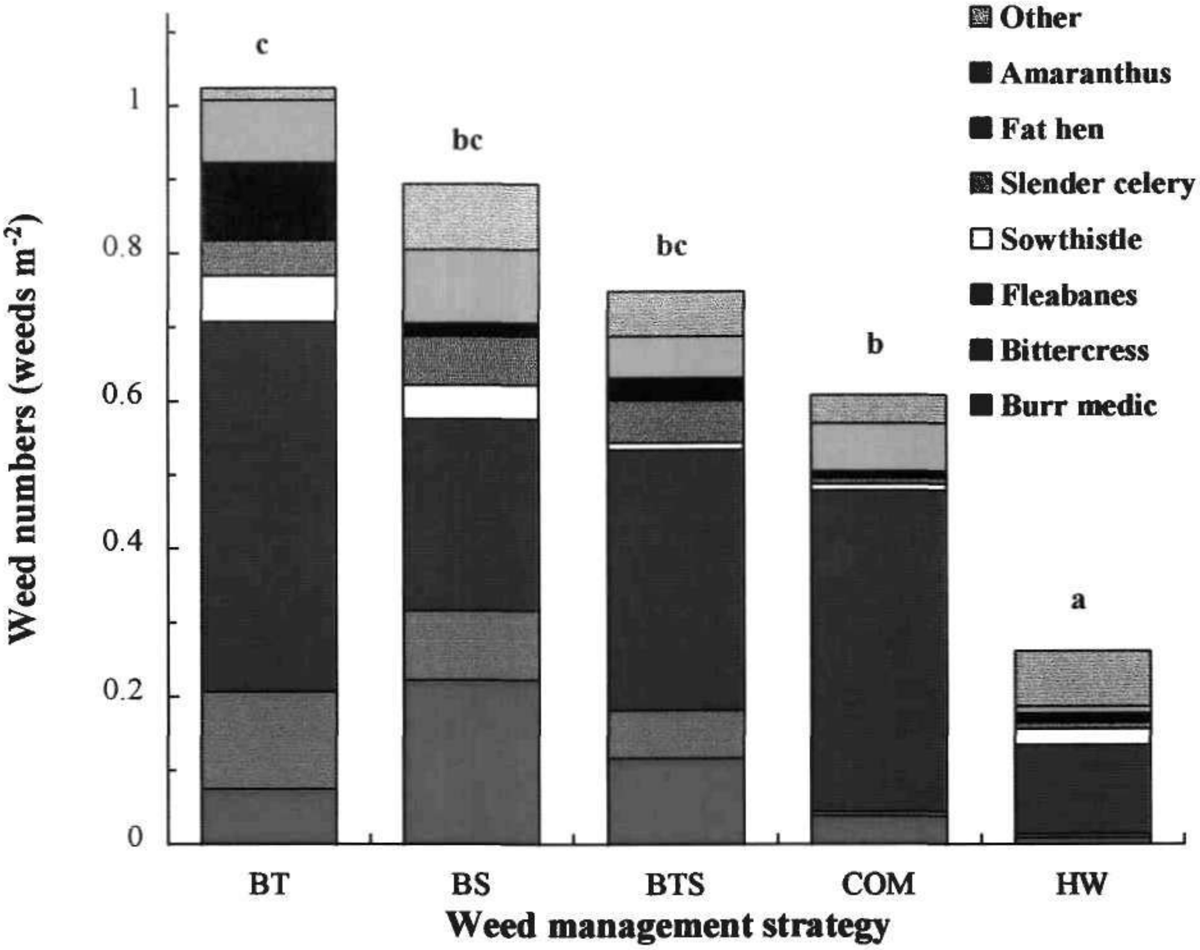


Figure 7. Weed management strategies affect the numbers of various weeds in a beetroot crop 79 DAS. Treatments with the same lettering do not have significantly different total weed numbers.

By the time the beetroots were harvested, the numbers of weeds had increased about 10-fold compared to previous weed counts. The hand-weeded treatment had fewest weeds (about 1 m^{-2}), most of which were fleabanes and fat hen (Fig. 8). The **COM** and **BTS** strategies had similar total weed numbers; the **BTS** plots had slightly more bittercress and fleabane, with no significant difference in counts of other species. The **BT** and **BS** strategies had nearly twice as many weeds as the other 2 herbicide treatments. This was mainly due to greater numbers of burr medic and bittercress, and to a lesser extent slender celery. Comparing the **BT** and **BS** strategies, the former was more effective against burr medic, but less effective against bittercress and fat hen (Fig. 8).

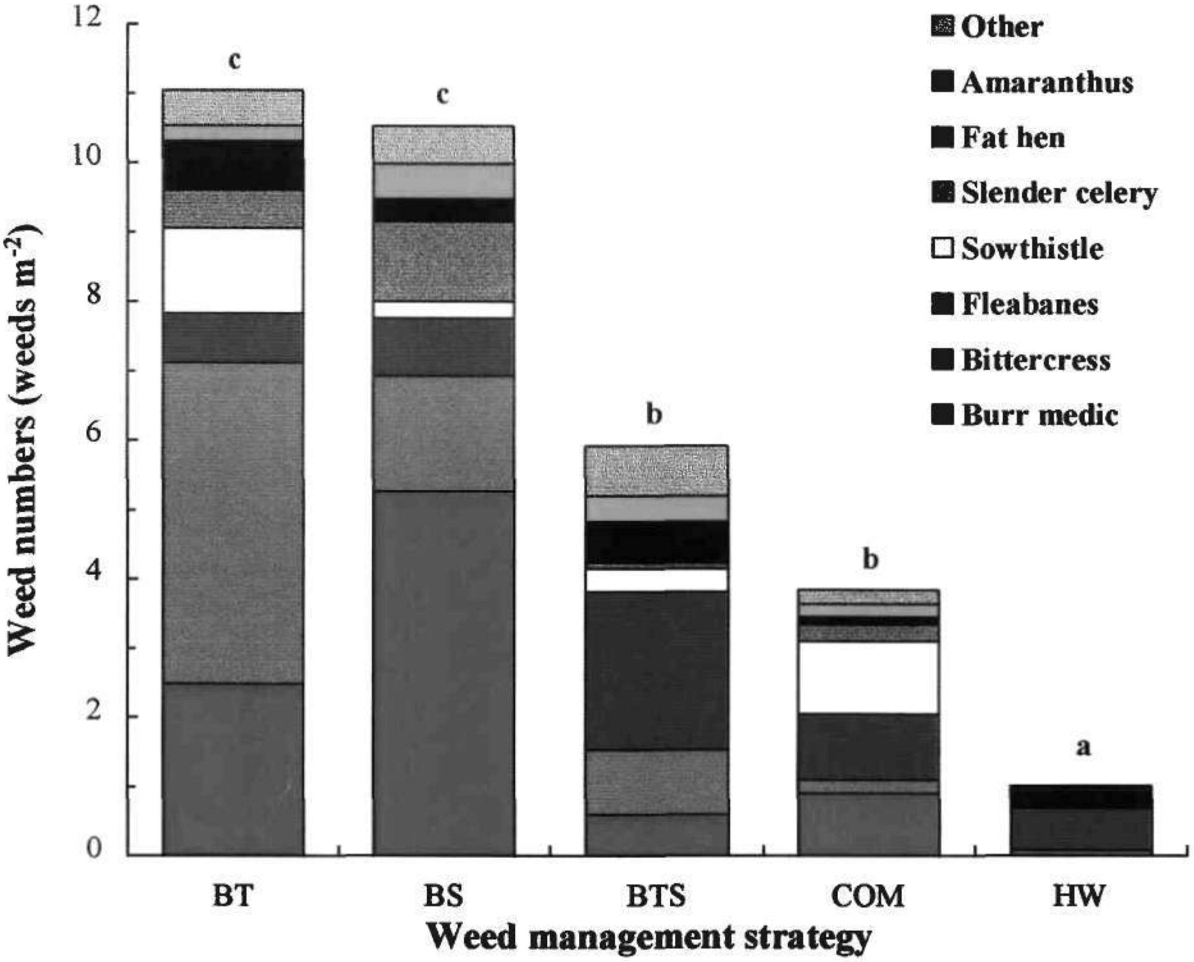


Figure 8. Weed management strategies affect the numbers of various weeds in a beetroot crop immediately after harvest (115 DAS). Treatments with the same lettering do not have significantly different total weed numbers.

The hand-weeded strategy (**HW**) had the least weed biomass present when the beetroots were harvested (Fig. 9a). The low rate BETANAL®/TRAMAT® sequence (**BTS**) and standard commercial (**COM**) strategies had significantly more weed biomass, but less than 20% of the average biomass in the other 2 herbicide treatments. Three species, burr medic, bittercress and sowthistle, comprised most of the weed biomass (Fig. 9).

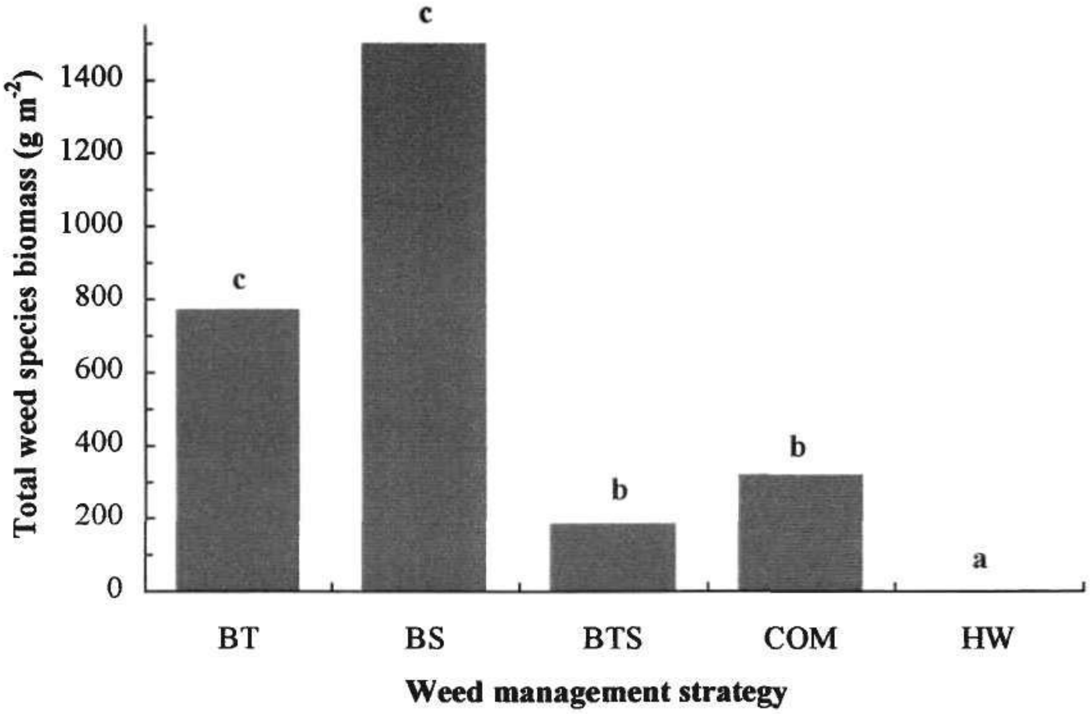


Figure 9. Weed management strategies affect total weed biomass in a beetroot crop immediately after harvest (115 DAS). Treatments with the same lettering do not have significantly different total weed biomass.

Both the **BTS** and **COM** strategies gave good control of burr medic. The single application of low-rate BETANAL/TRAMAT mixture **(BT)** gave reasonable suppression of burr medic, whilst the BETANAL sequence **(BS)** was significantly less effective (Fig. 10). Bittercress control was effective in both the **BTS** and **COM** strategies. The **BS** treatment gave slightly better suppression than the single low-rate **BT** strategy. Sowthistle growth was effectively controlled by the sequential strategies **BT** and **BTS**, whilst the single applications of BETANAL/TRAMAT mixtures at both low **(BT)** and commercial **(COM)** rates were less successful (Fig. 10).

The most effective herbicide treatment for slender celery management was the **BTS** strategy, which was slightly better than the **COM** treatment, and significantly better than both the remaining low-rate strategies (Fig. 10). The **COM** strategy gave significantly better control of the 'other' weed species, principally small-flower mallow. There were no significant differences between treatments in the biomass of other weed species such as fat hen, fleabane and amaranthus.

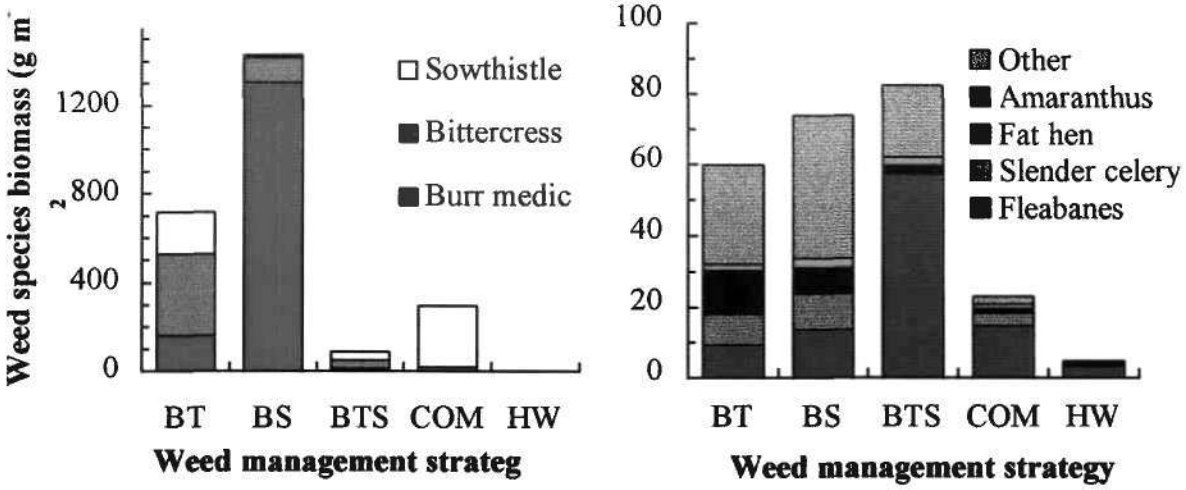


Figure 10. Weed management strategies affect the biomass of weed species in a beetroot crop immediately after harvest (115 DAS).

Conclusions

In most seasons, the heavy rain we encountered soon after sowing would have resulted in the complete loss of the beetroot crop. We were fortunate that mild weather following the rain enabled the beetroot plants to re-establish their root systems. As in previous experiments, using tensiometers to schedule irrigation meant water was efficiently used, with no apparent periods of crop stress nor water wastage through excess irrigation. The good yields in the experiment, (averaging 42 t/ha across all treatments), particularly in the light of the terrible early growing conditions, reflect sound agronomic management during the growing period.

The commercial strategy of applying 5 L/ha of both BETANAL® and TRAMAT® when beetroots have 4-6 true leaves significantly reduced early growth of the beetroot, but the plants had recovered by harvest to give yields equivalent to the other treatments. Each of the weed management strategies had similar numbers and weights of beets in the 3 size grades. There may have been a slight trend for marginally lower yields in the low-rate BETANAL® sequence treatment (**BS**), possibly due to less effective weed control.

Each of the 4 herbicide strategies gave good early suppression of weeds, with **BTS** and **COM** treatments most effective. By 71 DAS, there was less than 1 weed m^{-2} in all treatments. The **BTS** and **COM** treatments still had fewer weeds than the other 2 herbicide strategies.

By the time the beetroot were harvested, burr medic, bittercress and sowthistle made up the bulk of the weed biomass. The areas sprayed with low-rates of BETANAL®/TRAMAT® in a sequence had slightly more weeds than the standard commercial treatment, but total weed biomass was less in the former. Both the **BTS** and **COM** strategies effectively controlled burr medic, bittercress, sowthistle, slender celery, and fat hen. Efficacy against fleabane and amaranthus cannot be determined, however these did not contribute significantly to weed biomass. The sequenced application seemed to give better control of burr medic and sowthistle, but was not as effective as the commercial strategy against bittercress nor small-flower mallow. This could have been because of rain soon after the first spray application, when both bittercress and small-flower mallow may have already emerged.

Weed control in the **BT** and **BS** treatments was probably commercially acceptable, although it may have adverse implications for seedbank build-up. The extent of burr medic growth in the **BS** treatment may have caused a slight suppression in beetroot yield. Incorporating low rates of TRAMAT® (one tenth of the recommended rate) in the BETANAL® sequences (**BTS** vs **BS** strategies) dramatically improved weed control, particularly of burr medic, bittercress and slender celery. Even a single application of the low-rate BETANAL®/TRAMAT® mixture (**BT**) gave better burr medic control than 2 applications of BETANAL® alone (**BS**). In contrast, an additional BETANAL® spray improved control of bittercress and sowthistle.

Because of the heavy rain at the beginning of May, we were unable to apply the herbicide treatments at their optimum time. In addition, rain soon after the herbicide application may have reduced the efficacy of the BETANAL® component in the sprays. In these adverse circumstances, the low-rate sequences were still sufficiently robust to give effective weed control. The optimum time of application for such sequences is still probably at the 2 and 4 leaf stages of the beetroot, rather than the 4 and 6 leaf stages investigated in this experiment.

A:ne that in all the herbicide strategies the applications are only sprayed over the central thof each beetroot row, and that inter-row weeds are controlled by cultivation. Further asıe that post-emergence spraying with 5 L/ha of BETANAL® mixed with 5 L/ha of TIMAT® is the standard commercial practice, and that yields from each of the strategies w:dentical. Costs for application are $5/ha, whilst BETANAL® is priced at $50/L, and TIMAT® $45/L. We can calculate that herbicide application cost-savings for the **BT** stıgy was $110/ha, for the **BS** strategy $80/ha, and for the recommended **BTS** strategy $(a.

A| from achieving equivalent or better weed control with low-rate sequences, there is also le:hance of crop damage or of herbicide residues adversely affecting following crops, coared to the standard commercial strategy,. In previous experiments, increases in pr ability have largely been due to less crop damage from the low-rate herbicide trıents, although there was about a $60/ha contribution from reduced weed control costs. C(nercial applications of these weed control strategies need to be tested over larger areas, in)ducers' crops, and in situations with greater weed burdens. The practicality of this syn will be evaluated on beetroot producers' properties during the 1997 season.

Appendix 7. Experiment CORN1 January-May 1994

Performance of sweet corn cultivars under different planting pattern and irrigation regimes at 2 sowing times

by Craig Henderson and Mick Webber
QDPI Gatton Research Station

Summary

The experiment was conducted at Gatton Research Station, January-May 1994. Sweet corn was planted in late-January and mid-February, in blocks irrigated according to pre-set intervals, or scheduled using tensiometer data. Within each irrigation block, cultivars Florida StaySweet or the QDPI-bred H5 were sown, at 0.75 m or 1 m inter-row spacings, and sowing rates of 50 000 or 70 000 seeds/ha.

The most important factor affecting production was cultivar selection. Due to Maize Dwarf Mosaic virus infection, Florida StaySweet yields in Planting 1 were around 12 t/ha less than H5, due to both fewer and smaller cobs. Cobs from H5 were significantly better quality than Florida StaySweet.

In our 2 plantings, scheduling irrigation using tensiometers did not increase yields or quality of sweet corn, compared to the system where crops were irrigated with a set amount on a regular basis. However, by using tensiometers, total irrigation applied was reduced by 0.5 ML/ha (20%) in the early sowing and 0.8 ML/ha (30%) in the later sowing. If less rain had fallen during the growing period, water savings may have been more substantial

Results for plant arrangement and population were inconclusive, however there appeared to be a yield advantage from sowing in narrow rows. In an ideal situation, optimum profitability would probably be achieved with a system producing a single cob per sweet corn plant. This would synchronise silking and maturity, (reducing the number of insecticidal sprays required) and increase the uniformity and quality of machine harvested cobs. This production system would be best achieved by high population of plants in a relatively square planting arrangement, i.e. equal distances between rows and plants within the row. This hypothesis will be tested in future experiments.

Introduction

In Queensland, sweet corn is grown on about 3000 ha per annum (circa 20% of Australian production), with a gross return of approximately $25 million. The cost-price squeeze is adversely affecting profitability of this industry. To remain viable, producers must reduce their costs per unit product, or develop new, value-added products. By utilising new tropical sweet corn genetics developed by QDPI, there is potential for marked expansion in Queensland production (up to 10 000 ha). Developing agronomic packages to utilise this genetics is an important prerequisite to that expansion.

This experiment was part of a project developing agronomic packages to reduce growers' per unit costs. In southern Queensland, average sweet corn yields are around 15-20 t/ha. There is scope for slight increases in yields and enhanced cob quality by combining new cultivars with improved agronomy. High yielding, quality sweet corn depends on good stand establishment and effective nutrient and water management. Factors such as sowing densities, planting arrangements and soil insect management appear to be prime determinants of cob density/ha. Sweet corn is a major user of irrigation water, however at the present time there is little use of irrigation scheduling in sweet corn production. This experiment sought to examine the effectiveness of different planting strategies under a range of irrigation regimes.

Objectives

This experiment investigated how sweet corn cultivars respond to planting densities and arrangements, under a range of irrigation regimes, on black earth soils, at 2 times of planting.

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 overall experiment involved 2 planting dates, 2 irrigation regimes, 2 row spacings, 2 cultivars and 2 sowing populations. Each planting date was sown in a separate area. At each planting, 2 sweet corn blocks were sown; with dimensions 100 m long and 10 m wide, separated by a 15 m buffer zone. One block was irrigated according to a calendar schedule, the other block irrigated based on tensiometer readings within the block.

Within each irrigation block, one half was planted with 1 m between the sweet corn rows, while the inter-row spacing in the other half was 0.75 m. Within each of these half blocks was a complete factorial experiment, containing the 2 cultivars and 2 planting populations, replicated in 4 blocks. Each half-block was statistically analysed as a separate experiment, with results then combined where appropriate. Cultivars used were a standard commercial line *Florida StaySweet*, and the QDPI-bred-*H5*. *H5* has been bred for resistance to Maize Dwarf Mosaic (MDM) virus and rust, to which *Florida StaySweet* is susceptible. Plant populations sown in this experiment were 50 000 (low pop.) and 70 000 (high pop.) seeds/ha.

It was intended to irrigate the calendar scheduled blocks with 60 mm every 12 days until tassel emergence, increasing to 40 mm every week until harvest. The tensiometer scheduled blocks were to be watered according to schedules determined from tensiometers placed in plots planted at the high sowing rate. Tensiometers installed 15 cm below ground level were used to determine when the crop needed irrigating; tensiometers at 60 cm indicated drainage below the effective root zone. The scheduled block was watered at shallow tensiometer values of 50 kPa. Tensiometers were also installed and monitored in the calendar scheduled irrigation blocks. Each block was irrigated using lines of solid-set sprinklers running down the edges of the block. Irrigation blocks were separated by 15 m of fallow ground, to prevent irrigation interference.

LOCTRONIC® tensiometers were used in this experiment, 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 at 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 air gap. Tensiometer readings were recorded daily, usually around 8:30 am. 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.

Each sweet corn plot was 3 rows wide and 10 m long. The soil was prepared as per standard practice for sweet corn. The first planting was sown using a cone planter on 25 January 1994; the second planting was sown 3 weeks later on 17 February 1994.

In each planting, basal compound fertiliser, containing 46 kgN/ha, 8 kgP/ha, 47 kgK/ha and 66 kgS/ha, was applied 10-12 days before sowing. A side dressing of 80 kgN/ha (as urea) was broadcast 31 days after sowing (DAS) in Planting 1 and 33 DAS in Planting 2. A foliar spray containing 1 kg/ha urea and 1 kg/ha zinc sulphate was applied 49 DAS in Planting 1.

The first planting was sprayed with 4 L/ha DUAL® (720 g/L metolachlor) 3 DAS, for pre-emergence weed control. As the experimental area was relatively free of weeds, this herbicide was not applied to the second planting. Both areas were mechanically cultivated when the sweet corn was about 40 cm high.

The insecticide ROGOR® (400 g/L dimethoate) was sprayed at 0.5 L/ha 15 DAS and 49 DAS in Planting 1 and 42 DAS in Planting 2. LANNATE® (225 g/L methomyl) was applied at 2 L/ha 28,49, 63, 73, and 78 DAS in Planting 1 and 42, 69, 75 and 82 DAS in Planting 2. THIODAN® (350 g/L endosulfan) was applied at 2.1 L/ha 63, 67, 73 and 78 DAS in Planting 1 and 69, 75 and 82 DAS in Planting 2.

The establishment of sweet corn plants was assessed by counting the number of healthy plants in the 10 m length of the middle row from each plot. Plants were counted 16 DAS in Planting 1 and 21 DAS in Planting 2. Heights of 5 randomly selected plants in these middle rows were measured 28 DAS in Planting 1 and 22 DAS in Planting 2. *Florida StaySweet* were hand harvested from the middle row of each plot in the first planting on 12 April 1994 (77 DAS). *H5* were hand harvested from Planting 1 on 21 April 1994 (86 DAS). In the second planting, only *H5* were harvested; which took place on 27 May 1994 (99 DAS). At each harvest, the numbers of cobs were counted and the total weights of unhusked cobs recorded. Five cobs were randomly selected from each plot and rated (0=poor quality; 10=perfect quality) for the degree of tip fill, filling at the bottom of the cob, blanking over the whole cob and alignment of kernels (symmetry).

Results

In Planting 1, there were no differences in irrigation applied nor tensiometer fluctuations between the calendar and tensiometer scheduled irrigation blocks for the first 7 weeks after sowing (Fig. 1). During the next 5 weeks until harvest, shallow tensiometers in the calendar scheduled block showed values of 80 kPa between irrigations (Fig. 1a), compared to those in the tensiometer scheduled block, which only reached maxima of 60 kPa (Fig. 1b). Values for deep tensiometers installed in *H5* plots in the calendar scheduled block increased steadily from about 55 DAS until harvest. Results for deep tensiometers in both irrigation blocks indicate some slight deep drainage from excess irrigation at 19 DAS, with no other significant instances during the rest of the growing period. There was probably some deep drainage following rainfall around 25 and 35 DAS.

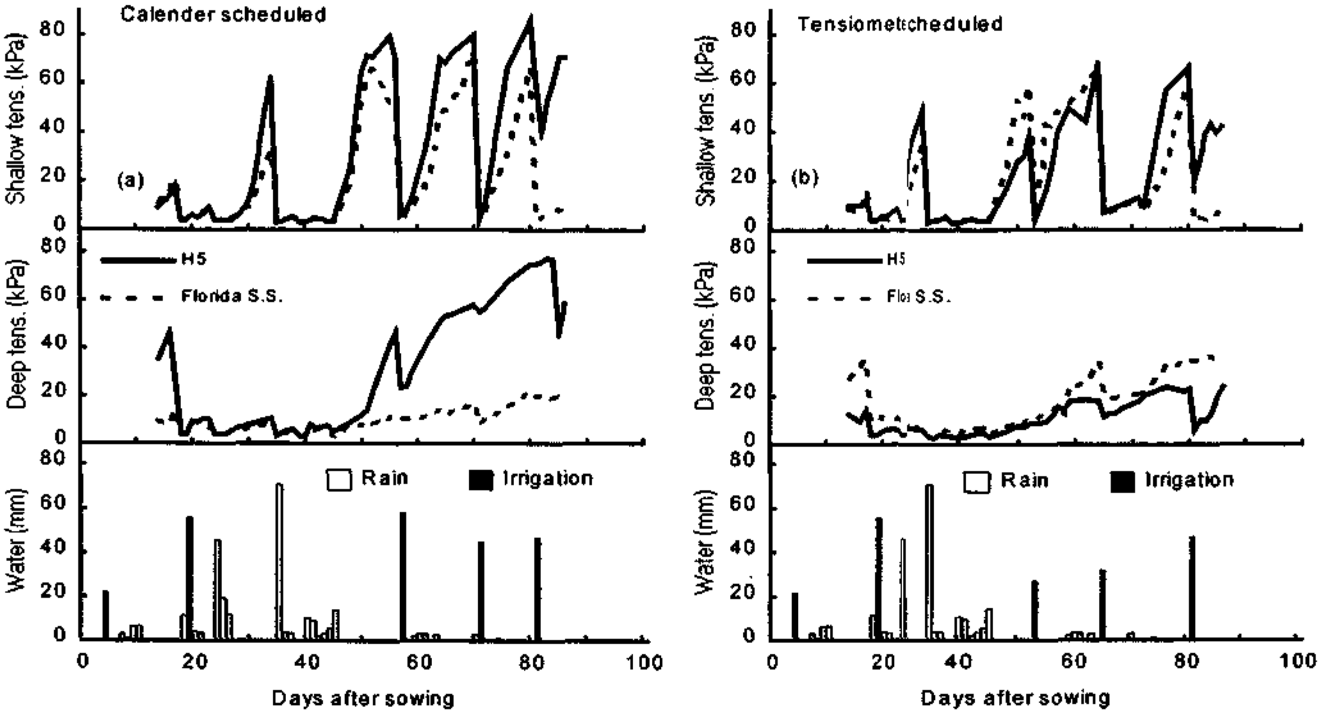


Figure 1. **Fluctuations in soil matric suction at 15 cm (shallow) and 60 cm (deep) below ground level; and water received from rainfall or irrigation; where the first sweet corn plantings were irrigated according to (a) a calendar schedule or (b) tensiometer readings.**

With the second planting, rainfall early in the growing period meant irrigation was not required for the first 5 weeks after sowing (Fig. 2). Shallow tensiometers in both the calendar and tensiometer scheduled blocks fluctuated between 0 and 60 kPa for the whole of the growing period. Between 80 and 90 DAS, sweet corn in the calendar irrigated block were wetter than the tensiometer scheduled crop. Deep tensiometers in both blocks rose to 40-60 kPa after 50 DAS. Values remained relatively high in the tensiometer scheduled block (Fig. 2b), but declined after successive irrigations around 80 DAS in the calendar irrigated sweet corn (Fig. 2a). There was probably no deep drainage of irrigation water in the tensiometer scheduled sweet corn after 40 DAS, while some drainage may have occurred in the calendar irrigated block at 50 and 85 DAS (Fig. 2).

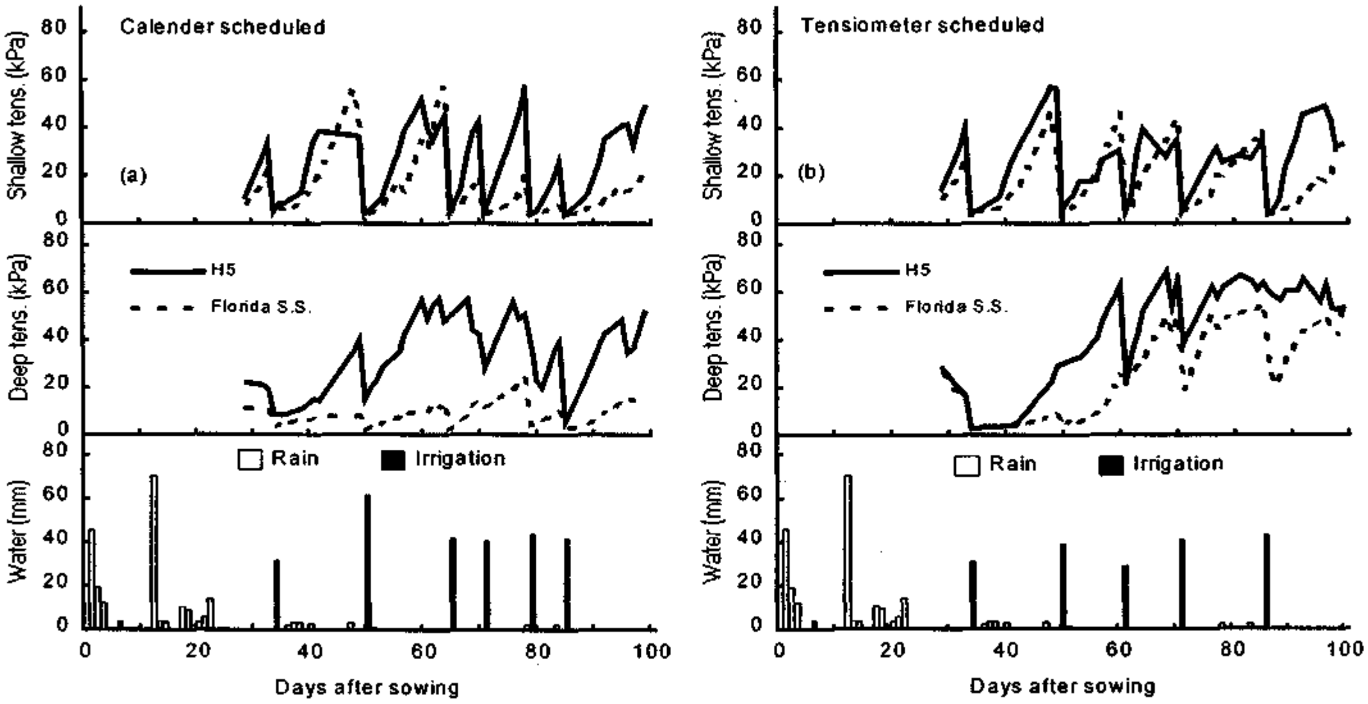


Figure 2. Fluctuations in soil matric suction at 15 cm (shallow) and 60 cm (deep) below ground level; and water received from rainfall or irrigation; where the second sweet corn plantings were irrigated according to (a) a calendar schedule or (b) tensiometer readings.

The first planting received 250 mm of rain, while the second planting received slightly less, at 220 mm. The tensiometer scheduled blocks in both plantings were irrigated with 185 mm of water Totals of 230 mm and 265 mm of irrigation were applied to the calendar scheduled blocks in the first and second plantings respectively.

There were no significant effects of irrigation, row spacing or cultivar on the number of sweet corn plants established at either time of planting (Fig. 3). Consistently across the whole experiment, about 80% of seeds sown established sweet corn plants. This led to significantly more plants in treatments where greater seed populations were planted (Fig. 3). The establishment rate was about 2% lower in sweet corn sown on 17 February (Fig. 3b) compared to that sown on 25 January (Fig. 3a).

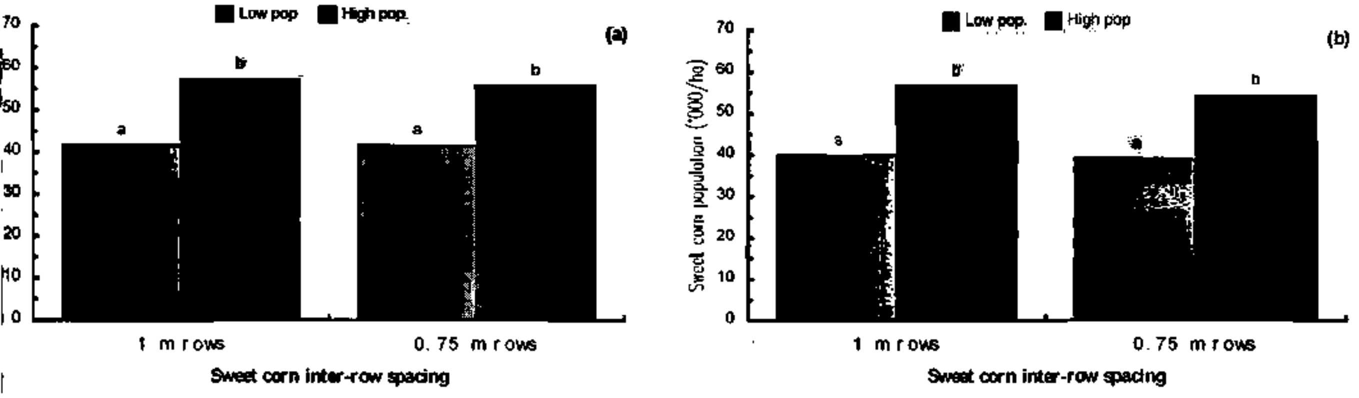


Figure 3. **Sweet corn plant populations were unaffected by irrigation regime, cultivar or row spacing, but were significantly affected by sowing rate, whether sown on (a) 25 January 1994 or (b) 17 February 1994. Within each planting, bars labelled with the same letter are not significantly different.**

The heights of sweet corn plants at 28 DAS in Planting 1 (Fig. 4a) and 22 DAS in Planting 2 (Fig 4b) were not affected by irrigation regime nor sowing rate. In both plantings, sweet corn were taller in the narrower rows, and cultivar *H5* was always taller than *Florida StaySweet.*

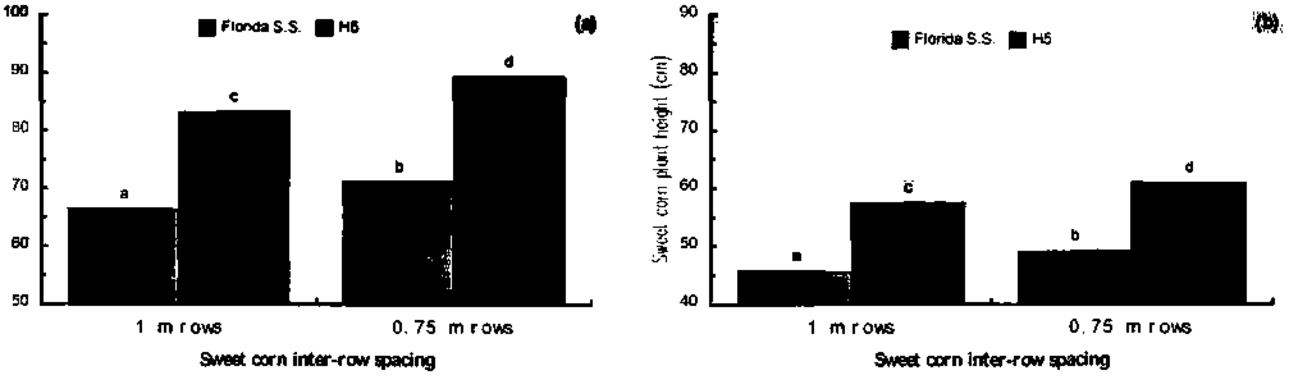


Figure 4. **Sweet corn plant heights were unaffected by irrigation regime, or sowing rate, but were significantly increased by sowing in narrow rows or using a virus resistant cultivar, whether sown on (a) 25 January 1994 or (b) 17 February 1994. Within each planting, bars labelled with the same letter are not significantly different.**

There were no differences in sweet corn yields or cob quality between blocks irrigated according to a calendar schedule, compared to those irrigated based on tensiometer readings. This was consistent across both planting times. The dominant treatment effect in this experiment was the poor performance of the *Florida StaySweet* cultivar, compared to the QDPI-bred *H5*. *Florida StaySweet* was severely affected by MDM virus, particularly in the second planting. Infected plots were severely stunted, producing fewer and smaller cobs. In Planting 2, no marketable cobs were produced in *Florida StaySweet* plots.

Florida StaySweet yields in Planting 1 were around 12 t/ha less than *H5* (Fig. 5a), due to both fewer and smaller cobs (Figs. 5b,c). Cobs from *H5* had significantly better kernel filling around the bottom of the cob, less blanking and better kernel alignment than marketable cobs harvested from *Florida StaySweet* plots (Fig. 5d).

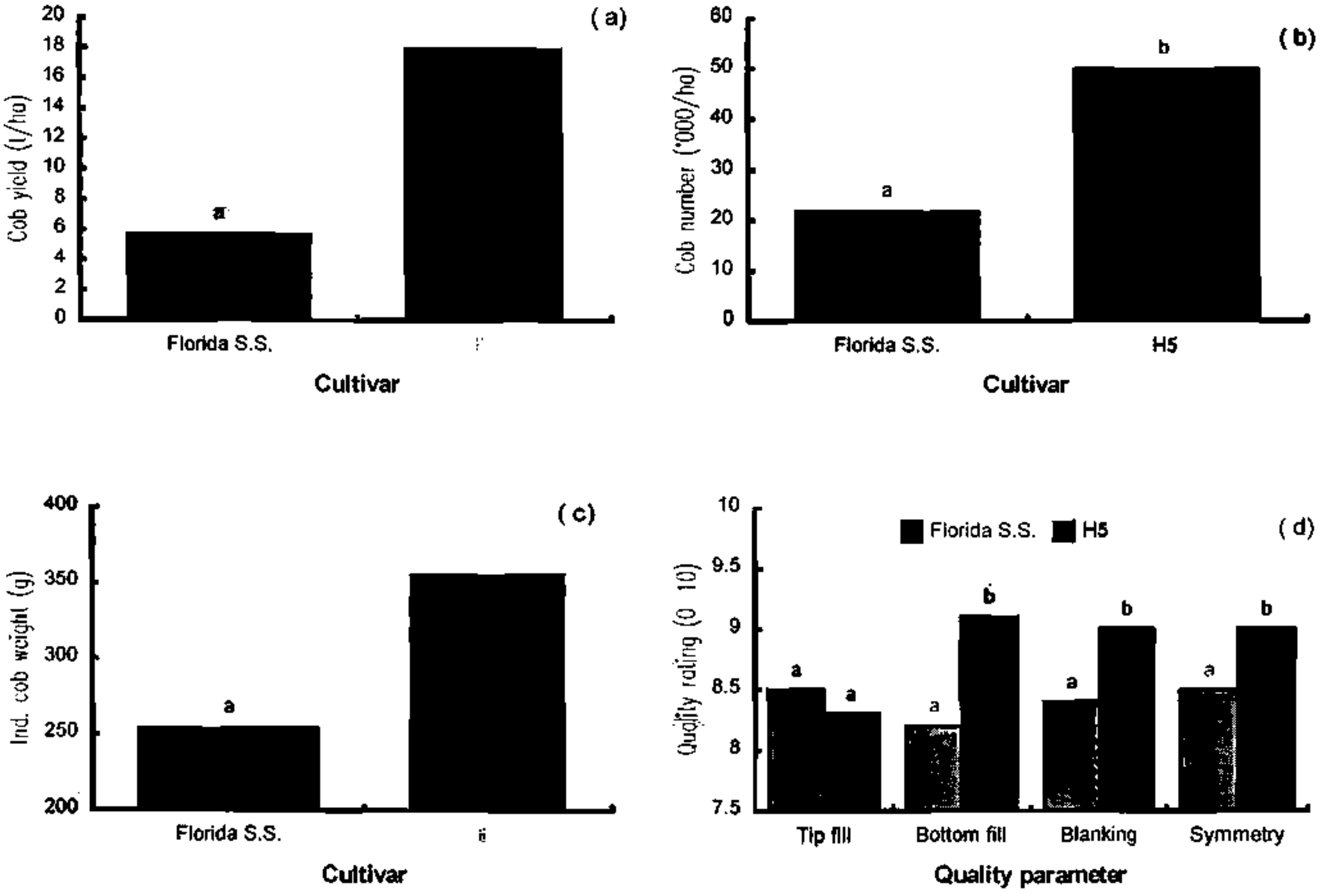


Figure 5. When grown in late summer, the MDM virus resistant sweet corn cultivar *H5* gave superior (a) unhusked cob yields, (b) cob numbers, (c) individual cob weights and (d) cob quality, when compared with the virus susceptible cultivar *Florida StaySweet*. Bars labelled with the same letter are not significantly different.

Because yields of *Florida StaySweet* were so poor, results for this cultivar were excluded when analysing effects of row spacings and plant populations on sweet corn yields and cob quality. Results presented in Figs. 6-9 are for the *H5* cultivar only.

There were consistent trends across both sweet corn plantings for slightly higher yields in plots planted with inter-row spacings of 0.75 m, compared to 1 m row spacings (Fig. 6). There also appeared to be minor yield advantages from higher sowing rates, although gains were more pronounced in Planting 1, compared with Planting 2. Differences in total yields were due to variation in the number of harvested cobs (Fig. 7), rather than differences in the average size of individual cobs (Fig. 8). Neither inter-row spacing nor sowing rate significantly affected the quality of harvested cobs, with all parameters rating 8.5-9.5 (on a 0-10 quality scale), as shown in Fig. 9.

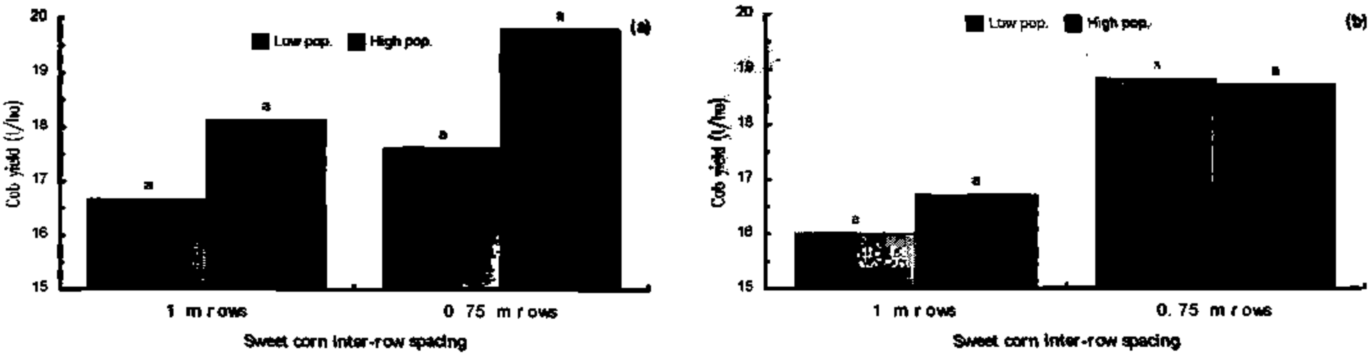


Figure 6. Inter-row spacing and plant populations affect yields of sweet corn cultivar *H5*, sown on (a) 25 January 1994 or (b) 17 February 1994. Within each planting, bars labelled with the same letter are not significantly different.

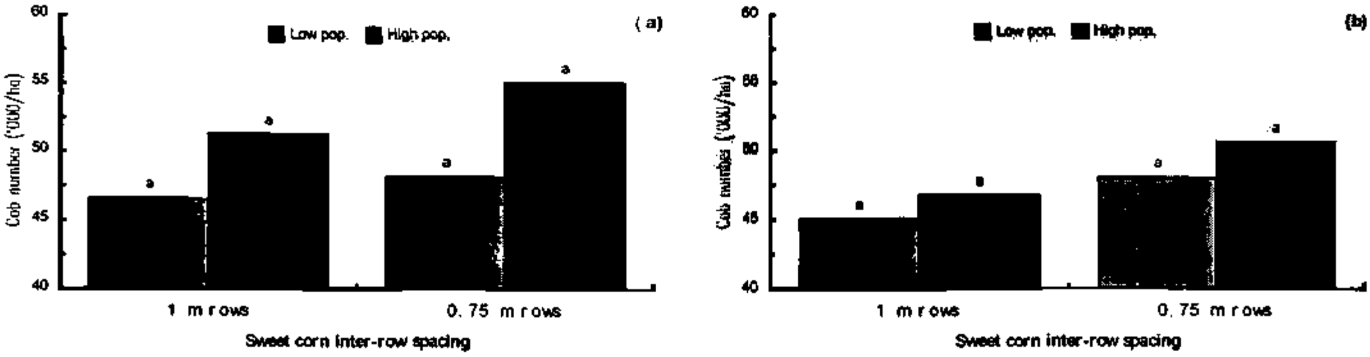


Figure 7. Inter-row spacing and plant populations affect the number of marketable cobs harvested from the sweet corn cultivar *H5*, sown on (a) 25 January 1994 or (b) 17 February 1994. Within each planting, bars labelled with the same letter are not significantly different.

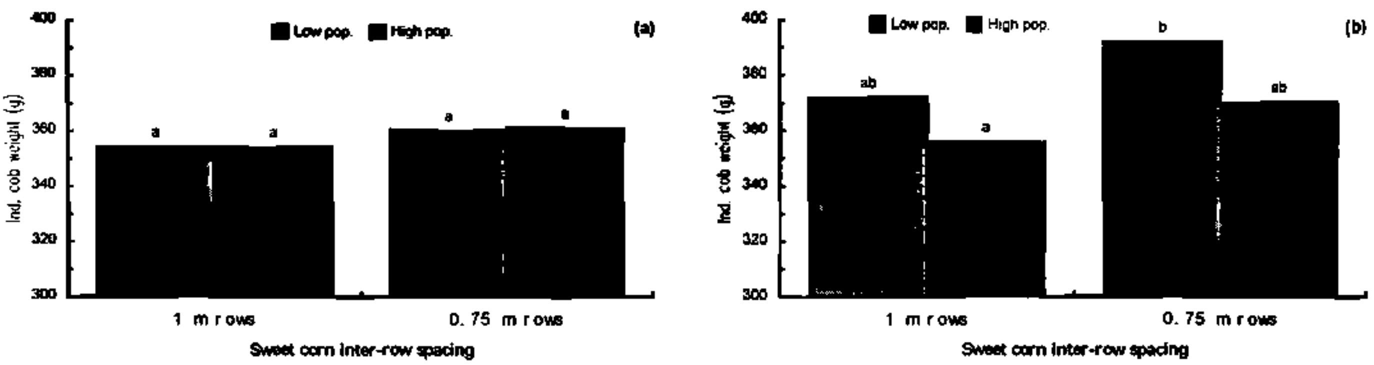


Figure 8. **Inter-row spacing and plant populations have no significant effects on the individual weights of cobs harvested from the sweet corn cultivar *H5*, sown on (a) 25 January 1994 or (b) 17 February 1994. Within each planting, bars labelled with the same letter are not significantly different.**

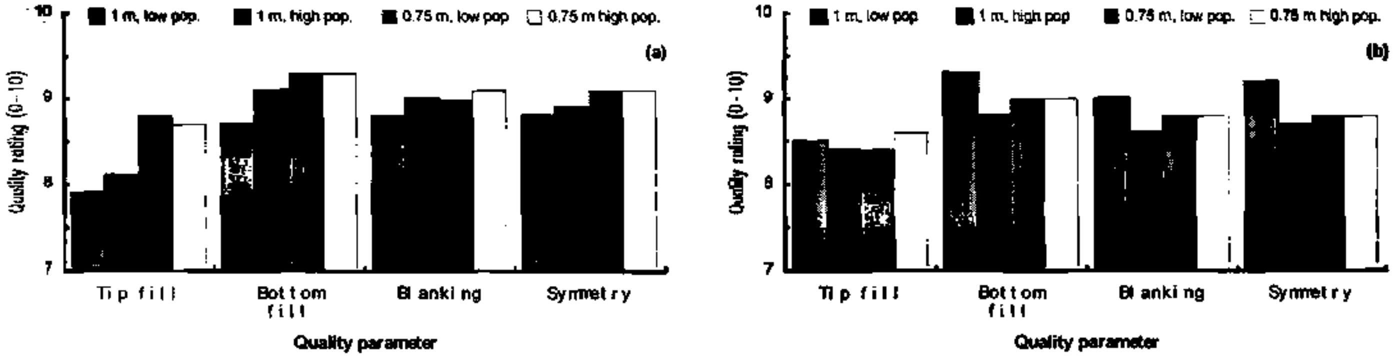


Figure 9. **Inter-row spacing and plant populations have no significant effects on the quality of cobs harvested from the sweet corn cultivar *H5*, sown on (a) 25 January 1994 or (b) 17 February 1994.**

Discussion

The most important factor affecting production in this experiment was cultivar selection. As has been previously shown in cultivar research and grower experience, performance of MDM susceptible cultivars sown after Christmas in southern Queensland is often disastrous. The disease is spread rapidly by aphids, and is carried over by a range of host plants, particularly Johnson Grass (*Sorghum halapense*). At present, the only viable management strategy is use of resistant cultivars. In sweet corn sown after Christmas, this disease infects sweet corn crops early in their life cycle, as evidenced by the stunting of *Florida StaySweet* soon after planting (Fig. 4). This early infection and stunting reduces water uptake (note the lower tensiometer readings for *Florida StaySweet* compared to *H5* in Figs. 1 and 2), photosynthesis, yield and cob quality (Fig. 5).

In absolute terms, yields and quality of the virus resistant cultivar *H5* is obviously commercially acceptable. Availability of this cultivar (and material with similar genetics) enables sweet corn to be sown well into autumn in south-east Queensland. This increases options and potential viability of expanding the sweet corn industry, particularly targeting exports of both fresh and processed products.

In our 2 plantings, scheduling irrigation using tensiometers did not increase yields or quality of sweet corn, compared to the system where crops were irrigated with a set amount on a regular basis. However, by using tensiometers, total irrigation applied was reduced by 0.5 ML/ha (20%) in the early sowing and 0.8 ML/ha (30%) in the later sowing. If less rain had fallen during the growing period, water savings may have been even more substantial. In previous irrigation research, we found a sweet corn crop generally required a total of 3.5-4.0 ML/ha of water (irrigation + effective rainfall) for maximum production, which matches the quantities received by the tensiometer scheduled crops.

Costing tensiometers at $40/ha (including depreciation, installation and monitoring costs), and irrigation at $65/ML, the tensiometer scheduling system paid for itself on irrigation savings alone. Although yield differences between the 2 scheduling systems were not significant, highest yields were obtained in the tensiometer scheduled, narrow-row, high sowing rate plots. In growing periods where intermittent rainfall or conditions of variable evaporative demand occurred, using tensiometers may increase crop yields by enabling more accurate matching of water application with crop requirements. If using tensiometers reduces deep drainage, risks of leaching nutrients or pesticides into groundwater are also minimised.

Results for plant arrangement and population were inconclusive, however there appeared to be a yield advantage from sowing in narrow rows (Fig. 6). In an ideal situation, optimum profitability would probably be achieved with a system producing a single cob per sweet corn plant. This would synchronise silking and maturity, (reducing the number of insecticidal sprays required) and increase the uniformity and quality of machine harvested cobs. This production system would be best achieved by high population of plants in a relatively square planting arrangement, i.e. equal distances between rows and plants within the row. This hypothesis will be tested in future experiments. The requirements for such a system are; (i) accurate seed placement within the row, (ii) effective early season weed control, (iii) a harvesting system capable of handling narrow rows. All of these are possible with slight adaptations of current practices.

Appendix 8. Experiment CORN2 January-April 1995

Planting arrangements for high yielding sweet corn

by Craig Henderson and Mick Webber
QDPI Gatton Research Station

Summary

*An experiment investigating irrigation scheduling, row spacings and plant population densities in sweet corn production was conducted at Gatton Research Station during January-April 1995. The experiment compared sweet corn cultivar H5 sown in Wide (0.75 m) and Narrow (0.375 m) row spacings at Low (70,000 seeds/ha) and High (100,000 seeds/ha) populations. The 4 treatments were labelled **WL, WH, NL** and **NH** respectively. Growth and yields of sweet corn were measured, as were amounts of irrigation and pesticides used.*

Yields in this experiment were relatively high, particularly given an obvious problem with zinc deficiency in part of the experimental area. Highest yields of 22-25 t/ha unhusked marketable cobs in the southern section of the experiment demonstrated the yield potential. Using tensiometers and drip irrigation enabled efficient watering, with no obvious drainage events (apart from that following heavy rainfall), and no periods of water stress likely to have affected crop performance. In previous experiments, irrigation scheduling has led to higher sweet corn yields, more efficient water use, and greater profitability.

There was no yield advantage from increasing the population of sweet corn seeds sown from 70,000/ha to 100,000/ha. Although the number of cobs harvested increased by about 5,000/ha, each cob was smaller. The actual ratio of cobs harvested to seeds sown was much higher in low population areas (96%), compared to high density plantings (72%).

There may have been a slight yield advantage (circa 1 t/ha) from sowing in narrow rows, compared to conventional row spacings. This yield increase would not justify the expense and effort of changing management practices to accommodate these narrower row spacings. Because of low weed numbers, the impact of changing planting arrangements on weed control strategies could not be determined.

Results from this experiment suggest our sweet corn research effort should concentrate on irrigation and heliothus management. This will be pursued in future experimental and demonstration work.

Relevance to industry

High yielding, quality sweet corn depends on good stand establishment, and effective nutrient and water management. Factors such as sowing densities and planting arrangements appear to be prime determinants of cob density/ha. Studies by Dr John Teasdale in Maryland, USA, have shown weed control benefits from plant arrangements with narrower rows and higher populations than conventionally employed. Although a major user of water, at the present time there is little use of irrigation scheduling in sweet corn. Previous experiments have shown increases in yields and irrigation efficiency from using tensiometers in sweet corn.

Objectives

This experiment investigated how the tropically adapted cultivar *H5* responded to changes in planting densities and row spacings under a scheduled irrigation regime. Effects of treatments on weeds, sweet corn growth, yield and cob quality were measured, as were fertiliser, pesticide and irrigation inputs. Information gained was used to develop strategies for further evaluation and extension to commercial producers.

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 split-plot, with row-spacing as main plots and plant populations as sub-plots. Row spacings of 0.75 m (**Wide**) and 0.375 m (**Narrow**) were achieved by respectively sowing 2 and 4 rows inside the planting-tractor wheel tracks. The **Low** (70,000 seeds/ha) and **High** (100,000 seeds/ha) populations were realised with intra-row spacings of 0.190 m (53 seeds/10 m row) or 0.133 m (75 seeds/10 m row) for the **Wide** plots, and 0.381 m (27 seeds/10 m row) or 0.267 m (38 seeds/10 m row) for the **Narrow** plots respectively. The result was 4 planting arrangement treatments:

1. Wide rows, low population (**WL**). This is the standard commercial practice.
2. Wide rows, high population (**WH**). This arrangement resulted in the closest spacing of sweet corn plants within the row.
3. Narrow rows, low population (**NL**). This treatment had a nearly square planting pattern, resulting in least inter-plant competition.
4. Narrow rows, high population (**NH**).

Each plot was 10 m long and 2.5 m wide, with the central 9 m * 1.5 m used for measurements. Arrangement of sweet corn plants in rows and in relation to drip-lines is shown in Figure 1.

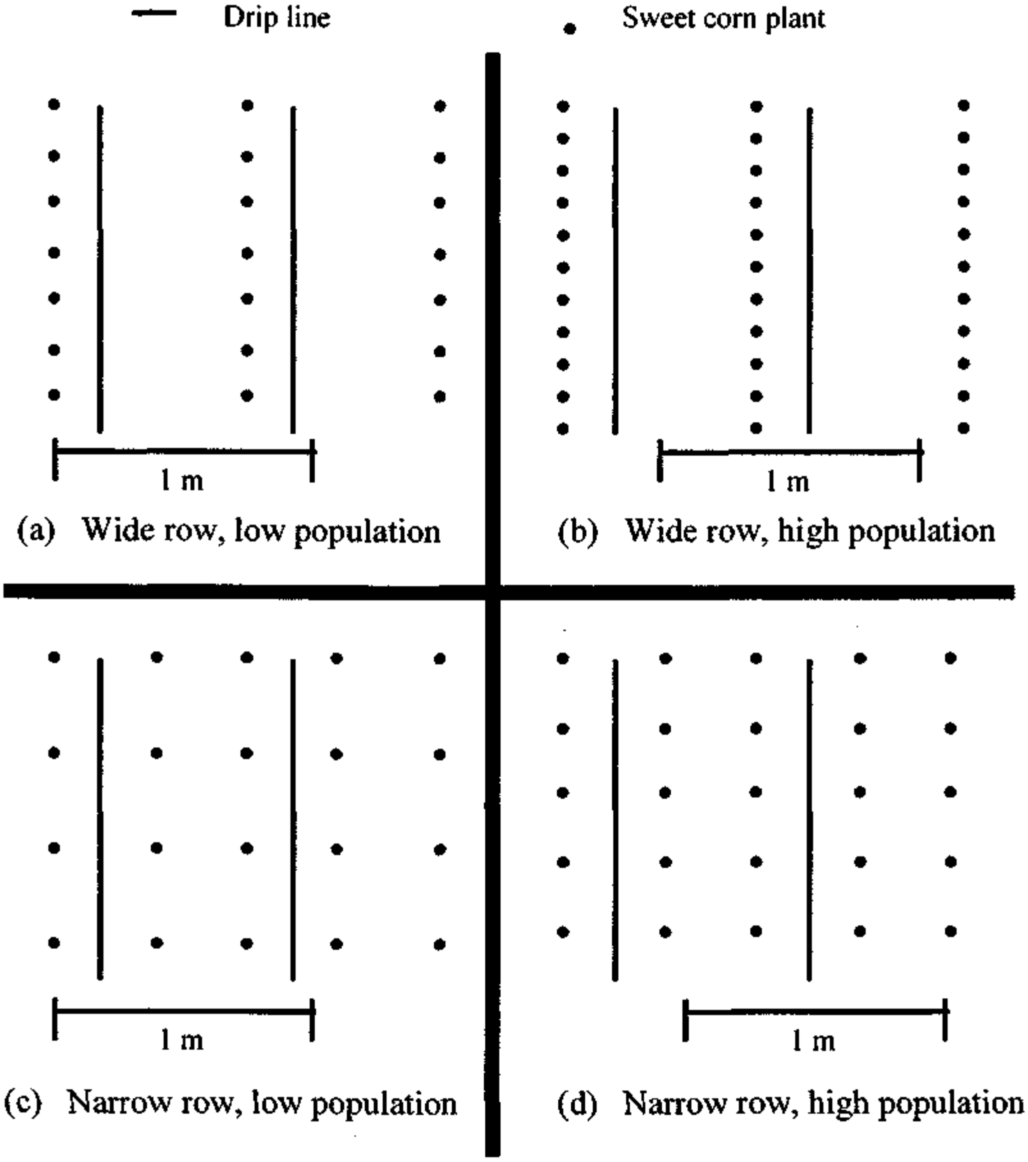


Figure 1. Relative arrangements of sweet corn plants and drip-lines in 4 row-spacing and plant population treatments.

The soil was prepared as per standard practice for a sweet corn crop. The sweet corn cultivar *H5*, with resistance to viral and rust diseases prevalent in summer, was sown on 16 January 1995. A fertiliser application of 80 kgN/ha as urea was broadcast immediately after sowing and incorporated with irrigation. Side-dressings of 30 kgN/ha of urea were applied through drip irrigation on 22 February 1995 (37 days after sowing) and again on 6 March 1995 (49 days after sowing). A boom-spray was used to apply 1 kg/ha each of urea and zinc sulphate hepta hydrate on 3 March 1995 (46 days after sowing). The following insecticides were used to control aphids and heliothus. LANNATE® (methomyl) was sprayed at 2.1 L/ha 46, 68 and 74 days after sowing (DAS); 0.9 L/ha ROGOR® (dimethoate) at 68 DAS, and 0.35 L/ha PHOSDRIN® (mevinphos) 74 DAS.

Irrigation

The first post-sowing irrigation of the sweet corn, totalling 39 mm, was applied with hand-shift lines of sprinklers. All other irrigations used drip-lines spaced 0.75 m apart (Fig. 1), with emitters every 0.2 m, and an output of 7 L/m/hr (9 mm/hr over the total area). Irrigations were scheduled based on tensiometer data from stations installed in the crop about 22 DAS.

Tensiometers were installed 20 cm and 60 cm below ground level in 4 **WL** plots and 4 **NH** plots, distributed in a systematic fashion throughout the experimental area. LOCTRONIC® tensiometers were used, which consist of a standard ceramic tip and tube, but no vacuum gauge. To obtain readings, a hollow syringe is forced through the rubber septum at the top of the tensiometer, and an electronic vacuum gauge senses the vacuum in the small air gap below the septum. Tensiometer readings were recorded around 8-9 am daily.

There were few weeds in the sweet corn. The only management required was hand chipping on 27-28 February 1995, (42 DAS).

Measurements

The heights of 5 randomly selected sweet corn plants from each plot were measured on 21 February 1995, 36 DAS. Marketable cobs from the central 9 m of sweet corn row were hand-picked from each plot on 10 April 1995, 84 DAS. The cobs were counted, weighed, and rated for tip fill, bottom fill, degree of blanking and symmetry of kernel lines. Rating scales were from a low of 1 to a perfect 10.

Data analyses

All sweet corn growth and yield variables were analysed using standard analysis of variance.

Results and discussion

Irrigation

A total of 306 mm of rain fell during the sweet corn growing period, which was supplemented by 218 mm of irrigation. Substantial rainfalls during the first 6 weeks after sowing meant little irrigation was required during that time (Fig. 2). Drip irrigation between rainfall events during the rest of the growing period occurred about every 2 days. Between 5-8 weeks after sowing, amounts of irrigation applied through the drip-line were less than evapotranspiration, gradually increasing the soil water deficit in the root zone. Augmenting the average input to around 15 mm per irrigation reduced the deficit in the surface zone, however only when 33 mm of rain fell 72 DAS did the soil water deficit in deeper root zone decline (Fig. 2). During the latter part of the growing period, shallow tensiometers in high population plots tended to reach higher values more rapidly than instruments in low population plots. Both shallow and deep tensiometer values were less than 40 kPa for the bulk of the growing period, except 6-8 weeks after sowing, when they reached 60 kPa. Substantial drainage followed heavy rainfall 32 DAS, but there were no indications of drainage at other times. Note the consistently high values for deep tensiometers, with no dips to low values indicating saturation (Fig. 2).

Irrigation in this sweet corn experiment was probably sufficient to maximise yields, with no periods of extended stress. The deficit irrigation strategy between 5-8 weeks after sowing enabled a soil water deficit to develop in the deeper parts of the root zone. This could then act as a reserve to capture rainfall, making more efficient use of precipitation and reducing the overall irrigation requirement. In this experiment, irrigation was very efficient, with no indications of excess drainage.

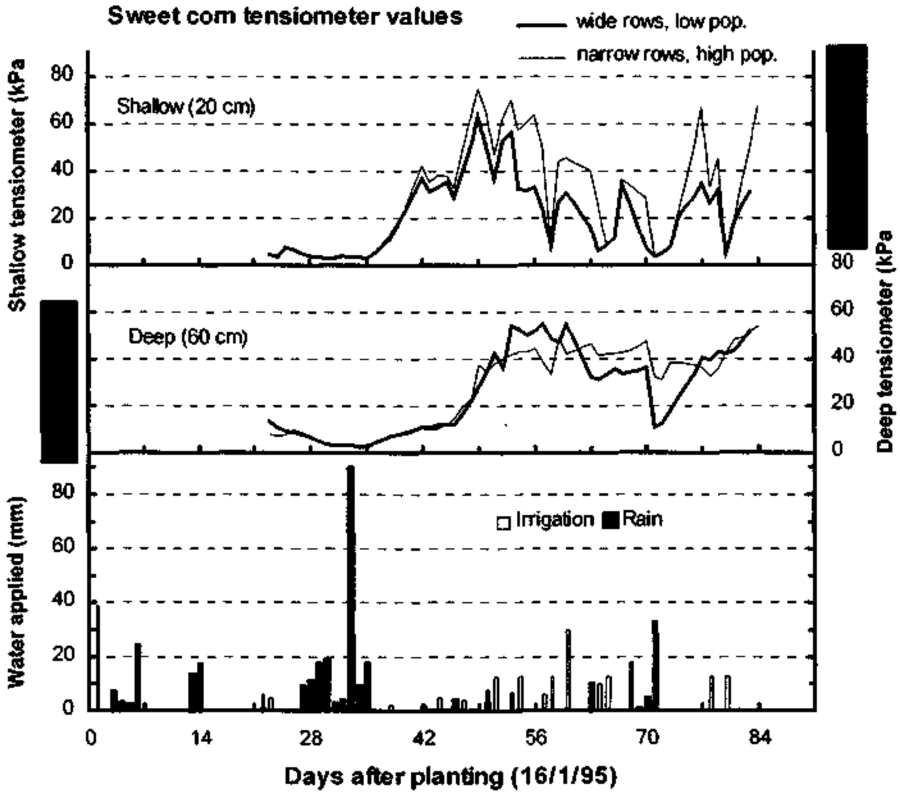


Figure 2. Fluctuation in tensiometer values with rainfall and irrigation during the growing period of sweet corn.

Row spacings and plant populations

Sweet corn growth and yield

A few weeks after emergence, it was evident that sweet corn in the northern end of the experimental area (Blocks 1-4) was performing poorly in comparison with southern plots. Affected plants were stunted, with short internodes and white striping between leaf veins. The symptoms suggested zinc deficiency. This diagnosis was confirmed by nutrient analysis of soil samples. Zinc concentrations in deficient plots were 0.8-1 ppm, compared to 6.8 ppm in the normal plots. Zinc deficiency caused significant stunting and yield loss in affected plots. It also significantly reduced overall quality of cobs from those areas (Fig. 3).

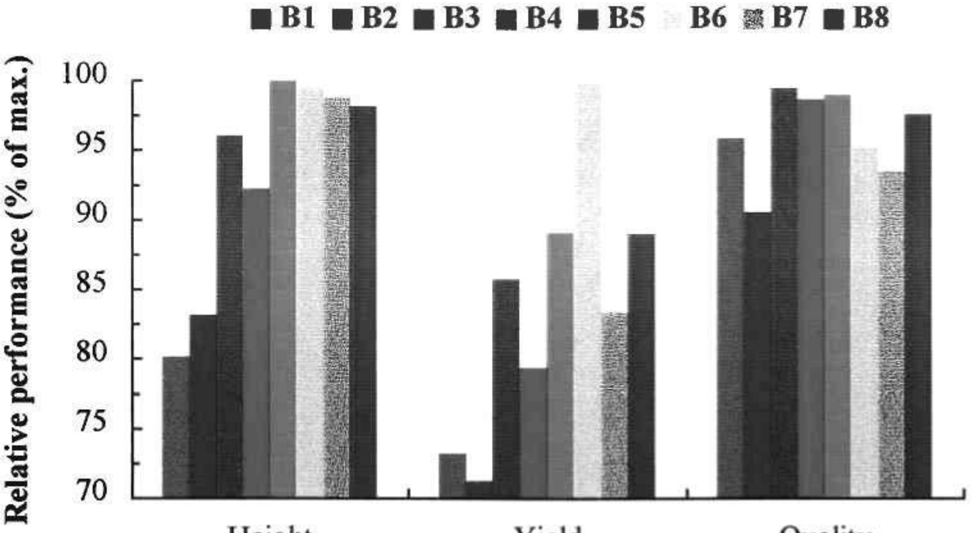


Figure 3. Zinc deficiency reduces the performance of Blocks 1-4 compared to the sufficient Blocks 5-8 in a sweet corn experiment.

Plants sown at high population in narrow rows were significantly taller than low population treatments at the same row width. At the normal 0.75 m row spacings, there were no differences between heights of sweet corn plants at the 2 populations (Fig. 4). There are no obvious explanations for these differences; which may have resulted from a statistical anomaly.

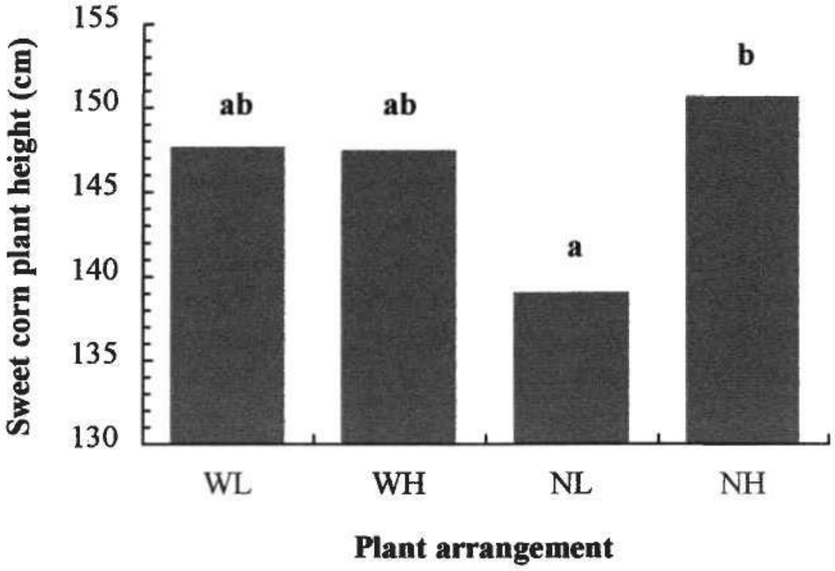


Figure 4. Planting arrangement slightly affects heights of sweet corn plants. Treatments with the same lettering are not significantly different.

There were no significant effects of plant arrangement on total yields of marketable cobs, which averaged 21 t/ha across the whole experimental area (Fig. 5). There was a marginal trend for slightly higher yields from areas planted at the lower density (70,000/ha) in narrow rows, ie. in the square planting arrangement. There were significantly more marketable cobs harvested from high population treatments; however individual cobs were significantly smaller compared to low population areas (Fig. 6a, b).

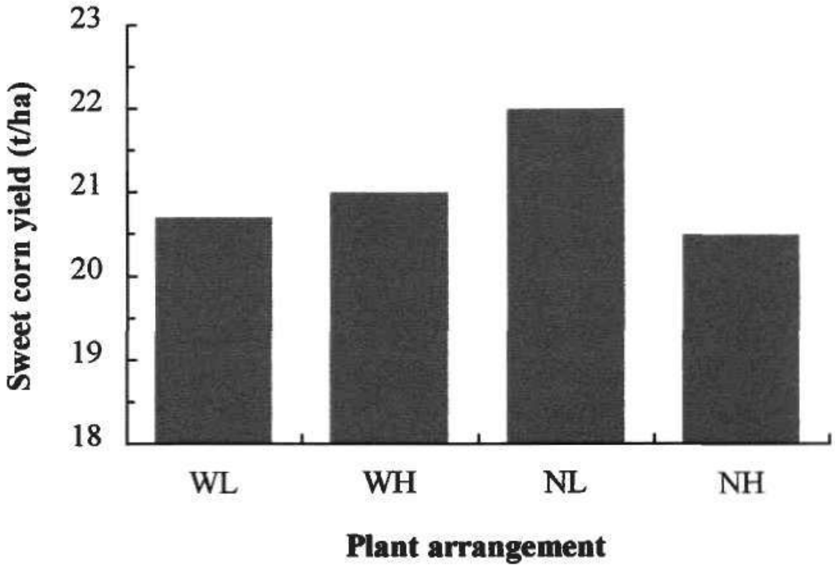


Figure 5. Planting arrangement has no significant effects on total yields of marketable cobs from a sweet corn crop.

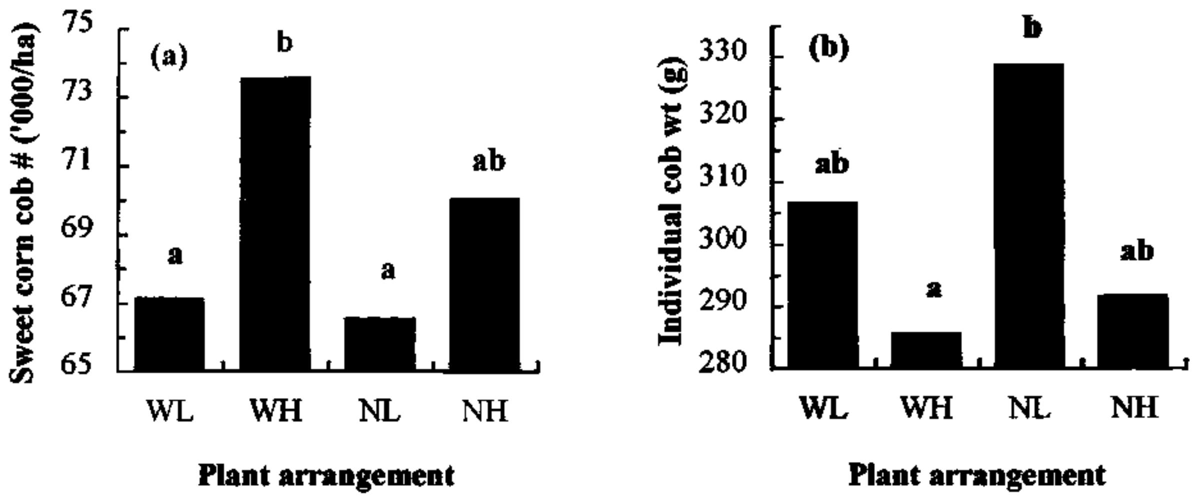


Figure 6. Greater planting population (a) increases the number of marketable cobs and (b) reduces mean individual cob size, in a sweet corn crop planted at 2 row spacings. Treatments with the same lettering are not significantly different.

There was a slight trend for better quality cobs in the NH treatment, however differences were probably not commercially important. The sweet corn cultivar H_5 does have a minor problem with cob tip fill and symmetry of kernel lines, compared to other supersweet cultivars. This is being addressed in current breeding programs.

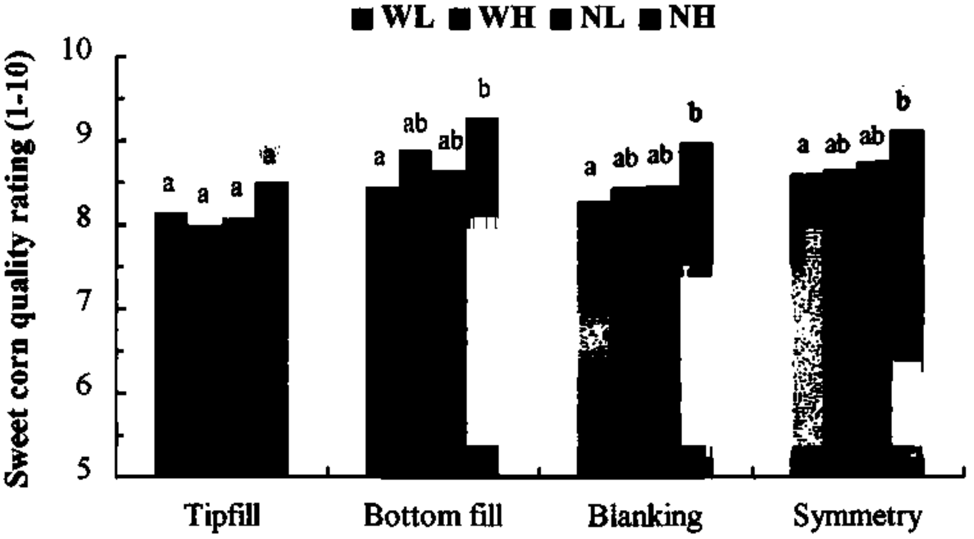


Figure 7. Planting arrangement slightly influences quality parameters in marketable sweet corn cobs. Treatments with the same lettering are not significantly different.

Conclusions

Yields in this experiment were relatively high, particularly given obvious problems with zinc deficiency that inhibited overall performance. Highest yields of 22-25 t/ha unhusked marketable cobs in the southern section of the experiment demonstrated the yield potential. In this experiment, we used drip irrigation because of restrictions on water availability at Gatton Research Station. Drip irrigation would not normally be used for commercial sweet corn. Irrigation efficiency in this experiment was high, with no obvious drainage events (apart from following heavy rainfall), and no periods of water stress likely to affect crop performance. In previous experiments, irrigation scheduling has led to higher sweet corn yields, more efficient water use, and greater profitability.

Heliothus control in this experiment was poor, due to inadequate monitoring, particularly around silking. Most cobs had larvae in the tips of the cobs, which would have had little impact on a processing crop, but limited fresh market potential of the product. In future experiments, more care will be taken of this phase of crop management.

There was no yield advantage from increasing the population of sweet corn seeds sown from 70,000/ha to 100,000/ha. Although the number of cobs harvested increased by about 5,000/ha, each cob was smaller. The actual ratio of cobs harvested to seeds sown was much higher in low population areas (96%), compared to high density plantings (72%).

There may have been a slight yield advantage (circa 1 t/ha) from sowing in narrow rows, compared to conventional row spacings. This yield increase would not justify the expense and effort of changing management practices to accommodate these narrower row spacings. Because of low weed numbers, the impact of changing planting arrangements on weed control strategies could not be determined.

Results from this experiment suggest our sweet corn research effort should concentrate on irrigation and heliothus management. This will be pursued in future experimental and demonstration work.

Appendix 9. Experiment CORN3 Sep. 1996 - January 1997

Evaluation of weed management systems in vegetable production

Long Term Weed Management - Sweet Corn

by Craig Henderson and Dan Galligan
QDPI Gatton Research Station

Summary

An experiment investigating 4 alternative weed management strategies was continued at Gatton Research Station between September 1996 and January 1997. Weed control practices included use of DUAL® (metolachlor) and STARANE® (fluroxypyr) herbicides, in combination with selective hand-weeding. Two sweet corn cultivars, Pacific H5 and Golden Sweet, were sown in 2 blocks 88 m long and 14 rows (0.75 m apart) wide. In the ***Short-term*** *and* ***Future*** *treatments, DUAL® herbicide was sprayed after sowing at 3 L/ha. In the* ***Long-term*** *and* ***Eradication*** *treatments, DUAL® was sprayed at 4 L/ha. The* ***Future*** *treatment also received an application of 0.7 L/ha of STARANE® 34 days after planting (DAP). Both* ***Eradication*** *and* ***Future*** *treatments were also hand-weeded. Growth and yields of sweet corn and weeds were measured, as were amounts of irrigation and pesticides used.*

Although shallow tensiometer values were generally below 50 kPa, there may have been sufficient water stress between 50 DAP and 70 DAP to reduce sweet corn yields. Low yields (average 5 t/ha) in the Golden Sweet were mostly due to early and severe infection with Johnson Grass Mosaic Virus. Normally we would expect Pacific H5 to yield 18-20 t/ha. Yields of 13-14 t/ha in this experiment were disappointing, and may have been due to insufficient water at critical times, too high a planting population, or inadequate nutrition. In neither cultivar did weed management strategies affect yields or cob quality. There was no evidence of crop phytotoxicity from either the DUAL® or STARANE® herbicides, nor was there any yield advantage from hand-weeding in the ***Eradication*** *or* ***Future*** *treatments. Golden Sweet cobs had better average tip fill than Pacific H5 cobs, but the Golden Sweet cobs also had more kernel blanking and heliothus damage.*

Weed competition was not a significant factor affecting crop performance. Total weed numbers were less than 4 weeds/m² under the least effective weed management strategy. Hand-weeding virtually eliminated weeds from ***Eradication*** *and* ***Future*** *treatments. There was no weed control benefit from increasing the application rate of DUAL® herbicide from 3 L/ha to 4 L/ha. Although weed numbers under the 2 sweet corn cultivars were similar, total weed biomass was 3-4 times greater where Golden Sweet was planted, due to reduced shading. Growth of bellvine and burr medic was particularly favoured in the Golden Sweet block. Given the Pacific H5 block was more representative, the most cost-effective strategy in this instance was the* ***Short-term*** *treatment.*

Relevance to industry

Some crops are more susceptible to infestation from specific weeds. Although levels of control are possible using registered herbicides, high costs, risk of crop damage, rotation restrictions, resistance build-up, environmental constraints and the need for expensive hand-weeding are of concern. There is a strong community move towards reduced herbicide use in vegetable production. By developing more integrated weed management programs, we may be able to make more efficient use of our current herbicides, and obtain more effective long-term weed control. This would benefit producers and the community as a whole.

Objectives

This experiment involved the third crop in a series investigating long-term weed management strategies in vegetable production. The sweet corn was planted in plots undergoing various weed management practices through an ongoing sequence of several crop rotations. Weed populations, production practices and outcomes, and the economics of the management system are monitored throughout the life of the crop. Information gained will be used in conjunction with that from other experiments, to develop better weed management practices, for demonstration and extension to commercial producers.

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 two blocks 88 m long and 10.5 m wide stacked end to end in a north south orientation. Each block contained 14 rows of sweet corn 0.75 m apart, running longitudinally down the block. Each block comprised 2 replicates of 4 weed management treatments.

The soil was prepared as per standard practice for a sweet corn. Two sweet corn cultivars were planted. In the northern block cv. *Pacific H5* was planted; in the southern block cv. *Golden Sweet* was sown. Both sowings took place on 19 September 1996, with intra-row spacings of 0.17 m.

Urea fertiliser at 80kgN/ha was broadcast across the entire experiment on 9 September 1996, 10 days before planting, and again on the 25 October 1996, 35 days after planting (DAP). ZINCTRAC® was sprayed as a foliar nutrient at 1 L/ha 20 DAP and 27 DAP. Insecticides applied during the cropping period included 750 mL/ha of ROGOR® (dimethoate) 20 DAP and 27 DAP; 0.4 L/ha of ALPHACORD® (alphamethrin) 11 DAP; and 2.1 L/ha of LANNATE® (methomyl) 67, 69, 74 and 81 DAP.

Irrigation

The sweet corn was irrigated by lines of hand-shift sprinklers running down the long edges of both blocks. Irrigations were scheduled, based on data from tensiometer stations installed in the crop about 2 weeks after planting. The tensiometers were installed 15 cm and 60 cm below ground level in one plot of each block. LOCTRONIC® tensiometers were used, which consist of a standard ceramic tip and tube, but no vacuum gauge. To obtain readings, a hollow syringe is forced through the rubber septum at the top of the tensiometer, and an electronic vacuum gauge senses the vacuum in the small air gap below the septum. Tensiometer readings were recorded around 8-9 am daily.

Weed management strategies

The pre-emergence herbicide DUAL® (metolachlor) registered for grass and broadleaf weed control in sweet corn at 3-4 L/ha was used in this experiment. This herbicide is the most commonly used product for weed control in sweet corn in the Lockyer Valley. It is effective against most of our grass species, and a range of broadleaf weeds. STARANE® (fluroxypyr) was also used. This chemical is registered for broadleaf weed control in a range of cereals and pastures. It is registered for use on sweet corn in NSW, but not in Queensland. It would have a role for controlling some broadleaf species that are not managed by current strategies.

The 4 weed management strategies compared in this experiment are detailed below.

1. ***Short-term***. DUAL® herbicide sprayed at 3 L/ha one day after sowing and incorporated with 19 mm of irrigation.
2. ***Long-term***. DUAL® herbicide sprayed at 4 L/ha one day after sowing and incorporated with 19 mm of irrigation.
3. ***Eradication***. DUAL® herbicide sprayed at 4 L/ha one day after sowing and incorporated with 19 mm of irrigation. This treatment was hand weeded on 4 November 1996 (45 DAP) and 25 November 1996 (66 DAP).
4. ***Future***. DUAL® herbicide sprayed at 3 L/ha one day after sowing and incorporated with 19 mm of irrigation. This treatment was sprayed with 0.7 L/ha of STARANE® as a directed spray on the 24 October 1996 (34 DAP). The treatment was also hand weed on 11 November 1996 (52 DAP).

The DUAL® herbicide was applied with a conventional hydraulic boom operating at 500 kPa and applying 440 L/ha of solution. The STARANE® herbicide was applied with a motorised knapsack sprayer. This 1.5 m wide hand-held boom had 110° flat-fan nozzles spaced 0.30 m apart, and operated at 200 kPa, spraying 270 L/ha.

Measurements

Growth of sweet corn and weeds were monitored throughout the experiment. Heights of 70 randomly selected sweet corn plants from each plot were measured on 16 October 1996 (26 DAP).

Due to differences in maturation times of the 2 cultivars, harvests were staggered. The *Golden Sweet* was harvested on the 17 December 19, 88 DAP, while *Pacific H5* was harvested on the 2 January 1997, 104 DAP. On each occasion, 10 m was harvested from the central 10 rows of each plot, giving a harvested area of 75 m^2 per plot.

Numbers of broadleaf weeds were counted in all plots on the 21 October 1996, 31 DAP. Immediately after the sweet corn were harvested, all large weeds capable of flowering were removed from eaach plot, sorted into species, counted and weighed. Weeds from the ***Eradication*** treatment were destroyed, whilst weeds from the other treatments were returned to their original plots. The times taken to hand-weed the ***Eradication*** and ***Future*** treatments during the growing period were recorded on each occasion.

Data analyses

All sweet corn growth and yield variables were analysed using standard analysis of variance. Owing to the nature of their distributions, weed counts and biomass were log-transformed before analysis. Conversion of the data to its original form took place prior to presentation.

Results and discussion

Irrigation

A total of 166 mm of rain fell during the life of the sweet corn. Supplementary irrigation was required on numerous occasions. Although the shallow tensiometer values tended to stay below 50 kPa for most of the growing period (Fig. 1), this may under-emphasise the possibility of water stress, particularly with *Pacific H5*. This cultivar grew much more vigorously, with higher water use and slightly greater tensiometer values, than did *Golden Sweet*. With only a single irrigation in the 3 week period between 50 and 70 DAP, it is possible that some water stress may have occurred. That 60 mm of irrigation could be applied at 58 DAP, without causing much deep drainage (shown by the deep tensiometer values not dipping back to zero), suggests that the soil was relatively dry. Generally however, irrigation was relatively efficient, with no excessive irrigation causing deep drainage.

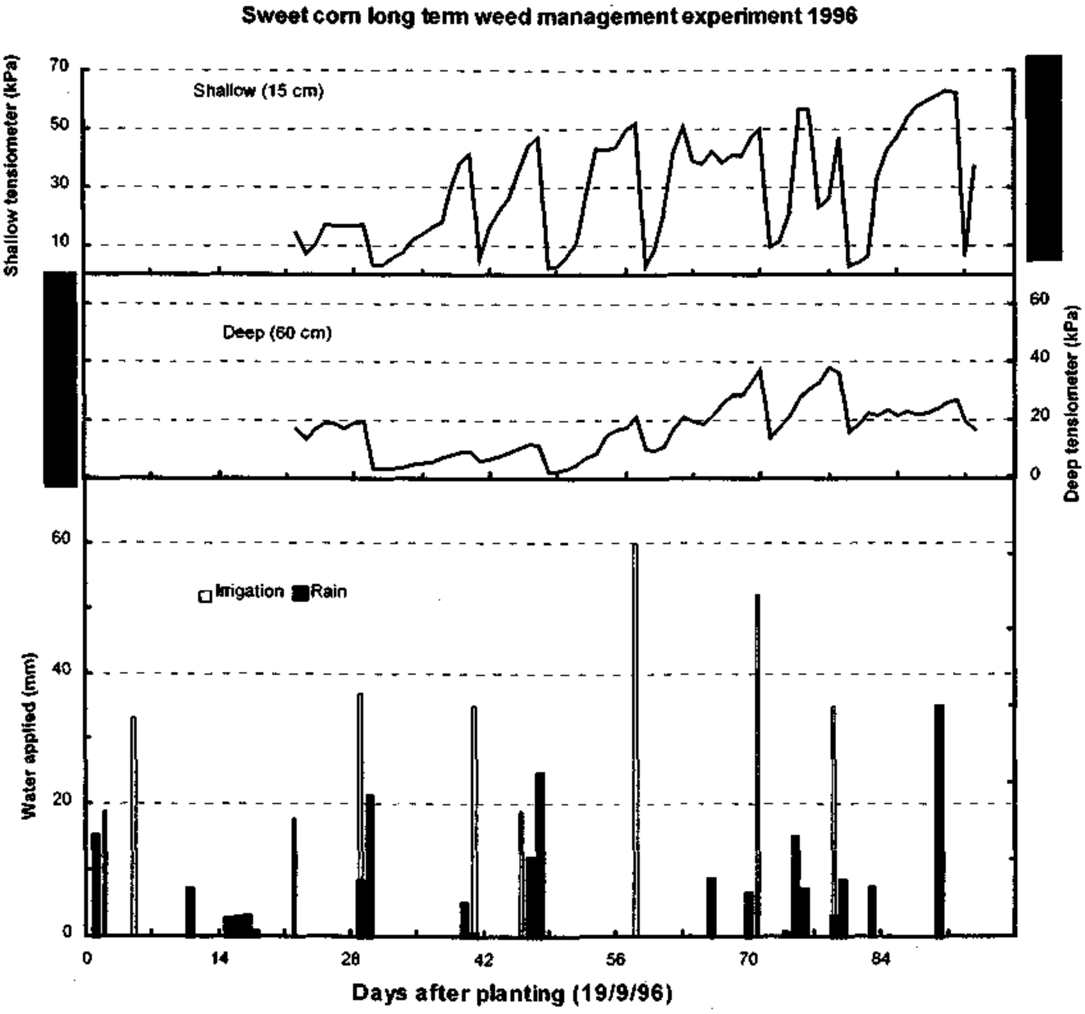


Figure 1. Fluctuation in tensiometer values with rainfall and irrigation during the sweet corn growing period.

Weed management strategies

Sweet corn growth and yield

Overall sweet corn emergence was satisfactory, although in some areas it was sub-optimal. During emergence there was some evidence of moisture stress, ie. shrivelled and brown coleoptiles on the sweet corn at and just below the soil surface. After inspecting the crops around 3 weeks after planting, the presence of Johnson Grass Mosaic Virus was detected in the *Golden Sweet*. During the ensuing weeks it became evident that most plants of this cultivar were affected. *Golden Sweet* is highly susceptible to this virus, however this disease is generally not a problem in crops that are due to harvest before Christmas. Its appearance this early in the season was disconcerting, particularly at such a young growth stage. The affected plants remained stunted for the remainder of the growing period, and yielded very poorly.

When crop heights were assessed at 26 DAP (Fig. 2) no significant differences were found between weed management strategies within cultivars. *Pacific H5,* with an average height of 47 cm, appeared to be in excellent health and was not suffering from any observable symptoms of mosaic virus. *Golden Sweet* is an inherently shorter cultivar, and had an average height of 42 cm (Fig. 2). At this stage the stunting effects of the mosaic virus may have already started to become pronounced.

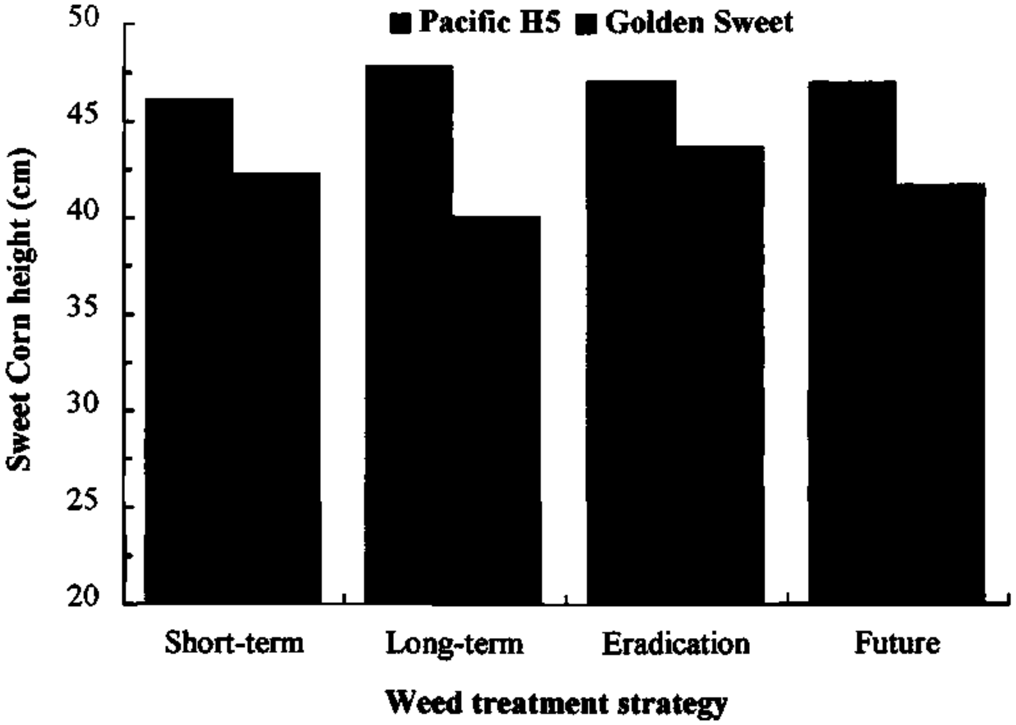


Figure 2. Heights of sweet corn plants at 26 DAP were unaffected by weed management strategies, but there were significant cultivar differences.

Cultivar *Golden Sweet* matured 16 days earlier than *Pacific H5*. By the time the *Golden Sweet* was harvested, mosaic virus had caused substantial damage to the crop, with an average unhusked cob yield of only 5 t/ha across the 4 weed management strategies (Fig. 3). The yield of *Pacific* H5 was also disappointing, averaging only 13 t/ha across the experiment. There was a trend in the ***Short-term*** and ***Future*** treatment plots, which were only sprayed with 3 L/ha of DUAL®, to produce around 2 t/ha more cobs than ***Long-term*** and ***Eradication*** plots, which received 4 L/ha of this herbicide (Fig. 3). We have not seen evidence of DUAL® damage to sweet corn previously, so this may not have been a real effect. There was no evidence of crop damage from application of STARANE® herbicide in the ***Future*** treatment.

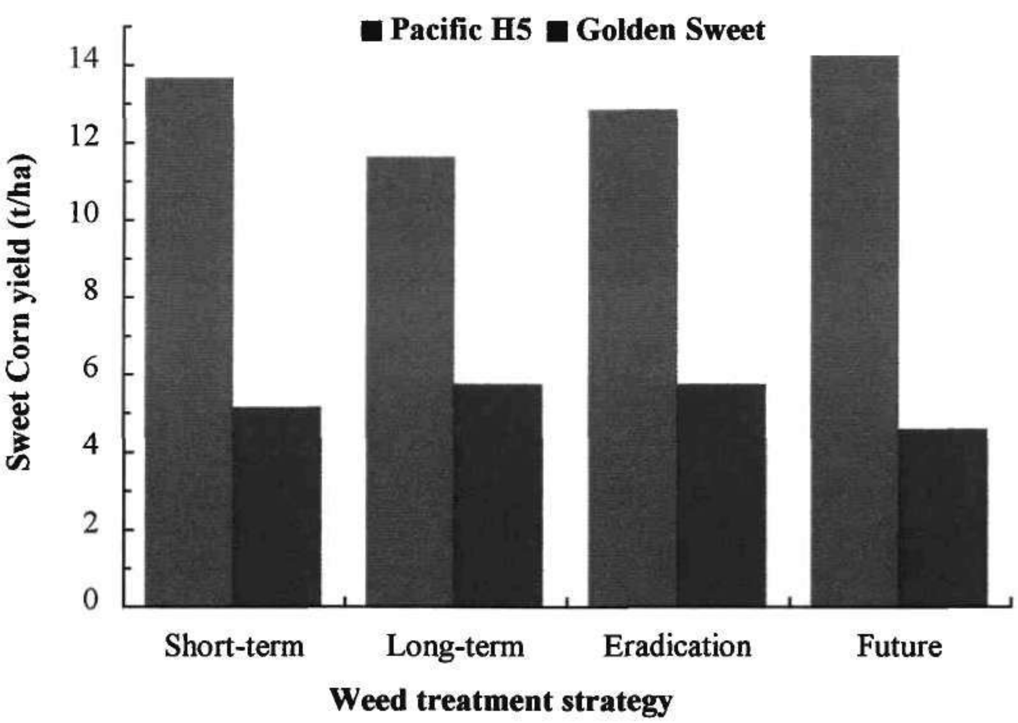


Figure 3. Sweet corn yields are substantially affected by cultivar selection, but not by weed management strategy.

Low sweet corn yields were primarily due to low numbers of marketable cobs (Fig. 4). The *Golden Sweet* corn only produced an average 18,000 cobs/ha, probably as a response to the viral infection. We also believe that the original planting rate of 80 000 sown plants/ha may have been too dense for optimum crop performance. Even the *Pacific H5* only produced an average of 45,000 cobs/ha, 2 cobs for every 3 plants. Normally we expect around 1 marketable cob per plant from this cultivar. As with overall yield, there was a slight suggestion that the ***Eradication*** and ***Long-term*** treatments had fewer cobs than the other strategies (Fig. 4). In the context of the experiment however, there were no significant effects of weed management strategy on any aspect of sweet corn yield. There were certainly no substantial effects of any treatment on the mean size of marketable cobs, which ranged from 250-300 g, average 285 g (Fig. 5).

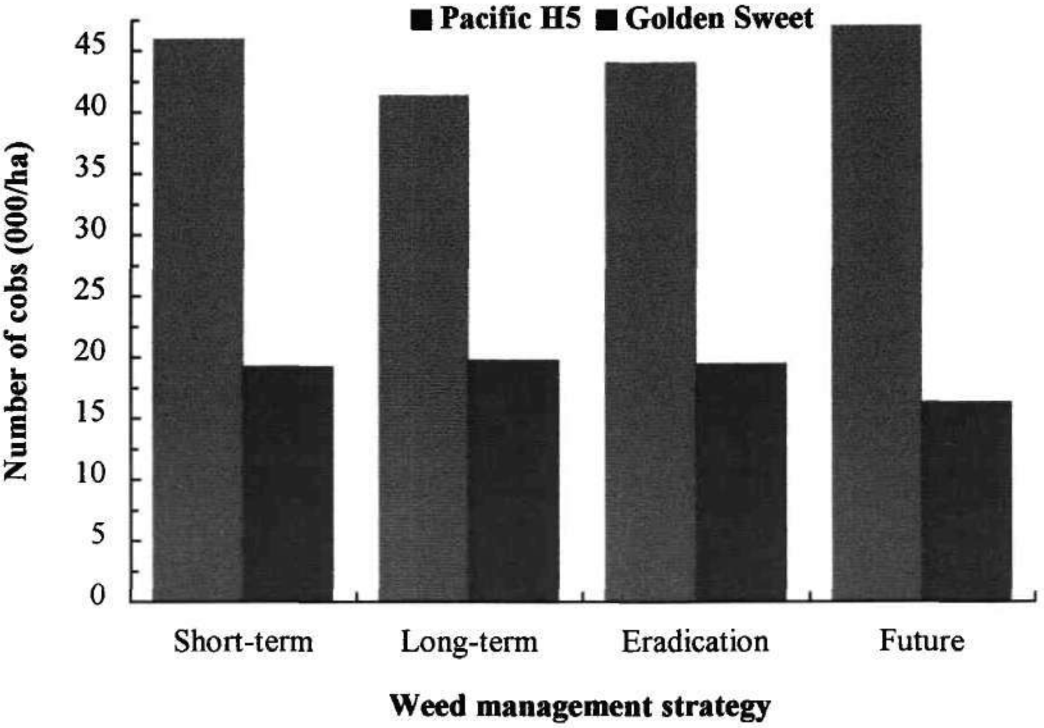


Figure 4. Sweet corn cob numbers are substantially affected by cultivar selection, but not by weed management strategy.

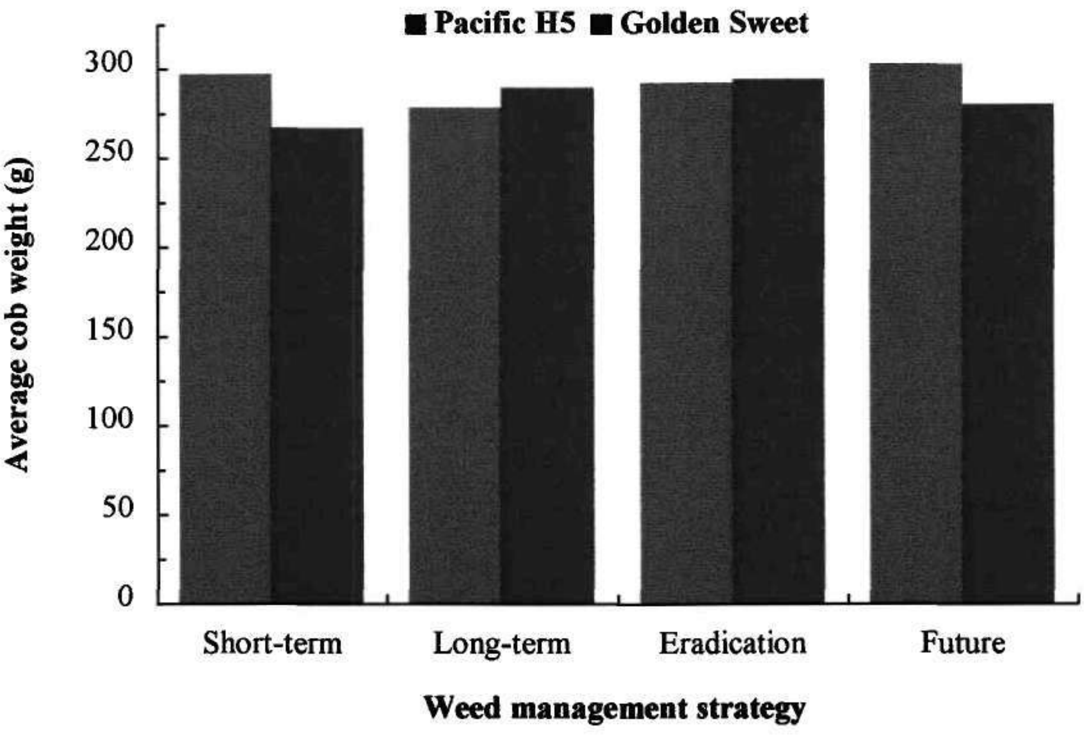


Figure 5. Sweet corn cob size is unaffected by cultivar or weed management strategy.

Sweet corn quality

There was more heliothus damage in *Golden Sweet* cobs compared to cobs from *Pacific H5* plants. The occurrence in the former was around 95%; closer to 60% in the latter. The poor insect control reflects the magnitude of this problem; it is probably the major factor limiting sweet corn production in southern Queensland (as well as other parts of Australia). Better performance from *Pacific H5* is probably due to a tighter wrap of leaves around the tip, restricting early larval migration into the head and increasing insecticide exposure.

Weed management strategy did not affect the quality of cob tip-fill in either cultivar (Fig. 6). With an average rating of 9 out of 10, *Golden Sweet* was significantly better than *Pacific H5*, which only scored around 7.4 (Fig. 6). The improved performance of *Golden Sweet* compared to *Pacific H5* mainly reflects genetic differences between the cultivars.

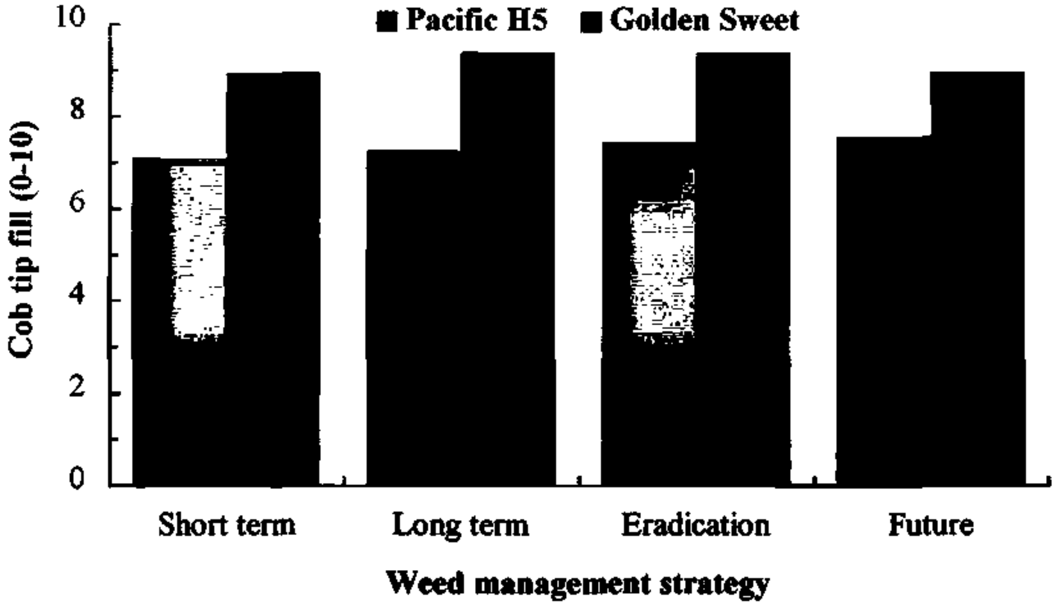


Figure 6. Cultivar selection affected tip-fill score; weed management strategy did not.

There were no significant effects of either cultivar nor weed management strategies on scores for bottom-fill (Fig. 7), or symmetry of kernel rows (Fig. 8). Bottom-fill score averaged 8.2, with row symmetry 7.9 out of 10.

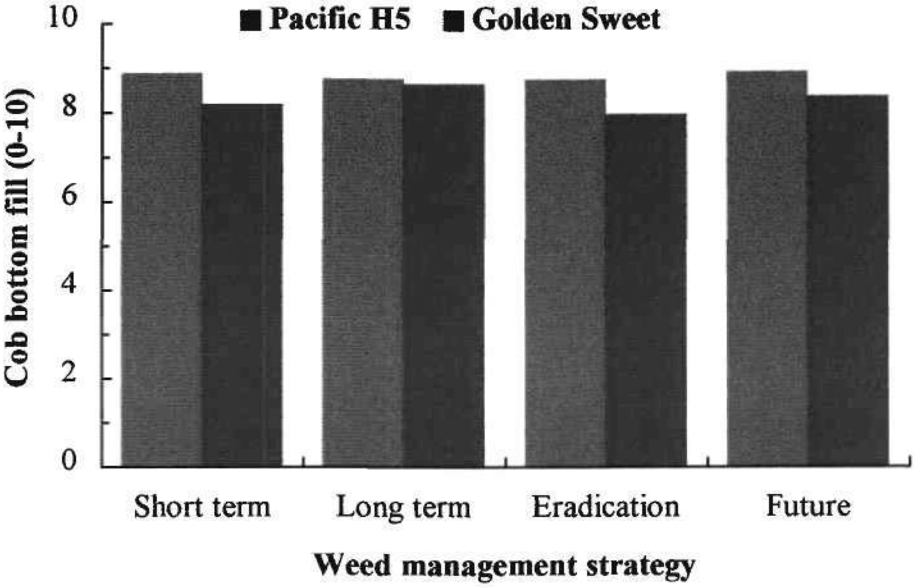


Figure 7. Neither cultivar selection nor weed management strategy affected cob bottom-fill.

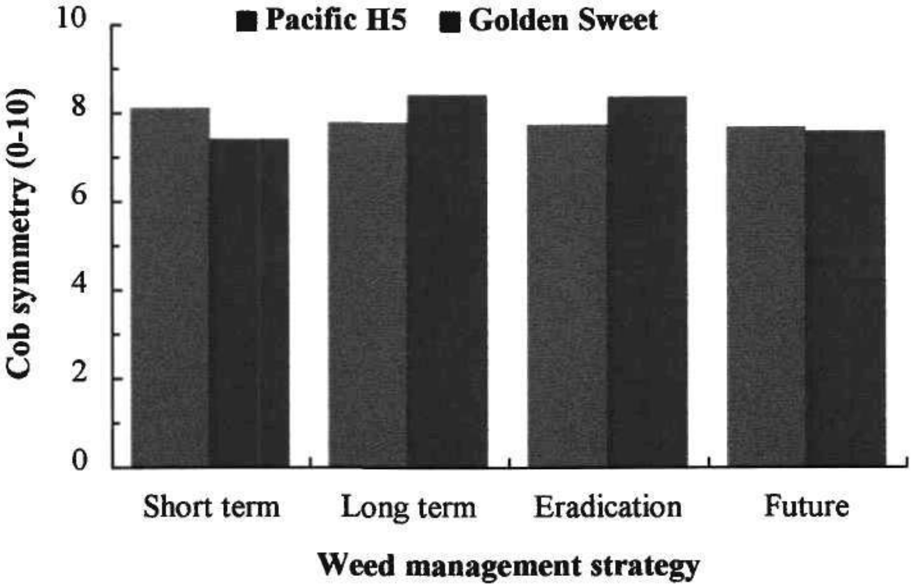


Figure 8. Neither cultivar selection nor weed management strategy affected the symmetry of kernel rows within the cob.

Cob kernel blanking is generally an indicator of ineffective pollination, either due to poor genetics, or more commonly, adverse weather at the time of pollination. *Pacific H5* showed little blanking, with an even rating (average 9.3) across all weed management treatments (Fig. 9). *Golden Sweet* cobs were less uniform, with trends for the ***Eradication*** treatment to be better than the ***Short-term*** plots. With a mean score of 7.5, the average blanking rating of *Golden Sweet* was lower than for *Pacific H5*. This was unusual, and probably reflected effects of the virus, and possibly more adverse weather at pollination, rather than genetic differences.

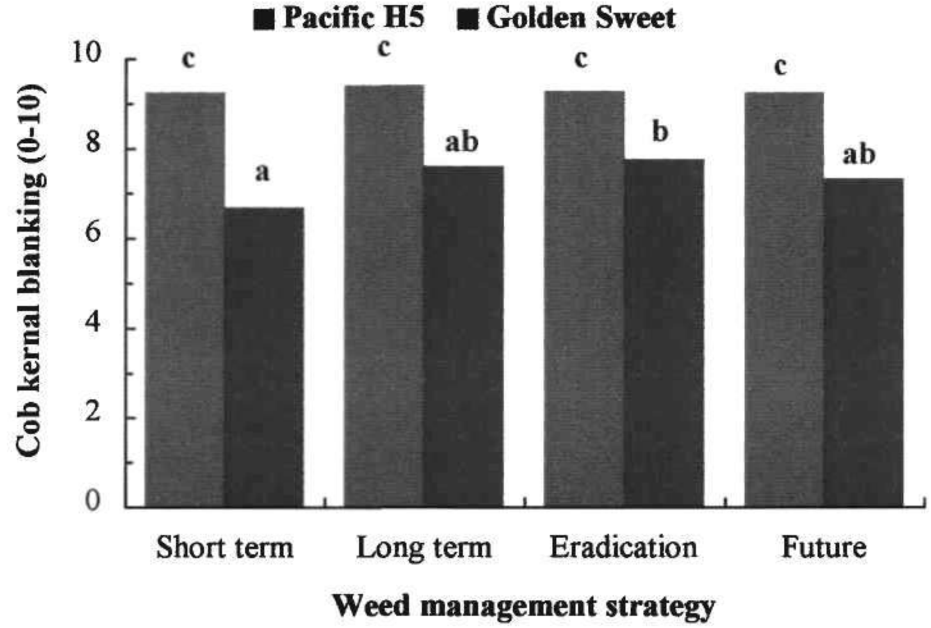


Figure 9. Cultivar selection significantly affects kernel blanking in sweet corn cobs.

Weed control

Weed species present in this experiment included; bellvine (*Ipomoea plebeia); burr* medic *(Medicago polymorpha);* fat hen (*Chenopodium album); g*iant pigweed *(Trianthema portulacastrum);* small-flowered mallow (*Malva parviflora);* sowthistle (*Sonchus oleraceus*), and various grasses. Of these the predominant species were bellvine, burr medic and fat hen. Weed populations were generally insufficient to hinder crop growth or yield. The weed of most concern was bellvine. Not only was this species present in substantial numbers, but because of its growth habit can often smother the plant, and dramatically affect harvesting.

At 31 DAP, just 3 days before the STARANE® herbicide was applied, an assessment was made of weed species distributions in each plot (Fig. 10). Burr medic was the predominant weed, however there were still only 0.2 plants/m^2. These numbers were very low, with no significant differences between weed management strategies. At this stage in the sweet corn growing period, pre-emergence application of DUAL® at 3-4 L/ha seemed to have done an excellent job of controlling weeds.

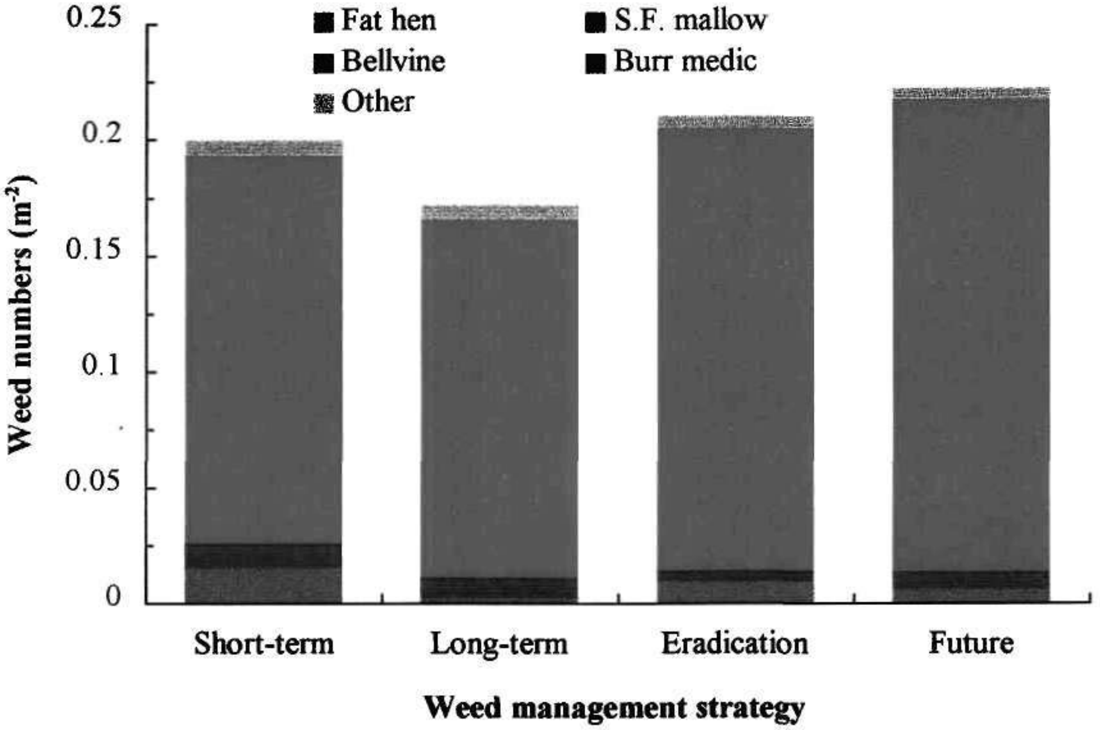


Figure 10. Weed management strategies did not affect the relatively low abundances of several weed species in a sweet corn experiment 31 DAP.

At 88 DAP, just before the sweet corn was harvested, there were considerably more weeds present than earlier in the growing period, particularly in the ***Short-term*** and ***Long-term*** plots (Fig. 11). Weed numbers and biomass in the ***Eradication*** and ***Future*** treatments were low, reflecting the benefits of the late hand-weedings, irrespective of what cultivar was grown (Figs. 11, 12).

Total weed numbers in the treatments that were not hand-weeded were not significantly different (Fig. 11), although there were trends for slightly more bellvine and burr medic in areas where *Golden Sweet* was grown, and more giant pigweed where *Pacific H5* was the sweet corn cultivar.

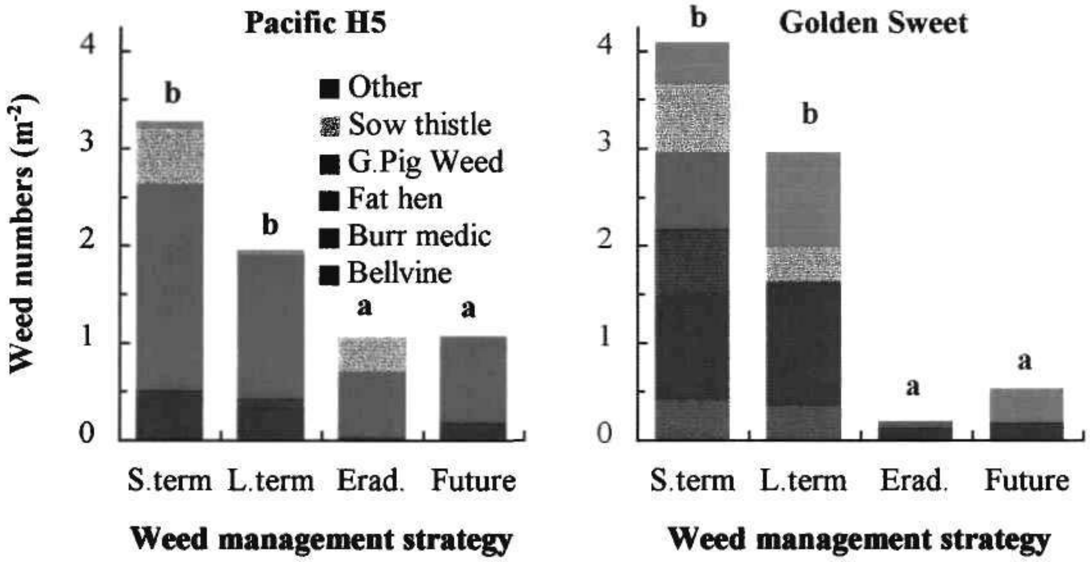


Figure 11. Weed management strategies affect relative abundances of several weed species in 2 sweet corn cultivars, Pacific H5 and Golden Sweet, at 88 DAP.

The effects of weed management strategies and cultivar are much more apparent when weed biomass is considered (Fig. 12). As noted previously, in the ***Eradication*** and ***Future*** plots in both cultivar blocks, there were very few weeds, and those that were present were small. Under the other 2 weed management treatments however, there was considerably greater weed biomass where *Golden Sweet* was grown, compared to where *Pacific H5* was the cultivar used. The much higher biomass in the *Golden Sweet* block can be attributed to the poor growth of this cultivar, which meant that there was still a substantial amount of light reaching the soil surface. In contrast, the rapidly growing and taller cultivar, *Pacific H5,* shaded most weeds relatively early in the growing period. Thus in the *Pacific H5,* even where there were similar weed populations to the *Golden Sweet* block, weed biomass was much lower (Fig. 12).

Where *Pacific H5* was grown, the predominant biomass in treatments that were not hand-weeded was associated with fat hen, and to a much lesser extent, with burr medic. At a total average biomass of about 6 g/m^2, the weed growth in these treatments was still relatively insubstantial. In contrast, the main species contributing to the much greater biomass where *Golden Sweet* was grown were bellvine and burr medic. The biomass of these 2 species alone was more than 3 times the total biomass in the *Pacific H5* block (Fig. 12).

There was no weed control benefit in this experiment from increasing the application rate of DUAL® pre-emergence herbicide from 3 L/ha to 4 L/ha, ie. the ***Short-term*** vs the ***Long-term*** treatment. In hindsight, it may have been better not to have hand-weeded the ***Future*** treatment. Because of the hand-weeding, it is not possible to judge the effectiveness of STARANE® in controlling the various weed species.

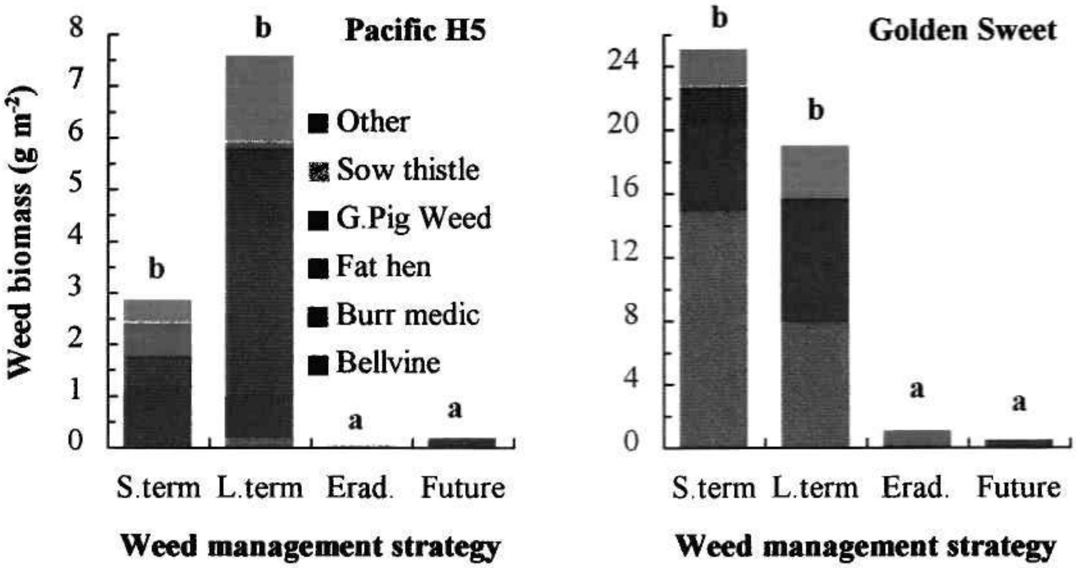


Figure 12. Weed management strategies affect relative biomass of several weed species in 2 sweet corn cultivars, Pacific H5 and Golden Sweet, at 88 DAP.

Conclusions

Irrigation management in this experiment was made difficult by the prevailing dry weather experienced during the growing period. Timely irrigation is important in sweet corn to ensure that the crop is not water stressed during important phases of crop growth, ie. silking and pollination. Although shallow tensiometer values were generally below 50 kPa, there may have been sufficient water stress between 50 DAP and 70 DAP to reduce sweet corn yields.

The average number of marketable cobs per plant was very low, 0.25 for the *Golden Sweet* and 0.67 for *Pacific H5.* The low yields (average 5 t/ha) in the *Golden Sweet* were mostly due to infection with Johnson Grass Mosaic Virus, which substantially stunted the plants and limited crop performance. This disease infected the *Golden Sweet* while it was still young, an unusual occurrence for so early in the sweet corn growing season. Normally we would expect average yields of 18-20 t/ha from *Pacific H5*. The lower yields of 13-14 t/ha from *Pacific H5* in this experiment were disappointing, considering this cultivar was not affected by the mosaic virus. The low yields may have been due to insufficient water at critical times, too high a planting population, or inadequate nutrition, particularly nitrogen.

In both cultivars, weed management strategies did not affect yields or cob quality. There was no evidence of crop phytotoxicity from either the DUAL® or STARANE® herbicides, nor was there any yield advantage from hand-weeding in the ***Eradication*** or ***Future*** treatments.

Golden Sweet cobs had better average tip fill than *Pacific H5* cobs, a feature commonly observed in cultivar comparison experiments. Conversely, *Golden Sweet* cobs had higher levels of kernel blanking, indicating less uniform cob pollination. This may have been a function of the viral infection, or just because of adverse weather at the time of pollination. Kernel blanking is generally not an important issue with this cultivar under normal growing conditions. The *Golden Sweet* had much higher levels of heliothus damage (virtually 100% affected) than did *Pacific H5*. This may reflect a more open cob tip, or possibly poorer insect control at the critical silking stage.

Weed competition did not appear to be a significant factor affecting crop performance in this experiment. Even at the end of the experiment, total weed numbers were less than 4 weeds/m^2 under the least effective weed management strategy. Hand-weeding late in the growing period virtually eliminated weeds from the ***Eradication*** and ***Future*** treatments. There was no weed control benefit from increasing the application rate of DUAL® herbicide from 3 L/ha to 4 L/ha. Although weed numbers in the areas grown to the 2 cultivars were similar, total weed biomass was 3-4 times greater where *Golden Sweet* was planted. This was due to its slower growth, and reduced shading, right through the growing period. The growth of bellvine and burr medic was particularly favoured in the *Golden Sweet* block.

The costs of each weed management strategy are detailed in Table 2, taking into account herbicides, application costs, and hand-weeding labour. It is obvious that the amount of hand-weeding implemented under each strategy had the major impact.

Table 2. Costs ($/ha) of 4 weed management strategies.

	Short term	***Long-term***	***Eradication***	***Future***
Herbicides	75	100	100	95
Application	5	5	5	10
Hand-weeding			709	447
TOTAL	**80**	**105**	**814**	**552**

In hindsight, hand-weeding the ***Future*** treatment was probably unnecessary, as weed populations were probably already relatively low. If we take the *Pacific H5* block as more representative (given that the *Golden Sweet* block was severely affected by virus), then the most cost-effective strategy in this instance was the ***Short-term*** treatment. Weed populations present at the end of the experiment in this treatment were low and would not warrant further control, particularly as there was no benefit from increasing the rate of DUAL® applied. Unfortunately we were unable to determine weed control benefits from spraying STARANE® in this experiment. This should be evaluated in future work.