First stage agronomic research for sub tropical chicory production

The Department of Agriculture, Fisheries and Forestry, Qld

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Media summary

The performance of chicory in a subtropical environment has been assessed by staff of the Queensland Horticulture Institute, Department of Primary Industries for Belgium firm Orafti.

Orafti are investigating the feasibility of establishing a major chicory processing industry in the Bundaberg-Childers-Maryborough region.

The project was jointly funded by Horticulture Australia Limited (HAL) and Orafti and evaluated the performance of chicory in rotation with sugar cane in the Bundaberg region.

The project assessed three different methods of irrigation and investigated the financial impact of growing chicory in rotation with sugar cane.

This project proved to be a good test of the ability of chicory to perform under the abnormal seasonal conditions experienced during land preparation and through the crop cycle.

The trials showed that acceptable yields can be achieved despite above average temperatures for much of the year, below average rainfall and a number of storms which impacted the early stages of the trial.

The project has provided useful information that will assist Orafti to define their requirements for successful chicory production in the Bundaberg, Childers, Maryborough area.

The information from this project will also help in their investigations to decide whether or not to establish a $250 million chicory processing plant near Childers.

Technical summary

The Belgium-based food ingredients company Orafti has been managing the production of chicory in Europe for a number of years. Inulin, a natural, high-value food ingredient and the sugar oligofructose, are extracted from the chicory root. Both are in high demand due to their particular properties in relation to human nutrition and both are confirmed as dietary fibres in most European countries.

Orafti have searched the southern hemisphere to find an area suited to chicory production so that they can increase their production and markets. They believe that the Bundaberg-Childers-Maryborough area of Queensland is suitable but need to be assured that this area is agronomically suitable before investing $250 million in a processing plant near Childers.

Chicory production in the subtropics will be different to Belgium production, irrigation which is not needed in Belgium will be essential here. In Belgium chicory is grown in rotation with other crops such as sugar beet, whilst here it will mainly be grown after sugar cane. Chicory production will therefore require much different management systems to succeed in this region.

The results of this project show that chicory can be grown successfully in rotation with sugar cane, using farming equipment commonly owned by cane farmers.

In this trial, plant emergence was low, around 40% on average and bolting was higher than desirable averaging 5% to 6% overall. It is believed that both of these problems can be attributed to the extreme conditions that occurred in the early stages of the crop and the breakdown of irrigation pumps.

Given the low plant population, yields were good and show that chicory will grow and perform well in this region. The inulin content is believed, from other crops grown in this region, to be at least equivalent to European levels. Inulin quality from this trial was similar to the Australian standard as a percentage of carbohydrates but the chain length was on average about 10% shorter. There was very little difference between irrigation methods.

Good weed control will be essential and should be an important goal in land preparation. Thorough land preparation will be essential to provide a largely weed free seed bed suited to the establishment of a small seeded crop. The registration of suitable herbicides will also be necessary.

All irrigation methods except the 45 cm row drip plots yielded above or close to the 45 t/ha average yield initially targeted. Given the low plant population this was considered acceptable. The combination of spraylines to establish the crop followed by winch irrigation was the most economically viable. Drip irrigation appeared to show some agronomic benefits but was not economically viable using the one drip tape to two rows system.

A whole farm analysis assessed chicory production in rotation with sugar cane. It showed that at $90 per tonne for chicory roots there are definite financial benefits to sugar cane growers who add chicory to their rotation provided no manual weed control is required.

This project identified that the Bundaberg-Childers-Maryborough area is suited to chicory production. The promise of the Paradise dam on the Burnett river should guarantee sufficient water to successfully develop this new industry.

A photographic record was made of the trial from land preparation through to post harvest cleanup and this will be given to Orafti separately.

Introduction

The aim of this trial was to establish parameters for producing irrigated chicory in subtropical Queensland. Components of the trial include land preparation after a sugar cane crop, a herbicide trial, a comparison of three irrigation systems using two irrigation regimes and two row spacings for the drip irrigation component.

The Belgium-based food ingredients company Orafti has been managing the production of chicory in Europe for a number of years. Inulin, a natural, high-value food ingredient and the sugar oligofructose, are extracted from the chicory root using patented extraction and refining technologies. Both are in high demand due to their particular properties in relation to human nutrition, and both are confirmed as dietary fibres in most European countries. Inulin fibre is sweet, doesn’t break down in the stomach and is a calorie free fibre.

Inulin is used as a fat replacement in bakery, cereal and dairy products without the loss of ‘mouth feel’. Inulin is in great demand in Europe and the USA.

Following lengthy investigations across several locations in the southern hemisphere, Orafti have identified the Bundaberg-Childers-Maryborough region of Queensland as most suited to production of chicory for extended periods during the year. This has significant advantage over their current European operations, where production is restricted to a few months a year due to climatic conditions.

Orafti’s experience with chicory is limited to production under mild climatic conditions, with very friable deep soils. Additionally, European production does not use irrigation and is undertaken by farmers with extensive experience in row crop production, including sugar beet.

The proposed production system is largely based on the integration of chicory production into the fallow period between sugarcane crops. Additional commercial crop area will be sought from ex-dairy and other land uses, including vegetable row crop producers in the region.

This research project involved the establishment of approximately 2.5 hectares of chicory at the Centre for Sustainable Horticulture, Bundaberg Research Station. This land had previously been planted to commercial sugar cane and therefore made an ideal site to test the integration of chicory production into land being fallowed from cane cropping.

All aspects of crop production were evaluated, starting with ground preparation, which required a very different approach to current European production systems due to the need to plough out and break down cane residues.

Crop establishment was a key factor researched, as chicory seed is very fine so needs a well-prepared, continually moist seed bed to successfully germinate and establish a high plant population.

Different forms of irrigation, including drip, overhead sprinklers and water winch, were evaluated in both the establishment and crop production phases, with some treatments combining these different methods at different crop phases. This project not only assessed different methods of applying irrigation, but also recorded the amount of water used by each method. Because of the current limited water supply, accurate scheduling of irrigation to obtain the most efficient production per megalitre is critical. It is also important to assess the effect of different irrigation methods on plant establishment.

A herbicide trial was included as part of the overall production trial. This research element was managed by local officers of the Bureau of Sugar Experiment Stations (BSES), thereby utilising the expertise they have developed through weed management in sugar cane.

Irrigation management throughout the crop production cycle was based on Enviroscan® soil moisture monitoring equipment. As part of this soil moisture management, two different moisture stress levels were imposed to determine their impact on final crop and extract yields.

Crop production physiology factors were monitored throughout the trial, including incidence of root forking and ‘bolting’ (early onset of flowering and seed set). Higher incidence of these and other production-limiting factors will assist in identifying system problems requiring future research.

Gross margin analyses was undertaken for the crop, both before and after the crop trial. This will assist the company to derive appropriate pricing structures for the crop, given that the yields and input costs are likely to be quite different to the European experiences, especially with the introduction of irrigation. A whole farm analysis was done after the trial to assess the financial impact of growing chicory in rotation with sugar cane.

Materials and methods

This trial was conducted at the DPI's Centre for Sustainable Horticulture, Bundaberg Research Station, on a red ferrosol (Australian soil classification), Euchrozem (great soil group) soil type. Figure 1 shows the layout of the chicory block. Rows were planted north/south.

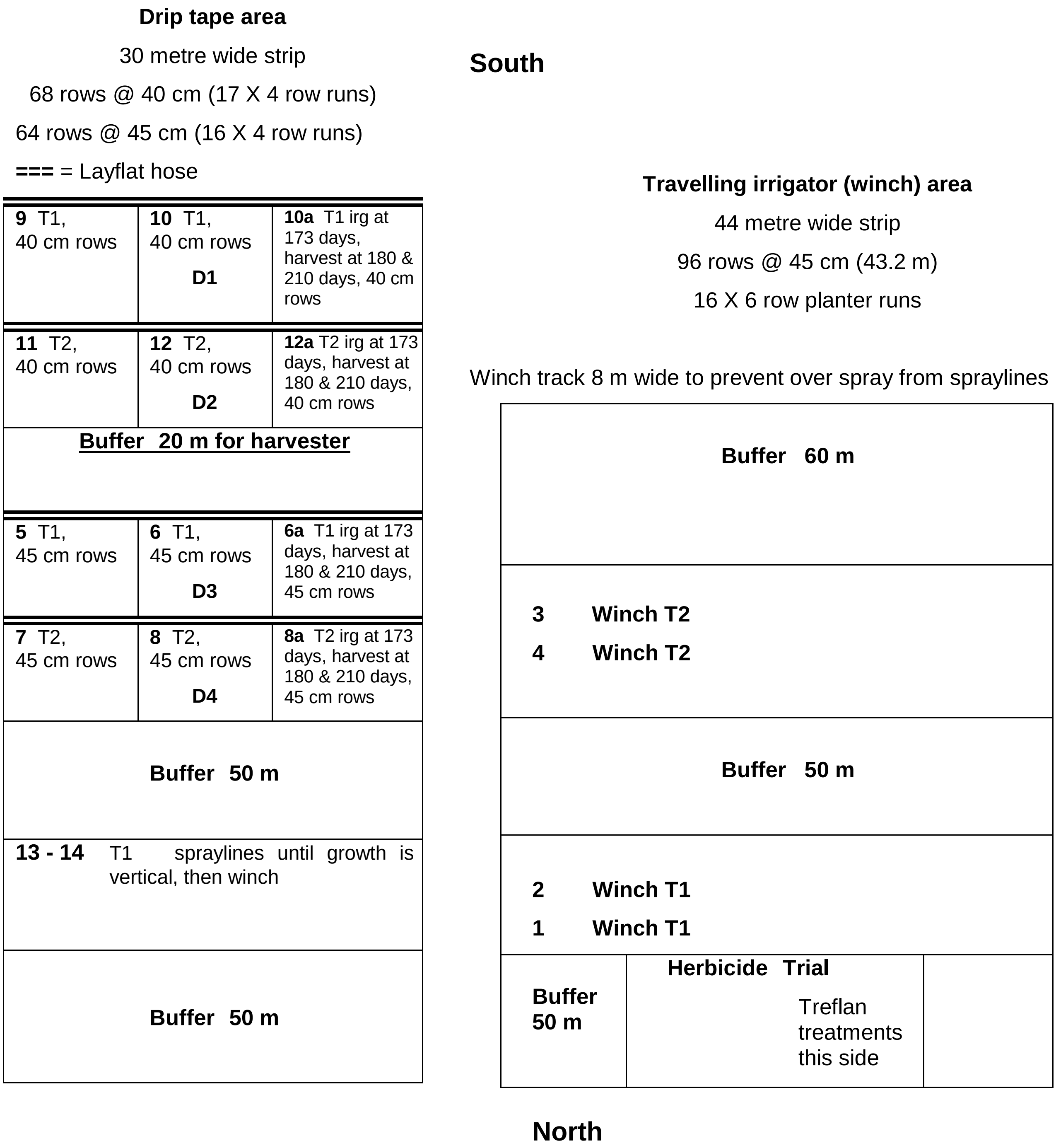

Figure 1. *Chicory trial layout*

The block is approximately 340 m long on the eastern side, 280 m long on the west (beside the macadamias) and 82 m wide. The data area for each drip treatment was 41 m long x 30 m wide, sprayline plus winch area was 60 m long x 30 m wide and each winch treatment was about 60 m long x 43 m wide. The plot numbers, for example 9, 10, 10a, indicate different harvest times.

Land preparation

The sugar cane was harvested on 20 June 2001, however because the block was not due for ploughing out that year, land preparation did not start until 1 August 2001, after the costs associated with proceeding were assured.

At Orafti's request, the cane trash was first sprayed with a mixture of molasses and urea in water to speed up trash breakdown. This treatment is used by some local farmers. Molasses was applied at 277 L/ha, with 32 kg/ha of urea in 236 L of water per hectare.

Land preparation was done by farm supervisor Mr John Taske, who has many years experience as a cane farmer. There was little sub-soil moisture in the block and the main land preparation period of August to October was dry, with a total of 106 mm of rain falling, mostly in small ineffective falls, the average for that period is 146.9 mm.

The block was rotary hoed on 2 August, with a pass over each row to chop up the cane stool to speed up breakdown. Heavy offset discs were then tried, but were not effective in incorporating the trash. On 7 - 8 August the block was ploughed with a disc plough and rotary hoed on 20 August, with a crumble roller attached. The soil was too dry for trash breakdown, so the block was irrigated with the winch (travelling irrigator) from the eastern side on 24 August, then the western side on 27 August. A total of 0.56 ML/ha of water was applied.

Soil samples were taken on 11 September to test for nematodes and soil nutrients.

On 24 September lime was applied at 3 t/ha, as recommended by Crop Tech from the soil analysis. The lime was incorporated into the surface soil with a multi-weeder on 26 September to reduce losses from wind blowing it away, the block was then ripped along the rows between 26 and 28 September, with a diamond harrow dragged behind the ripper to help break up clods. Ripping was necessary to break up a hard pan at between 30 cm and 40 cm deep.

The block was ploughed with the disc plough on 1 and 2 October to bury the undecomposed trash on the surface and disced with heavy offset discs on 19 October after 14.8 mm of rain over the previous five days, as there was still a considerable amount of undecomposed trash bought up to the surface by the previous ploughing. The block was ploughed again with the disc plough on 30 and 31 October after a further 14.8 mm over the previous three days.

The block was again irrigated with the winch from the eastern and western sides on 7 and 8 November to encourage further trash breakdown, another 0.56 ML/ha was applied. Following this irrigation 128.8 mm of rain fell and this was followed by the germination of weed seeds that had been dormant in the dry soil. Several large areas of nutgrass also appeared.

The area was sprayed on 30 November with glyphosate at 6 L/ha, with 4 kg/ha of technical grade sulphate of ammonia to boost its effectiveness. Planting was delayed and a further application of glyphosate at 4.8 L/ha, with 4 kg/ha of technical grade sulphate of ammonia was made on 8 December. It would have been preferable to have held off planting until the amount of nutgrass could be reduced further but Orafti were keen to plant as soon as possible.

Orafti agronomists were satisfied with the general condition of the soil, although undecomposed trash was still obvious.

Fertiliser was broadcast over the block on 12 December, with a Vicon® spreader. The pre-plant fertiliser requested by Orafti was 20 kg nitrogen (N), 70 kg of P_2O_5 ((30.59 kg of phosphorus (P)), and 150 kg of K_2O ((124.5 kg of potassium (K)) per hectare. To achieve this we spread 270 kg of GF 356 (7.4 N:10.7 P:11.3 K) and 230 kg of sulphate of potash (0:0:41) per hectare which applied a total of 20 kg nitrogen, 29 kg phosphorus and 125 kg potassium per hectare.

The final land preparation was done immediately before planting, with a power harrow with a crumble roller attached, which incorporated the fertiliser and Treflan® in the herbicide trial treatments and provided a firm, level seedbed.

Depth of planting trials

The original protocol required that the chicory seed be planted at greater than 1 mm and less than 5 mm deep, as is the practice in Europe. It was thought this shallow planting was necessary, because the small seed would not emerge evenly, or at all, from greater depths. I was concerned that in a well drained soil, in hot, dry, windy conditions, the soil would rapidly dry out to the depth of the seed and emergence would be poor. I therefore planted some preliminary depth of planting trials in a plastic house and then in the field to determine the most suitable depth to plant.

Planting

Orafti supplied a six row vacuum planter, and the chicory seed which was pelleted to give a more consistent seed size. All the 45 cm rows were planted on 13 December, and the 40 cm rows in the drip area were planted on the morning of 14 December. The winch and sprayline area were planted six rows at a time. For the drip area the outer two seed boxes were raised so that four rows were planted at a time. Seed was planted 10 cm apart in the rows, at the rate of 222,222 seed /ha at the 45 cm row spacing, and 250,000 /ha at 40 cm row spacing.

Plant emergence

Plant emergence was assessed seven and 21 days after planting. Six 10 m plots were marked out in each of the winch and sprayline plus winch areas, and in each of the 40 cm and 45 cm drip areas. At the seed spacing of 10 cm, each 10 m plot should contain 100 seeds. The plots were spaced across each area to allow for variations in irrigation.

Irrigation

Chicory is not irrigated in Belgium, but irrigation is necessary in this much drier and hotter climate. This trial included a three methods of irrigation and two irrigation treatments for the winch and drip treatments. The drip irrigation blocks were planted at 40 cm and 45 cm between the rows. Table 1 shows these treatments.

Table 1. *Irrigation methods and treatments*

Irrigation treatment	Irrigation method						
	45 cm rows			40 cm rows		45 cm rows	
	Winch 1 (W1)	Winch 2 (W2)	Sprayline + winch	Drip 1 (D1)	Drip 2 (D2)	Drip 3 (D3)	Drip 4 (D4)
Treatment 1 (T1) mild stress	✓		✓	✓		✓	
Treatment 2 (T2) moderate stress		✓			✓		✓

Irrigation was based on Enviroscan® and evapotranspiration readings once the crop was established. Assistance in setting up the Enviroscan® and adjusting the fill and stress point levels was received from Pat Menkens of Menkens Irrigation Services, John Hall of Crop Tech Laboratories and several of his staff.

Irrigation was frequent, as required, until the crop was well established. Two irrigation treatments (regimes) were applied to the winch and drip areas. For Treatment 1 (T1) irrigation started when the Enviroscan® indicated mild stress, described as 'when water usage slowed at 10 cm deep'. For Treatment 2 (T2) irrigation started when the Enviroscan® indicated moderate stress, described as 'when the ratio between evapotranspiration and daily water use indicated by the Enviroscan® falls below 0.5'. That is when daily water use is less than 50% of the daily evapotranspiration. Daily evaporation readings were received from the Bureau of Sugar Experiment Stations (BSES) weather station, about 200 m from the chicory block. A crop factor of 0.8 was used to determine daily evapotranspiration.

Ten Soilspec® tensiometers and four Jetfill® tensiometers were installed to compare readings with the Enviroscan® readings. Four Soilspec® tensiometers were place near the Enviroscan® probe at 10, 20 40 and 60 cm deep along with two Jetfill® tensiometers at 20 and 40 cm. Three Soilspec® tensiometers were placed near the Enviroscan® probe in D2 at 10, 20, 40 and 60 cm depth along with two Jetfill® tensiometers at 20 and 40 cm. Three Soilspec® tensiometers were placed near the Enviroscan® probe in winch 2 at 10, 20 and 40 cm with two Jetfill® tensiometers at 20 and 40 cm. A further three Soilspec® tensiometers were placed in the sprayline plus winch area.

Table 2 shows the planned treatments and layout of monitoring equipment.

Six rain gauges were spread evenly across the winch and sprayline areas, three in each. They were used to assess the uniformity of irrigation. A further two were later placed near the Enviroscan® probe sites in winch T1 and winch T2.

The crop was to be irrigated to field capacity 143 days after planting. All blocks were irrigated one week before the 150 day harvest on 7 May and blocks D1, D2 and D4 were irrigated again on 8 May to reach field capacity.

Sections of the drip area were also to be irrigated on 5 June, 173 days after planting to bring the soil to field capacity before harvests at 180 and 195 days after planting. As a result of a meeting with Orafti this was changed to a harvest at 210 days instead of the 195 day harvest. A 210 day harvest was also included for the winch and sprayline blocks, with them being irrigated to field capacity after the 180 day harvest due on 12 June. From 3 to 11 June, 187 mm of rain fell, saturating the soil and negating the need for irrigation to achieve field capacity.

Table 2. *Planned treatments and layout of monitoring equipment*

Treatment number	Enviroscan probes	Irrigation type	Irrigation timing	Harvest at	Row spacing
1		Winch	T1	150 days	45 cm
*2	**P1** Sens. 1-5+31 Run **A**; Address 1-6	Winch	T1	180 days	45 cm
3		Winch	T2	150 days	45 cm
*4Ss, 5,6,7; Jft, 13, 14	**P2** Sens 6-10 Run **A**; Address 7-11	Winch	T2	180 days	45 cm
5 #		Drip	T1	150 days	45 cm
6 #		Drip	T1	180 days	45 cm
*6a #	**P4** Sens 16-20 Run **B**; Address 1-5	Drip irrigate at 173 days	T1	180 & 195 days	45 cm
7 #		Drip	T2	150 days	45 cm
8		Drip	T2	180 days	45 cm
*8a #	**P3** Sens 11-15 Run **A**; Address 12-16	Drip irrigate at 173 days	T2	180 & 195 days	45 cm
9 #		Drip	T1	150 days	40 cm
10		Drip	T1	180 days	40 cm
*10a #	**P5** Sens 21-25 Run **B**; Address 6-10	Drip irrigate at 173 days	T1	180 & 195 days	40 cm
11 #		Drip	T2	150 days	40 cm
12 #		Drip	T2	180 days	40 cm
*12a # Ss, 1, 2, 3, 4; Jft, 11, 12	**P6** Sens 26-30 +32 Run **B**; Address 11-16	Drip irrigate at 173 days	T2	180 & 195 days	40 cm
13		Sprayline until growth is vertical, then winch	T1	150 days	45 cm
14 ## Ss, 8, 9, 10		Sprayline until growth is vertical, then winch	T1	180 days	45 cm

* = Enviroscan® sites

= Flow meters in drip lines

= Flow meters on sprinklers

Ss = Soilspec® tensiometers, 1, 5, 8 = 10 cm; 2, 6, 9 = 20 cm; 3, 7, 10 = 40 cm; 4 = 60 cm.

Jft = Jetfill® tensiometers, 11, 13 = 20 cm; 12, 14 = 40 cm.

Figure 2 shows the positioning of flow meters in the drip area and Enviroscan® sites

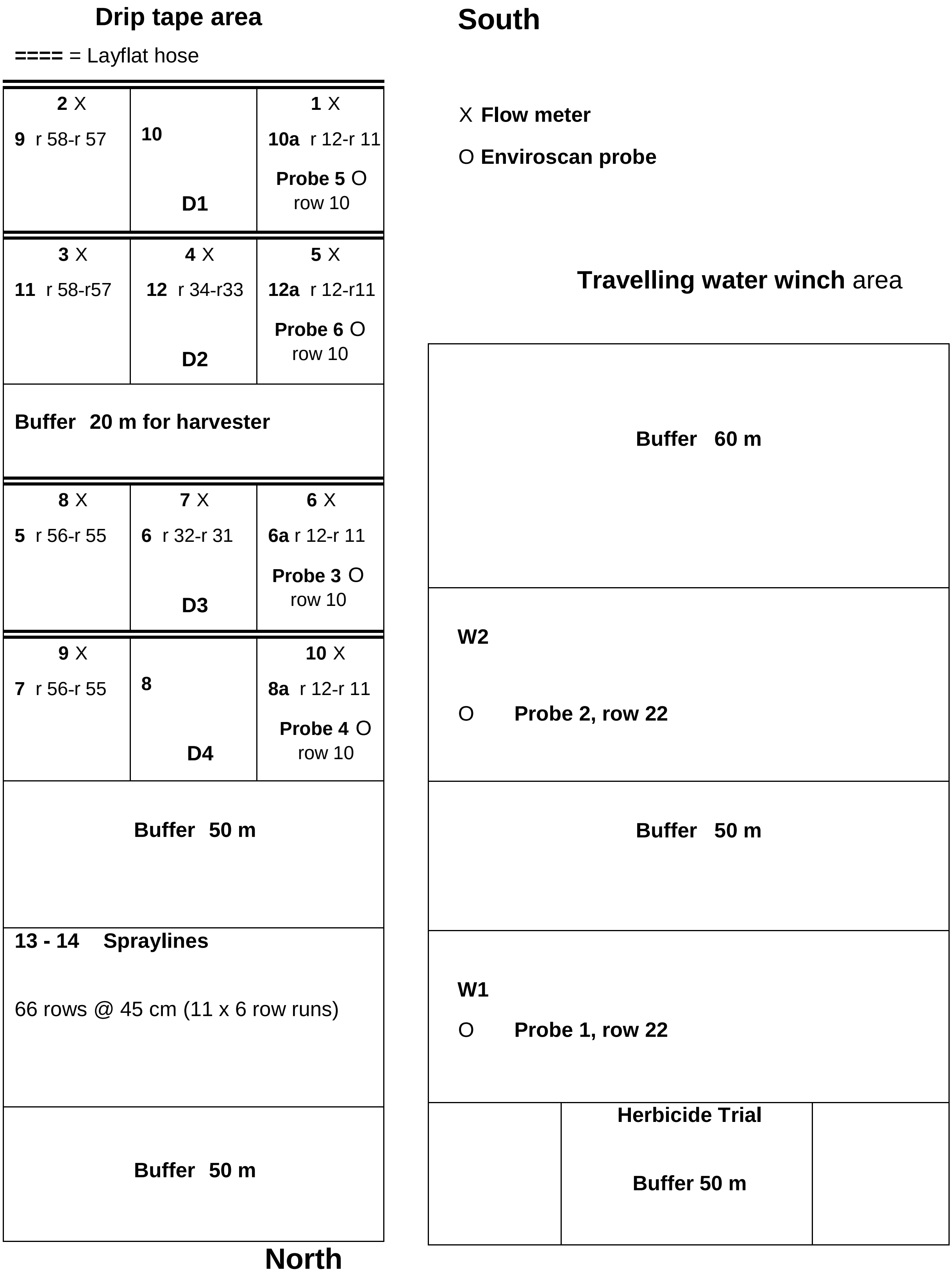

Figure 2. *Chicory trial layout showing drip flowmeter and Enviroscan® sites*

Winch blocks

Large buffer areas were needed to ensure that there was no over-spray of irrigation water onto other areas and so that there was sufficient area of each treatment that was receiving an even application of water. Each treatment area for data collection was 60 m x 43 m, they were referred to as winch 1 (W1) and winch 2 (W2) for treatments 1 and 2 respectively.

The trial area was set up so that the winch would be throwing water to the west, so the prevailing south east to north east winds would not blow water onto the sprayline and drip areas. Because of the probability of irrigation over-spray the winch area could only be irrigated from the eastern side of the winch block. Trial runs with the winch confirmed its out put at 90,000 L (0.09 ML) per hour.

Sprayline plus winch area

Two rows of spraylines were laid out to cover an area of 142 m x 30 m, the data collection area within this was 60 m x 30 m. Model S-II® Hardie Pope sprinklers with a 5.4 mm main jet and 2.5 mm rear jet were placed on 60 cm risers out of 9 m x 100 mm aluminium pipes. A 100 mm flow meter was placed in the line near the water outlet to measure the volume of water used.

Drip blocks

The drip tape used was T-Tape® 508-30-340. This is a one use tape, 0.2 mm thick, 16 mm diameter, with emitters 30 cm apart. It delivers 340 L of water per 100 m of tape per hour, that is about 1 L per emitter per hour. This is a low to medium flow rate and was chosen because higher flow rates reduce the length it is possible to run the tape and get uniform irrigation, and at higher outputs water tends to go vertically through the soil profile rather than spread laterally towards the plant rows.

The thin 0.2 mm thick tape was chosen to reduce the cost of drip irrigation. In hindsight using the more expensive but more commonly used 0.3 mm thick tape would have prevented or at least greatly reduced the cricket damage that occurred.

All the drip tape was laid out after planting on Friday afternoon 14 December. The drip tape was placed approximately 25 mm deep between rows, so that there was a drip tape in every second interrow. The soil was so dry that it was considered seeds would not absorb moisture and begin the germination process. Over Sunday and Monday 16 and 17 December, 35 mm of steady rain fell at the research station. The rest of the irrigation was laid out and connected up over 19 and 20 December. There were four separate blocks in the drip trial area, T1 and T2 each at 40 cm and 45 cm row spacing. They were referred to as D1, D2, D3 and D4 respectively. Flow meters were placed in some drip lines, two in each of D1 and D4 and three in each of D2 and D3. The flow meters were placed in similar row positions in each block.

Weed control

Weed control a very important part of chicory production and the trial protocol described the application of herbicides to be made to the main trial area. This project included a herbicide trial conducted by Mr Julian Collins of the Bureau of Sugar Experiment Stations (BSES). A copy of his report is attached as Appendix I. It was supplied to Orafti on completion.

Trial area

The trial area was sprayed three times with a mixture of the herbicides Broadstrike® and Kerb® as required by the protocol. Broadstrike® was applied at 10 g/ha and Kerb® at 500 mL/ha in 200 L of water. The first spray was applied at the cotyledon stage on 4 January 2002, the second on 11 January and the final spray on 21 January because it was too wet and windy on 18 January when it was due.

Broad leaf and grass weeds were removed by manually hoeing and nutgrass was killed using a 50/50 glyphosate and water mix in wick wipers.

Herbicide trial

The herbicide trial was planted in the central section of the buffer area at the northern end of the winch W1 irrigation area. Plots were 25 m long with six rows 45 cm apart. Table 3 shows the herbicide trial design.

Table 3. *Herbicide trial layout*

Winch 1 area							
BUFFER	**Treat 2** Cotyledon + once a week for 2 weeks Broadstrike® 10 g/ha (0.1 g) + Kerb® 500 mL/ha (6.1 mL)	**Treat 7** At cotyledon Broadstrike® 10 g/ha + Kerb® 500 mL/ha Then chicory at 4 leaf stage Dual Gold® 400 mL/ha (4.9 mL) + Broadstrike® 20 g/ha (0.2) g)	**Treat 1** Control chipped	**Treat 3** Treflan® 3 L/ha	**Treat 10** Treflan® 3 L/ha Weeds less than 3 leaf Spinnaker® 400 mL/ha (4.9 mL)	**Treat 4** Treflan® 1.5 L/ha	BUFFER
	Treat 9 Cotyledon + once a week for 2 weeks Broadstrike® 10 g/ha + Kerb® 500 mL/ha Nutgrass actively growing Sempra® at 100 g/ha and 50 g/ha	**Treat 8** At cotyledon Broadstrike® 10 g/ha + Kerb® 500 mL/ha Chicory at 6 leaf stage Dual Gold® 600 mL/ha (7.3 mL) Broadstrike® 20 g/ha (0.2 g)	**Treat 1** Control chipped	**Treat 5** Treflan® 3 L/ha Weeds less than 3 leaf Broadstrike® 20 g/ha (0.2 g)	**Treat 11** Treflan® 3 L/ha Weeds less than 3 leaf Spinnaker® 200 mL/ha (2.4 mL)	**Treat 6** Treflan® 1.5 L/ha When chicory at 2 leaf Dual Gold® 200 mL/ha (2.4 mL) + Broadstrike® 20 g/ha (0.2 g)	

Northern headland

The trial included the following treatments:

1. Control – No herbicide, weeds chipped.
2. Broadstrike® 10 g/ha and Kerb® 0.5 L/ha at cotyledon stage then once a week for two weeks.
3. Treflan® 3 L/ha during last ground preparation and pre planting.
4. Treflan® 1.5 L/ha during last ground preparation and pre planting.
5. Treatment 3 plus and 20 g/ha Broadstrike® at first weed germination.
6. Treatment 4 plus Dual Gold® 200 mL/ha and 20 g/ha Broadstrike® at two leaf stage.
7. Treatment 2 until 4 leaf stage then Dual Gold® at 400 mL/ha plus 20 g/ha Broadstrike®.
8. Treatment 2 until 6 leaf stage then Dual Gold® at 600 mL/ha plus 20 g/ha Broadstrike®.

9a. Treatment 2 plus Sempra® at 100 g/ha on active growing nutgrass.

9b. Treatment 2 plus Sempra® at 50 g/ha on active growing nutgrass.

10. Treatment 3 plus Spinnaker® at 0.4 L/ha when broadleaf weeds at less than 3 leaf stage and nutgrass actively growing.

11. Treatment 3 plus Spinnaker® at 0.2 L/ha when broadleaf weeds at less than 3 leaf stage and nutgrass actively growing.

Table 4 shows the chemicals and their active constituents.

Table 4. *Chemicals applied and their active constituents*

Commercial name	Active constituent
Broadstrike®	800 g/kg flumetsulam
Kerb®	500 g/kg propyzamide
Treflan®	480 g/L trifluralin
Sempra®	750 g/kg halosulfuron – methyl
Dual Gold®	960 g/L s-metolachlor
Spinnaker®	240 g/L imazethapyr

Treatments were applied with 200 L/ha water at 2 bar pressure (200 kpa) with the BSES motorised small plot sprayer. The Dual Gold®, Broadstrike® and Spinnaker® treatments were irrigated within three days of application. Table 5 shows the treatments, application dates and plant stage.

Table 5. *Treatments, application dates and plant stage*

Application date	Treatment number	Crop stage	Treatment
13/12/01	3, 5, 10, 11	Preplant	3 L/ha Treflan®
13/12/01	4 & 6	Preplant	1.5 L/ha Treflan®
19/12/01	2, 7, 8, 9	Cotyledon	10 g/ha Broadstrike® + 500 mL/ha Kerb®
26/12/01	5	2 Leaf	20 g/ha Broadstrike®
26/12/01	10	2 Leaf	400 mL/ha Spinnaker®
26/12/01	11	2 Leaf	200 mL/ha Spinnaker®
26/12/01	6	2 Leaf	200 mL/ha Dual Gold®+ 20 g/ha Broadstrike
26/12/01	2 & 9	2 Leaf	10 g/ha Broadstrike® + 500 mL/ha Kerb®
3/1/02	2 & 9	4 Leaf	10 g/ha Broadstrike® + 500 mL/ha Kerb®
3/1/02	7	4 Leaf	400 mL/ha Dual Gold®+ 20 g/ha Broadstrike®
9/1/02	8	6 Leaf	600 mL/ha Dual Gold® + 20 g/ha Broadstrike®
13/2/02	9a & 9b		100 & 50 g/ha Sempra®

Treflan® was applied on 13 December, 2001 and immediately incorporated into the soil with the power harrows.

Fertiliser

Basal fertiliser was applied and incorporated into the soil just before planting. Two further applications of 20 kg/ha of nitrogen were due during weeks eight and twelve after planting. On

6 February, in week eight, 20 kg of urea was applied to the drip area through the drip tape. A pump breakdown meant that we could not apply nitrogen to the sprayline and winch areas until the pumps were repaired. On 19 February 23.5 kg of urea was applied to the sprayline area with a Vicon® spreader and incorporated into the soil with irrigated. On 21 February 51 kg of urea was applied with a Vicon® to the winch area and irrigated in. On 12 March, in week 12, 76 kg of urea was applied to the winch and sprayline area and 20 kg to the drip area.

Forking

Roots were checked for forking at 60, 90 and 120 days after planting and at harvest times of 150, 180 and 210 days. For the 60, 90 and 120 day samples, 50 roots were dug at random across the winch, sprayline and drip areas, a total of 150 roots. The number of forks and the depth at which forking started was recorded. The plants were also assessed for the presence of disease and insects or damage caused by them.

The number of forks and the depth at which forking occurred was also recorded for all harvests, as well as insect damage and disease on the roots.

Bolting

Chicory is a perennial plant that normally flowers in the second year. Premature flowering, called bolting, appears to be caused by stress. The bolted plants were counted and removed 120, 150 180 and 215 days after planting in the six 10 m plots used for the emergence counts. At 120 days after planting, all the visibly bolted plants in the chicory block were counted and removed.

At Orafti's request a 20 m x 10 row plot was measured out for future bolting counts and marked with bright tape. These plots started two rows in from the side of the treatment blocks and about 2 m from the top of the block, each in the same relative position. The 150, 180 and 215 day counts were made in these blocks as well as the emergence plots mentioned above. Harvested plants that had bolted were also recorded.

Insects and disease

The crop was regularly checked for the presence of insects and disease and a record made.

Harvests

Harvests were originally scheduled for 150 and 180 days after planting, with the crop irrigated to field capacity 143 days after planting. Harvests were also to be taken in the drip areas at 180 and 195 days after planting with sections of the drip area to be irrigated 173 days after planting. As a result of a meeting with Orafti on 9 May, the 195 day harvest was dropped and all treatments were to be harvested 210 days after planting.

In the original protocol, six 10 m plots were to be harvested from each of seven treatments at each harvest. In discussion with Orafti this was reduced to a more manageable three 10 m plots per treatment, that is 21 plots per harvest, 63 plots over the three harvests.

From each treatment of each harvest, three roots, small, medium and large, were taken to Crop Tech laboratories for processing and sending to Belgium for inulin extraction.

For each plant harvested the following information was recorded:

- number of forks;
- depth of forking;
- presence of side roots;
- whether the root was broken;
- length of the root;
- weight of the top (foliage);
- weight of the collar if present;
- weight of the root;
- insect damage;
- disease, including nematodes;
- number and relative size and age of growth cracks;
- relative size of hollows in roots;
- whether the plant had bolted;
- whether the root fibres were soft or hard.

Further comments were recorded as necessary.

Figure 3 shows the positions of each harvest plot.

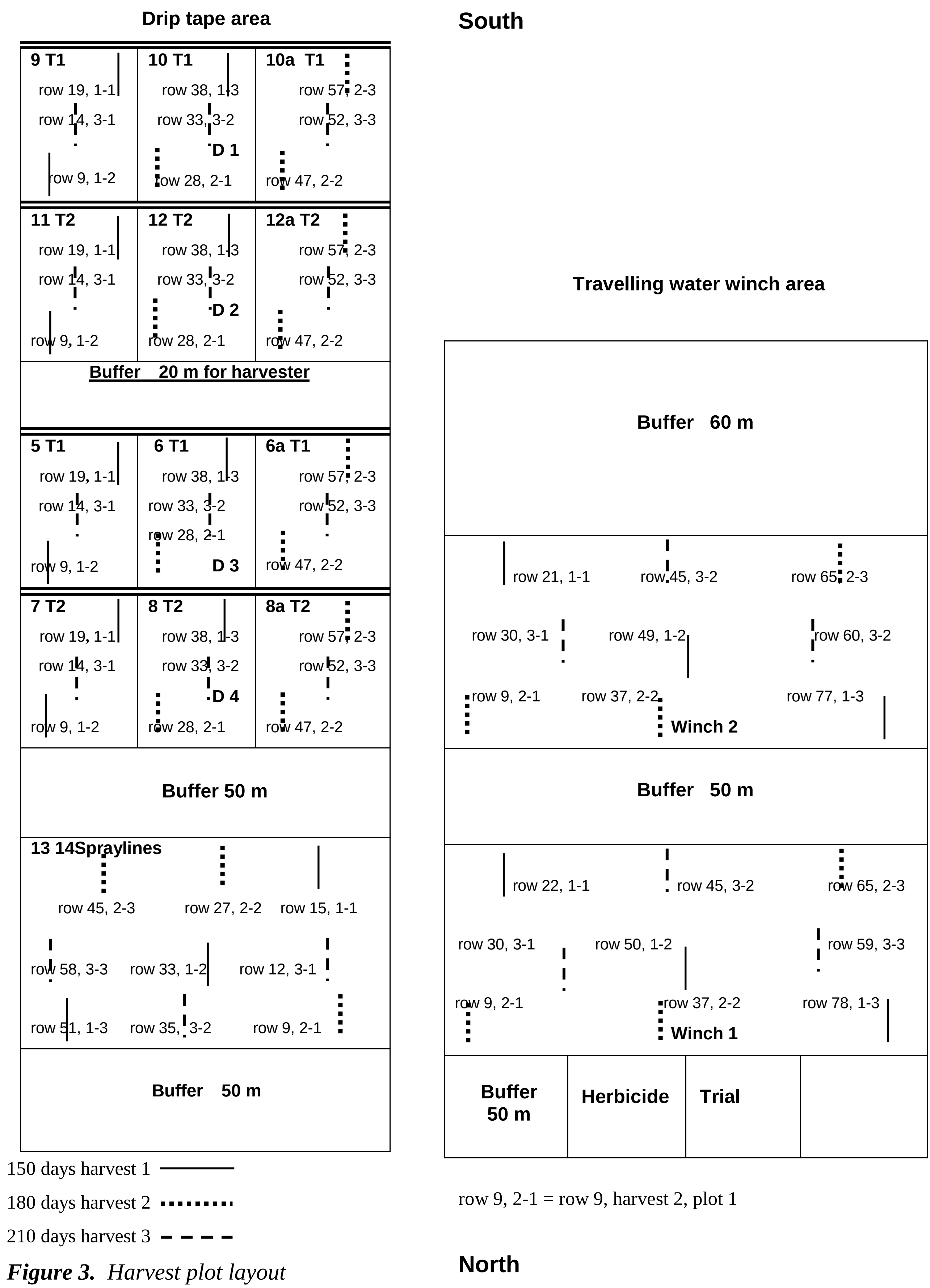

Figure 3. *Harvest plot layout*

Crop removal (postharvest cleanup)

Originally it was intended to use a six row harvester from Belgium to harvest the block after the trial harvests were completed. This did not eventuate, partly because of the low plant population, so a record was kept of the clean up process to remove the crop and subsequent regrowth.

Gross margin analysis

This project included a theoretical gross margin and whole farm budget done before the trial commenced, followed by a further analysis using the information gained from the trial.

In this type of analysis it is important to define exactly what is meant by a gross margin. Gross margins are determined by deducting variable costs (fertiliser, pest and disease control, irrigation, casual labour etc) from the gross farm income of a crop. Fixed costs are over and above the variable costs and are taken into account in whole farm analysis. When 'break even' figures are stated it is important to remember that this is only at the gross margin level. When break-even is achieved at this level, the crop is making *no* contribution to paying off fixed costs and interest.

The analysis is based on the experience gained in setting up and growing a 2.5 ha trial block of chicory at the Centre for Sustainable Horticulture in Bundaberg and use normal production methods and current prices of inputs. The gross margins were developed for the three different methods of irrigation and two irrigation treatments used in the trial. They are attached as Appendices II and III.

Theoretical pre-trial gross margin and whole farm budget

The theoretical pre-trial gross margin and whole farm budget was done by Mr Brian Richardson, a former financial counsellor and Business Development officer of Brisbane. His report was supplied to Orafti in August 2001, it includes the following assumptions:

- To focus on the target audience being canegrowers, this analysis was based on a 10 ha fallow area. This assumes an average cane farm of 60 ha, with a 1:5 rotation, has 10 ha of fallow available each year.
- Although gross margins are provided for four different types of irrigation, this analysis, to be as realistic as possible, is based on using only a winch for irrigation. Most cane growers with irrigation would use the winch only method.
- Expected yield will be 45 tonnes/hectare.
- No allowance was made for freight.
- Molasses and urea are sprayed on to the cane trash to help it breakdown prior to land preparation.
- Machinery costs are based on FORM – Fuel and Oil and Repairs and Maintenance.
- Planting ($100 per hectare) and harvesting ($400 per hectare) will be done on a contract basis by Orafti but paid for by the grower. Chicory seed is supplied.
- Water charges are $36.80 per megalitre. There is the possibility these charges will increase to $50 to $60 per megalitre in the next few years.
- With the drip irrigation system the drip tape only has a one use life. The lay flat tape and fittings however have a 5 use life, and allowing for wear and tear, have been spread over a 4 crop lifecycle.

- No allowance was made for a new filter system, which would cost about $3,000, with an expected life of 10 years.
- Capital equipment is bought new and ownership costs (included in farm fixed costs), are the sum of depreciation, interest, shelter and insurance costs.
- There is a sensitivity analysis included for each gross margin, the parameters being yields from 35 t/ha to 45 t/ha and a price range of $320 to $480 per tonne.
- The assumption chicory will be grown as a fallow crop, means fixed costs were calculated as 10% of a normal cane farms inputs. The exception includes capital expenditure for a set of power harrows and an irrigation main and other items such as electric fencing, nematode assessment and soil analysis.
- There is an in-built risk factor of 10% of working capital (equipment plus establishment costs) shown in this analysis. It also includes an allowance to management and an opportunity cost for rent.
- Figures used in this analysis were current as of August 2001.

It was decided that the one drip tape per row was too expensive and this method of irrigation was not used in this trial.

Post-trial gross margin and whole farm budget

The post trial gross margin and whole farm budget was done by Ms Trish Cameron, Extension Officer (Farm Business Management), from the Rural Industry Business Services group of DPI in Bundaberg, with Mr Jerry Lovatt and with input on sugar cane production from Mr Julian Collins of the Bureau of Sugar Experiment Stations (BSES). The gross margin and whole farm analysis include the following assumptions:

- This analysis assumes an average cane farm of 75 ha, with a 1:5 year rotation, has 15 ha of fallow land available each year.
- Yields used are those achieved in the trial.
- Price for chicory is $90 per tonne.
- No allowance has been made for freight.
- Molasses and urea are sprayed on to the cane trash to help it breakdown prior to land preparation.
- Machinery costs in the gross margins are based on FORM – Fuel, Oil, Repairs and Maintenance.
- Planting ($60 per hectare) and harvesting ($400 per hectare) will be done on a contract basis by Orafti but paid for by the grower. Chicory seed is supplied.
- Water charges are $50 per megalitre.
- With the drip irrigation system the drip tape only has a one use life. The lay flat hose and fittings however have a five use life so have been spread over five crops.
- Allowance has been made in the drip gross margins for a disc filter system, costing $2,400, with an expected life of 10 years.

- Allowance has been made for a travelling irrigator with a 20 year life and sprayline irrigation with a 15 year life spread over 75 ha as both will also be used on sugar cane.
- The cost of irrigation equipment is usually considered a fixed cost, but it is included in the irrigation costs to allow more accurate comparison of different irrigation methods.
- There is a sensitivity analysis included for each gross margin, the parameters being yields from 30 t/ha to 60 t/ha and a price range of $80 to $120 per tonne, and a price range of $250 to $300 per tonne for sugar.
- Capital equipment is bought new and ownership costs (included in farm fixed costs), are the sum of depreciation, interest, shelter and insurance costs.
- Farm fixed costs included in the whole farm budget were: accountancy and legal fees; postage and phone; electricity (workshop etc., not irrigation); farm utility; machinery ownership costs (excluding irrigation equipment); rates and $30 000 wages for the owner.
- Interest costs are not included in the whole farm analysis. The ‘bottom line’ is *operating return* which represents return on total assets. This is a useful figure as it can be compared to return on other possible uses of capital in or out of farming. *Business return* can be calculated by subtracting interest from *operating return* but this has not been done given the wide range of possible debt levels.

Results

Land preparation

Land preparation was more difficult and required more workings than anticipated because of the very dry conditions. Under conditions of average rainfall, it is expected that the land could be prepared satisfactorily with fewer cultivation passes and without the need to irrigate.

Orafti agronomists were satisfied with the general condition of the soil, although undecomposed trash was still obvious. The power harrow incorporated the trash into the surface soil well and left a firm, level seed bed except for the small furrow left at each side of the power harrow. This caused some problems when either the tractor wheel ran in the furrow making the planter unlevel, or the seed box lined up to plant into the furrow.

Soil test results

Soil samples were taken on 11 September to test for nematodes and soil nutrients.

Soil nutrients

On 24 September, lime was applied at 3 t/ha, as recommended by Crop Tech from a soil analysis taken on 11 September. The results are shown in Table 6.

Table 6. *Soil test results from the chicory trial block before planting*

				Comments
pH		6.1		Acidic
EC		0.05 mS/cm	50 µS/cm	Good
Nitrate-N		2 ppm		Low
Phosphate-P (BSES)		31 ppm		Medium
Phosphate-P (Colwell)		45 ppm		Medium – Good
Potassium		72 ppm	0.18 meq %	Medium – Low
	% cations	2.36%		Low
Calcium		837 ppm	4.19 meq %	Medium
	% cations	53.6%		Low
Magnesium		352 ppm	2.93 meq %	Good - High
	% cations	37.57%		Good - High
Sodium		116 ppm	0.5 meq %	Medium – Good
	% cations	6.46%		Medium
Sulfate – S		10 ppm		Medium
Zinc		12.2 ppm		Good
Copper		4.4 ppm		Good
Manganese		1.5 ppm		Medium - High
Iron		3.9 ppm		Good
Boron		0.02 ppm		Low
Organic carbon		1.44%		Medium – Low
Chloride		25 ppm		Good

After the last harvest soil samples were taken from the winch and drip areas for nutrient testing, the results are shown in Table 7.

Table 7. *Soil test results from the winch and drip areas at the end of the trial*

	Winch area			Drip area		
pH	6.8		Slightly acidic	6.2		Acidic
EC	0.04 mS/cm	40 μS/cm	Good	0.08 mS/cm	80 μS/cm	Good
Nitrate-N	3 ppm		Low	3 ppm		Low
Phosphate-P (BSES)	30 ppm		Good	27 ppm		Good
Phosphate-P (Colwell)	63 ppm		Good - High	57 ppm		Good - High
Potassium	105 ppm	0.27 meq %	Good	101 ppm	0.26 meq %	Good
% cations	2.81%		Medium – Low	3.84%		Good
Calcium	1,226 ppm	6.13 meq %	Good	784 ppm	3.92 meq %	Medium - Low
% cations	64.05%		Low	58.12%		Low
Magnesium	329 ppm	2.74 meq %	Good - High	274 ppm	2.28 meq %	Good
% cations	28.64%		Good - High	33.85%		Good - High
Sodium	99 ppm	0.43 meq %	Medium	65 ppm	0.28 meq %	Good
% cations	4.5%		Good	4.19 %		Good
Sulfate – S	7 ppm		Low	15 ppm		Good
Zinc	12.1 ppm		Good - High	11.1 ppm		Good - High
Copper	5.0 ppm		Good	4.5 ppm		Good
Manganese	1.16 ppm		Good	1.16 ppm		Good
Iron	1.2 ppm		Low	1.7 ppm		Low
Boron	0.01 ppm		Low	0.05 ppm		Medium
Organic carbon	1.71%		Medium – Low	1.69%		Medium – Low
Chloride	14 ppm		Good	21 ppm		Good

Nematode test results

Soil was sent to Biological Crop Protection for testing for nematodes. The numbers of nematodes in 200 mL of soil were root-knot nil; reniform 510; lesion 44; stubby 1; and dagger nematodes 2. The results of the nematode test were interpreted by Marcelle Stirling from Biological Crop Protection as follows:

> Root-knot nematode (*Meloidogyne* spp.), potentially the most damaging nematode to chicory, was not detected in the sample. The lesion nematode present is *Pratylenchus zeae* and the reniform nematode is most likely *Rotylenchulus parvus* (no males observed). Both these nematodes are hosted by grasses.

Depth of planting trials

The original protocol required that the chicory seed be planted at greater than 1 mm and less than 5 mm deep, as is the practice in Europe. I was concerned that in hot, dry, windy conditions, in a well drained soil, the soil would rapidly dry out to the depth of the seed and emergence would be poor.

On 24 September 2001, 10 seeds per row were planted in four polystyrene boxes at several depths and the boxes were placed in a plastic greenhouse. They received three ten minute waterings per day from small sprinklers, Table 8 shows the results.

Table 8. *Total seed emergence from 40 seed planted*

Seed depth	Number emerged	% emerged
0 mm	34	85%
5 mm	34	85%
10 mm	26	65%
15 mm	28	70%
20 mm	29	73%
30 mm	8	20%
40 mm	2	5%

This observation trial showed that under these conditions, emergence to 20 mm was satisfactory. Almost all plants that emerged had done so by day five or six after planting. Emergence at 30 mm and 40 mm was very poor and was not tested in the field.

On 19 October I planted two rows of seeds, 10 seeds at each depth from 0 to 20 mm, approximately 100 - 120 mm from a drip irrigation line at the end of two rows of rockmelons. They were irrigated two to three times a week. No seed placed on the surface (0 mm) germinated and much of it was blown away. On 1 November I planted seed on the opposite side of the drip tape at 5 - 20 mm deep. Table 9 shows emergence results of these plots.

Table 9. *Total seed emergence from 20 seed planted*

Seed depth	Planted 19 October 2001		Planted 1 November 2001		Average
	Number emerged	% emerged	Number emerged	% emerged	% emerged
0 mm	0	0%	–	–	
5 mm	14	70%	11	55%	62.5%
10 mm	14	70%	15	75%	72.5%
15 mm	16	80%	19	95%	87.5%
20 mm	16	80%	19	95%	87.5%

This observation trial showed that under field conditions and drip irrigation, emergence at 15 mm and 20 mm were best, and from 10 mm to 20 mm was better than 5 mm. The soil at 5 mm was often dry whereas the deeper soil maintained its moisture between irrigations. Almost all plants that emerged had done so by day six to eight after planting.

Orafti agronomists saw all these observation trials and were given the results as they became available. As a result of these preliminary observation trials it was decided to plant the main trial at 10 mm deep instead of greater than 1 mm and less than 5 mm deep in the original planting protocol.

Planting

Orafti supplied a six row vacuum planter and chicory seed that was pelleted to give a more consistent seed size. Seed was planted 10 cm apart in the rows, at the rate of 222,222 seeds /ha at the 45 cm row spacing, and 250,000 /ha at 40 cm row spacing.

It took a little time to set up the planter so that it was planting all six rows at about 10 mm deep. The trash in the soil caused some problems, building up in front of the planter share, but the main problem was the billets of cane and cane roots that had not broken down in the dry conditions. A build up of trash in front of the planter shares pushed soil up in front of it so that seed depth varied too much. The furrow formed on each side of the power harrow also caused some problems if the tractor wheel ran in it, or it coincided with a seed box.

Some seed was cracked at times in the planting process but this was restricted to one or two seed boxes. The soil was hot and dry at planting. Maximum soil temperature at 10 cm on planting days 13 - 14 December was 33°C and 34°C respectively.

Plant emergence

The soil was very hot and dry at planting. On 11 February I placed some Gemini® data loggers in the chicory block and on 12 February when the maximum soil temperature at the BSES weather station was 32.4°C at 10 cm, the data loggers in the chicory block recorded 33.3°C at 10 cm and 43.7°C at 1 cm deep. Maximum soil temperature at 10 cm reached 33.9°C in the week after planting, 35.6°C in the second week and 36.7°C in the third week. Based on the 12 February comparisons it could be assumed that the maximum soil temperature at 1 cm, where the seed was, would have reached between 40°C and 45°C for the three weeks after planting.

Plant emergence was assessed seven and 21 days after planting. Six 10 m plots were marked out in each of the winch and sprayline plus winch areas and in each of the 40 cm and 45 cm drip areas. Each 10 m plot should contain 100 seeds, so the number of plants emerged equals the percentage emergence. The plots were spaced across each area to allow for variations in irrigation. Table 10 shows the number of seedlings (the percentage of the total number of seeds planted), that have emerged in each plot at seven and 21 days after planting. Winch plots 1 and 6 were near the western side of the block, that is furthest from the winch, plots 3 and 4 were closest to the winch.

Table 10. *Number and percentage of seedlings emerged at seven and 21 days after planting*

Plot number	Number (%) of seedlings emerged							
	7 days after planting (21/12/2001)				21 days after planting (4/1/2002)			
	Winch	Sprayline	Drip 45 cm	Drip 40 cm	Winch	Sprayline	Drip 45 cm	Drip 40 cm
1	11	16	29	14	19	19	37	43
2	15	36	26	26	41	48	47	44
3	14	37	15	19	35	47	40	36
4	38	21	20	5	59	32	56	34
5	16	11	23	26	45	35	60	64
6	7	32	13	25	52	43	38	75
Total	**101**	**153**	**126**	**115**	**251**	**224**	**278**	**296**
Percent	**17%**	**26%**	**21%**	**19%**	**42%**	**37%**	**46%**	**49%**

The soil surface was still reasonably loose at the seven day count, although the drip plots were looser than the winch or sprayline plots. The soil surface of all plots was compacted at the 21 day count after two storms had dumped up to 65 mm and 47 mm in two sudden downpours. Some seed and seedlings, particularly in a low part of the sprayline area had been washed away and some plants had been covered with soil. At the seven day count the spray/winch combination was best averaging 26%, followed by drip at 20% and winch at 8% emergence.

Because emergence was so poor, I did some germination tests using the nude seed used in my depth of planting trials and the pelleted seed used to plant the trial. Some seed were placed in a cool room, some in the plastic house and some in my office. There was no real difference between nude and pelleted seed, the germination percentage was between 70% and 100%, mostly 80% to 90%. There were discussions with Orafti about whether to continue with the trial or re-plant in about March 2002 but the decision was made to continue with the trial.

During harvest, nine 10 m rows were selected at random from each treatment for harvest. The number of plants harvested from each treatment also gives an indication of the plant population for each irrigation treatment. Figure 4 shows the average percentage of the possible plant population at seven and 21 days in the emergence plots and in the harvested plots. The generally lower percentage of the possible population shown in the harvested blocks is likely to be partly the result of plant losses during hoeing and wick wiping operations. Two plots in D2 dropped to 24 plants per plot on 1 February, from 44 and 49 plants on 9 January. These plots were in an area heavily infested with nutgrass and during this time the area had been chipped and wick wiped with glyphosate.

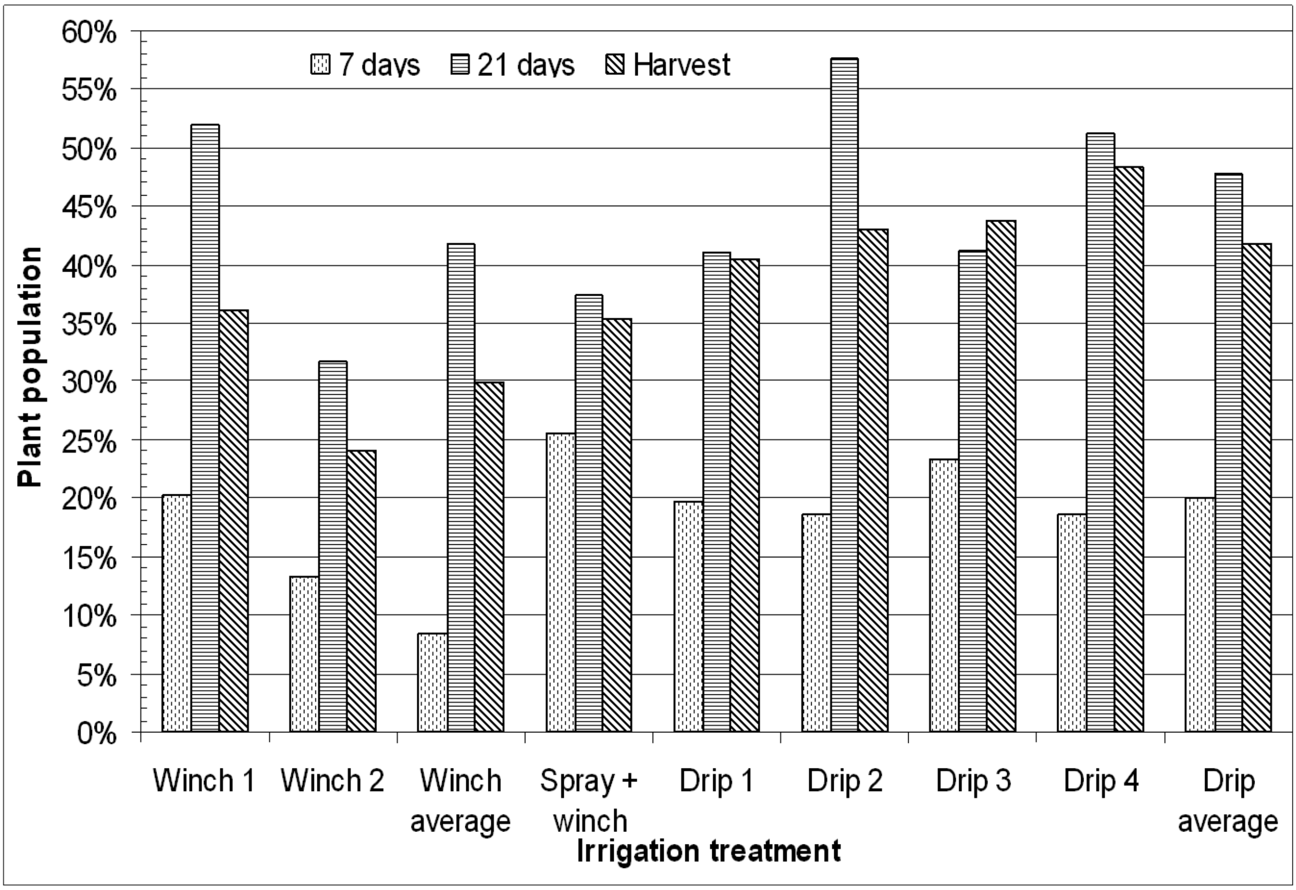

Figure 4. *Percentage plant population for the different irrigation treatments*

Irrigation

Irrigation was initially aimed at maintaining surface soil moisture until the seeds had germinated and the seedlings were well established. Hot dry weather, accompanied by moderate to fresh hot, dry northerly winds made this difficult, especially with the winch. The wind usually increased during the day and often changed direction by up to 90 degrees.

Steady rain, 15 mm on day three and 20 mm on day four after planting was expected to be enough to germinate all seed, based on the pre-trial plots where most seed had emerged by day five or six. All blocks were irrigated on day seven, 21 December, however it appears that a lot of seed may have germinated and then dried out in the two days between the rain and the irrigation.

The irrigation pumps became inoperable on 13 February, day 61, when the crop was due for an irrigation and nitrogen fertiliser. We were unable to irrigate until 19 February for sprayline and drip, and 21 February for the winch area. The previous irrigation had been on 4 February. This long delay stressed the plants, fortunately four periods rain produced a total of 43 mm during that time.

Chicory plants responded very quickly to water application and plant leaves would stand and green up as soon as the travelling irrigator water got close to them. It was difficult to determine whether it was a response to a slight water spray drift onto them or the increased humidity, but the response appeared to be almost instantaneous. Even when well watered the plants would often wilt in the heat of the day and stand up again by late afternoon.

Table 11 shows the quantity of water, irrigation plus rain, that the blocks received. The irrigation figures are from the irrigation record based on flow meters and the winch output. Holes chewed in the drip tape by crickets would have increased the amount of water used in the drip area, particularly for D1, D2 and to a lesser extent D3.

Most of the rain either fell very quickly in storms of up to 65 mm in less than an hour, which caused runoff, or as small ineffective falls of 1 mm to 6 mm. On 3 - 4 June 167 mm of heavy, steady rain fell. To calculate the volume of water in megalitres (ML) of rainfall per hectare, 100 mm of rain is equal to 1 ML/ha.

Table 11. *The quantity of water, irrigation plus rainfall received*

Water received (ML/ha)	W1 (T1)	W2 (T2)	Spray + Winch	D1 (T1)	D2 (T2)	D3 (T1)	D4 (T2)
Irrigation	4.876	6.389	4.738	5.167	5.603	4.951	4.044
Rainfall	5.261	5.261	5.261	5.261	5.261	5.261	5.261
Total water received	**10.137**	**11.650**	**9.999**	**10.428**	**10.864**	**10.212**	**9.305**

Table 12 shows the distribution of irrigation water over the winch area and the sprayline plus winch area. The winch track is between gauges three and four. The direction and speed of the wind has a considerable impact on the distribution of the irrigation water from any aerial application, particularly the winch. Rain gauge five was between the two spraylines and the overlap of the sprinklers at that position was not sufficient to give an even distribution over the whole area.

Table 12. Irrigation distribution in rain gauges

Irrigation method	Winch area, rain gauge number			Sprayline + winch area, rain gauge number		
	1	2	3	4	5	6
Sprayline				193 mm	128 mm	303 mm
Winch	225 mm	681 mm	577 mm	243 mm	145 mm	63 mm
Total	**225 mm**	**681 mm**	**577 mm**	**436 mm**	**273 mm**	**366 mm**

Soil moisture monitoring

Soil moisture was monitored using an Enviroscan® capacitance probe and Soilspec® and Jetfill® tensiometers.

Enviroscan®

The Enviroscan® and tensiometers were installed on 22 - 23 January and irrigation was based on the two irrigation treatments, T1 and T2 from 1 February, 2002. For T1 irrigation was applied when the Enviroscan® showed mild stress, that is when water usage slowed at 10 cm deep, irrigation was then applied to refill the soil profile to field capacity, the full line on the Enviroscan® graph. Whilst it was easy to determine this point from the Enviroscan graphs it is difficult to match Enviroscan® requirements with winch application, as you need to try to get it right in one pass of the winch. With drip and sprayline irrigation it is much easier to monitor and either increase or decrease the irrigation time.

For T2, irrigation was applied when the Enviroscan® showed moderate stress, described as 'when the ratio between evapotranspiration and daily water use indicated by the Enviroscan®' falls below 0.5. That is when daily water use is less than 50% of the daily evapotranspiration. At this point the Enviroscan® graph had usually started to flatten out and reach the 'onset of stress' line on the graph.

Rainfall and cool overcast weather reduces both evapotranspiration and water usage and both irrigation and rain will result in the Enviroscan® showing negative water usage. If the soil is wet and conditions are cool and overcast, evaporation readings may be close to normal, but water usage will be low, resulting in a water use to evapotranspiration ratio that is below 0.5, so an irrigation is indicated by this formula when it is not necessary and may be detrimental.

As with treatment 1, when the moderate stress point was reached, usually several days after the T1 treatment had been irrigated, the T2 treatment blocks were irrigated to refill the soil profile to field capacity. This is considered to be normal irrigation practice and usually required more water than T1 but was less frequent.

Unfortunately this was not what Orafti had intended that this treatment to be. Their intention had been to half refill the soil profile, stressing the plants by using approximately half the amount of water used in T1. This misunderstanding was disappointing to all concerned.

Table 13 shows the amount of water used for each treatment (T1 and T2), for winch irrigation and drip irrigation at 40 cm and 45 cm rows. Because of the holes made in the drip tape by crickets, the table shows the amount of water recorded by the flow meters and the quantity expected to be delivered by that drip tape for the number of hours it was operating.

Table 13. Amount of water used for (T1 and T2), for winch and drip irrigation

Irrigation treatment	Winch	Drip			
		40 cm		45 cm	
		Flow meters	Expected	Flow meters	Expected
Treatment 1	4.8761 ML/ha	5.1667 ML/ha	4.9745 ML/ha	4.9509 ML/ha	4.1867 ML/ha
Treatment 2	6.3893 ML/ha	5.6030 ML/ha	4.6885 ML/ha	4.0441 ML/ha	4.3241 ML/ha

Tensiometers

Two types of tensiometers, Jetfill® and Soilspec®, were placed in the crop on 23 January after the chicory was well established. Based on my experience in vegetable production, I would have irrigated when the 20 cm tensiometer reached around 30 centibars. The time at which this point was reached in the drip block was 0, 5, 4, 7 and 8 days before irrigation was indicated by the Enviroscan®, and 3, 3, 5, 4 and 8 days before indicated by the Enviroscan® in the winch block. However the tensiometers were in T2 blocks, so the plants were more stressed than they would be under normal growing conditions.

Soilspec® tensiometers were beside the Jetfill® tensiometers and one set was in the sprayline plus winch block which was irrigated as T1. Using 30 centibars on the 20 cm tensiometer, the Soilspec® tensiometers indicated irrigation 2, 1, 7, 3 and 4 days before the Enviroscan in the winch 2 block, and 3, 3, 3, 6 and 7 days before in the drip block, again these were in T2 blocks. In the sprayline plus winch block, which was irrigated at T1, the Soilspec® tensiometers indicated irrigation 0, 0, 3, 4, 6 and 4 days before irrigation based on the Enviroscan® probe in winch 1.

Tensiometers appear to be a reasonable guide to when to irrigate chicory.

Winch blocks

The winch blocks were irrigated from the eastern side with the prevailing wind but northerly winds in the early stages of the crop meant that the water often did not reach the western side of the block and there were fewer plants in the outside rows. When the wind was very strong much of the water fell into the middle of the block when the water from the winch jet was forced down by the wind and blown back towards the winch.

The heavy water droplets produced by the winch appeared to pound the soil and small seedling plants, sometimes partially covering them with soil. The winch did not appear to damage the plants once they had developed large leaves. It was not possible to speed the winch up enough to apply less than 25 to 30 mm at a time. A 1.46 inch (37 mm) ring was tried in place of the 1.6 inch (41 mm) ring in the winch, but this built up pressure so much it blew the hose from the hydrant and there were concerns it would damage the underground main lines. It is very difficult to regulate pump pressure with a turbine pump.

The top growth (foliage) in the winch blocks looked much bigger and lusher than in the other areas, and was considerably heavier at an average of 292 g and 301 g respectively for winch 1 and 2, compared to 181 g for the sprayline/winch area and 206 g for the drip blocks. The smaller number of plants in the winch blocks which gave each plant more space, could account for some of the variation but not all of it.

When harvesting, the soil in the winch area was noticeably more compacted and harder to dig than other areas.

Sprayline plus winch area

Spraylines were used to irrigate this block until the foliage started to grow vertically rather than prostrate as it does initially. This vertical growth was first noticed on 1 March, 77 days after planting. The winch was used for the next irrigation after that on 22 March and the block was irrigated with winch treatment 1.

Up to that time, the sprayline had been run for 31.5 hours and applied 1.349 megalitres (ML) of water, that is 3.168 ML/ha, applied in 11 applications. A further five applications with the winch took 22.5 hours and applied another 1.57 ML/ha, a total of 4.738ML/ha.

The spraylines were the easiest irrigation method to use for maintaining surface soil moisture and droplet size was smaller than from the winch. The soil in this area was less compacted and easier to dig than in the winch areas.

Drip blocks

When the drip irrigation system was turned on we found holes in the thin drip tape that we had used to reduce the cost of the drip irrigation method. Although no crickets or other insects were found the damage was consistent with crickets chewing the tape. This type of damage has previously been seen in vegetable crops in this district. To repair these holes about 150 joiners were inserted in the drip lines, particularly in the 40 cm row area D1 and D2, and the 45 cm row area adjacent to it, D3. There was little damage in the second 45 cm row area, D4. To reduce the risk of more damage chlorpyrifos was injected through the drip lines on 20 December, and a further application was made on 11 January, 2002. On 13 February new drip tape was run out on the surface for each row with a flow meter to ensure the flow meter readings were realistic.

Water usage measured by the flow meters was higher than expected for the drip treatments, Table 14 shows the quantity applied, based on flow meter readings, compared with the expected application based on the flow rate of the drip tape used. It also shows the number of joiners used in each block and the number of holes found in the tape after the last harvest. Drip irrigation blocks D1 and D2 were at 40 cm row spacing, D3 and D4 were at 45 cm row spacing.

Table 14. *Quantity of water applied compared with expected application for drip irrigation blocks*

	Drip irrigation block					
	D1	**D2**	**D3**	**D4**		
				up to 6/2/2002	**after 6/2/2002**	**Total**
Drip tape / block	1394 m	1394 m	1312 m	1472 m	1312 m	
Tape output (L/100 m/hr)	340 L	340 L	340 L	340 L	340 L	
Expected L /block/hr	4739.6 L	4739.6 L	4460.8 L	5004.8 L	4460.8 L	
No. of hours of irrigation	121.75 hr	114.75 hr	110.75 hr	45.00 hr	69.25 hr	114.25 hr
Expected L/block	577,046 L	543,869 L	494,034 L	225,216 L	308,910 L	534,126 L
Expected ML/ha	4.9745 ML	4.6885 ML	4.1867 ML	1.7062 ML	2.6179 ML	4.3241 ML
Average from flow meters	5.167 ML/ha	5.603 ML/ha	4.951 ML/ha			4.044 ML/ha
Difference (expected versus applied) ML/ha	0.1921 ML	0.9145 ML	0.7641 ML			–0.2799 ML
No. of joiners per block	155	256	104			15
No. of holes per block	9	26	36			1

Table 15 shows the flow meter readings, the expected water usage based on the tape flow rate, the variation between expected and actual water usage and the number of holes or joiners per drip tape for each flow meter.

Table 15. *Flow meter readings, expected usage, variation from expected and holes per drip tape*

Drip treatment		Holes/Joiners	ML/ha used	Expected ML/ha	Variation ML/ha
Drip treatment 1					
D1-40 cm	Meter 1	12	4.9292	4.9745	-0.0454
	Meter 2	8	5.4041	4.9745	0.4296
	Average	**10.0**	**5.1667**	**4.9745**	**0.1921**
D3-45 cm	Meter 6	25	5.0184	4.1867	0.8316
	Meter 7	16	4.9137	4.1867	0.7269
	Meter 8	20	4.9206	4.1867	0.7338
	Average	**20.3**	**4.9509**	**4.1867**	**0.7641**
Drip treatment 2					
D2-40 cm	Meter 3	21	5.8588	4.6885	1.1703
	Meter 4	10	5.1015	4.6885	0.4130
	Meter 5	21	5.8488	4.6885	1.1602
	Average	**17.3**	**5.6030**	**4.6885**	**0.9145**
D4-45 cm	Meter 9	0	4.3567	4.3241	0.0326
	Meter 10	1	3.7316	4.3241	-0.5925
	Average	**0.5**	**4.0441**	**4.3241**	**-0.2799**

The drip area was irrigated for 4 hours on 19 February and 4.5 hours on 20 February to wet up the soil, even though there had been 35 mm of steady rain on 16 - 17 February. It required a further 8 hours on 24 February to maintain moisture in the surface soil around the seed. These long irrigations markedly increased the amount of water used in comparison to the anticipated usage.

The water rarely moved past the row of plants, so the interrow that did not have a drip tape in it remained dry except after rain. This was particularly noticeable during harvesting when digging in the non-irrigated interrow.

Weed control

Weed control a very important part of chicory production. This project included a herbicide trial conducted by Mr Julian Collins of the Bureau of Sugar Experiment Stations (BSES). The full report of this trial is attached as Appendix I. The three applications of Broadstrike® and Kerb® were at very low rates and appeared to have limited effect on the weed population. Some stunting and distortion was noticed in the bellvine and Star of Bethlehem and the crowsfoot grass was stunted with very little root growth, however all the weeds grew normally after the herbicide applications stopped.

To maintain a weed free crop area manual hoeing was necessary to control most weeds. Nutgrass control was achieved using a 50/50 glyphosate/water mix in wick wipers which wipe the mixture onto the nutgrass. This was extremely effective in removing almost all of the nutgrass during the cropping period, however there were some plant losses in the areas heavily infested with nutgrass, particularly blocks D1 and D2 and to a lesser extent D3.

Herbicide trial

Plant counts

The trial suffered germination problems due to intense rainfall immediately after planting followed by an extended period of hot dry windy weather. Approximately 40% of the seed planted established into plants. Plant counts before and after herbicide applications were made to assess plant mortality due to the herbicide treatments. Two rows 25 m long were counted before and every week after spraying. The results are presented in Table 16.

The plant counts vary widely both within and across the herbicide treatments. None of the herbicide treatments caused any substantial plant death. Treatments 5, 7 and 8 had higher plant mortality than the control however plant death does not correspond with the herbicide applications. The poor germination made it difficult to measure the effect of the Treflan® treatments (3, 4, 5, 6, 10, 11) on chicory germination. However these treatments have similar plant counts compared to the untreated control.

Table 16. *Chicory plant counts per 25 m of row*

Treatment	Row	26/12/01	7/1/02	14/1/02	24/1/02	1/2/02	11/2/02	1/3/02	% change 26/12 to 1/3
1 Control	1	86	87	87	88	87	86	82	-5
	2	105	111	112	110	109	109	103	-2
	3	43	42	44	43	43	55	49	+14
	4	28	27	26	28	28	33	28	0
2	1	76	76	77	77	78	81	80	+5
	2	91	91	92	92	93	83	85	-7
3	1	19	18	17	18	18	16	19	0
	2	39	38	37	39	39	38	36	-8
4	1	42	40	42	43	43	43	42	0
	2	55	55	56	56	56	57	53	-4
5	1	98	98	99	99	99	97	85	-13
	2	69	68	69	69	70	71	68	-1
6	1	35	35	34	32	32	33	34	-3
	2	23	22	20	21	22	22	23	0
7	1	116	115	115	113	113	108	104	-10
	2	126	125	123	120	120	118	113	-10
8	1	84	85	85	85	85	73	72	-14
	2	92	93	95	103	100	95	85	-8
9	1	79	84	86	86	87	81	89	+12
	2	68	69	69	70	70	67	67	-3
10	1	29	30	31	31	31	27	25	-7
	2	39	39	42	42	43	42	43	+10
11	1	38	39	39	40	40	40	39	+1
	2	19	19	21	20	20	21	23	+21

Weed control and crop damage assessment

Each treatment was visually assessed for crop damage and herbicide efficacy. Weeds present in the trial area are shown in Table 17.

Table 17. *Weeds present in the trial area*

Dicotyledons	**Monocotyledons**
Sida ritusa (*Sida rhombifolia*)	Barnyard grass (*Echinochloa* sp)
Bell vine (*Ipomoea plebeia*)	Summer grass (*Digitaria ciliaris*)
Morning glory (*Ipomoea purpurea*)	Green summer grass (*Brachiaria subquadripara*)
Pigweed (*Portulaca oleracea*)	Crowsfoot grass (*Eleusine indica*)
Blackberry nightshade (*Solanum nigrum*)	Nutgrass (*Cyperus rotundus*)
Mexican poppie (*Argenome ochroleuc*)	
Cobbler's pegs (*Bidens pilosa*)	

The results of the treatments are shown below.

Treatment 2 Broadstrike® 10 g/ha and Kerb® 0.5 L/ha at cotyledon stage then once a week for two weeks.

Comments: *Ipomoea* sp, sida ritusa and blackberry nightshade suppressed during spraying but recovered quickly. No control of nutgrass or monocotyledons.

Crop damage: No visual crop damage.

Treatment 3 Treflan® 3 L/ha during last group preparation and pre planting.

Comments: Good control of monocotyledons but no control of nutgrass or dicotyledon weeds.

Crop damage: No visual crop damage.

Treatment 4 Treflan® 1.5 L/ha during last ground preparation and pre planting.

Comments: No control of dicotyledon weeds and nutgrass, acceptable grass control, some crowsfoot grass.

Crop damage: No visual crop damage.

Treatment 5 Treatment 3 plus and 20 g/ha Broadstrike® at first weed germination

Comments: Sida ritusa, bell vine and cobbler's pegs stunted, no control of monocotyledons or nutgrass

Crop damage: No visual crop damage.

Treatment 6 Treatment 4 plus Dual Gold® at 200 mL/ha and 20 g/ha Broadstrike® at two leaf stage.

Comments: Good control of both monocotyledon and dicotyledon weeds no effect on nutgrass.

Crop damage: No visual crop damage.

Treatment 7 Treatment 2 until 4 leaf stage then Dual Gold® 400 mL/ha plus 20 g/ha Broadstrike®.

Comments: No weed control.

Crop damage: No visual crop damage.

Treatment 8 Treatment 2 until 6 leaf stage then Dual Gold® at 600 mL/ha plus 20 g/ha Broadstrike®.

Comments: No weed control.

Crop damage: No visual crop damage.

Treatment 9a Treatment 2 plus Sempra® at 100 g/ha on active growing nutgrass.

Comments: Nutgrass and pigweed controlled but other monocotyledon and dicotyledon weeds were not controlled.

Crop damage: Slight leaf necrosis but plant recovered.

Treatment 9b Treatment 2 plus Sempra® at 50 g/ha on active growing nutgrass.

Comments: Some yellowing in nutgrass but no control of other monocotyledon and dicotyledon weeds.

Crop damage: Slight leaf necrosis but plants recovered.

Treatment 10 Treatment 3 plus Spinnaker® at 0.4 L/ha when broadleaf weeds at less than 3 leaf stage and nut grass actively growing.

Comments: Nutgrass stunted and yellow, *Ipomea* sp. stunted good control of monocotyledons.

Crop damage: No visual crop damage.

Treatment 11 Treatment 3 plus Spinnaker® @ 0.2 L/ha when broad leaf weeds at less than 3 leaf stage and nut grass actively growing.

Comments: Nutgrass stunted and yellow, *Ipomea* sp. stunted, good control of monocotyledons.

Crop damage: No visual crop damage.

Forking

An assessment of root forking was done at 60, 90 and 120 days after planting, taking 50 plants at random from the winch, sprayline and the drip areas. The roots harvested at 150, 180 and 210 days were also assessed. Tables 18 and 19 show the percentage of forked roots, the average depth at which forking took place and the range from minimum to maximum depth of forking for these two sets of assessment. The soil in the winch areas was noticeably more compacted than other areas and the interrows without a drip tape in them were very dry and hard.

Figure 5 shows the average percentage of forked roots at 60, 90, 120, 150, 180 and 210 days after planting for the three methods of irrigation.

Table 18. *Assessment of forking at 60, 90 and 120 days after planting*

		W1	W2	Winch (1&2)	Spray + Winch	D1	D2	D3	D4	Drip (all)
60 days	No. of roots	25	25	**50**	**50**	13	12	13	12	**50**
	% forked	20.0%	24.0%	**22.0%**	**26.0%**	23.1%	25.0%	15.4%	0.0%	**16.0%**
	Av. depth (cm)	8.3	6.8	**7.6**	**10.8**	9.3	9.2	5.3	0	**6.0**
	Min. depth (cm)	2.5	3.0	**2.8**	**3.5**	3.0	1.5	1.5	0	**1.5**
	Max. depth (cm)	17.0	14.0	**15.5**	**28.5**	15.0	17.0	9.0	0	**10.3**
90 days	No. of roots	25	25	**50**	**50**	15	10	12	13	**50**
	% forked	32.0%	8.0%	**20.0%**	**20.0%**	26.7%	10.0%	0.0%	7.7%	**12.0%**
	Av. depth (cm)	8.4	6.0	**7.2**	**9.7**	5.0	3.0	0.0	7.0	**3.8**
	Min. depth (cm)	5.0	5.0	**5.0**	**4.5**	4.0	3.0	0.0	7.0	**3.5**
	Max. depth (cm)	19.0	7.0	**13.0**	**16.0**	8.0	3.0	0.0	7.0	**4.5**
120 days	No. of roots	25	25	**50**	**50**	12	13	12	13	**50**
	% forked	12.0%	40.0%	**26.0%**	**16.0%**	25.0%	15.4%	16.7%	23.1%	**20.0%**
	Av. depth (cm)	10.3	12.1	**11.2**	**15.5**	8.7	11.0	12.5	14.3	**11.6**
	Min. depth (cm)	6.0	6.0	**6.0**	**6.0**	7.0	6.0	4.0	13.0	**7.5**
	Max. depth (cm)	14.0	24.0	**19.0**	**26.0**	14.0	16.0	21.0	15.0	**16.5**
Total number of roots		75	75	**150**	**150**	40	35	37	38	**150**
Average % forked		21.3%	24.0%	**22.7%**	**20.7%**	25.0%	17.1%	10.8%	10.5%	**16.0%**
Average depth (cm)		9.0	8.3	**8.7**	**12.0**	7.7	7.7	5.9	7.1	**7.1**
Average Min. depth (cm)		4.5	4.7	**4.6**	**4.7**	4.7	3.5	1.8	6.7	**4.2**
Average Max. depth (cm)		16.7	15.0	**15.8**	**23.5**	12.3	12.0	10.0	7.3	**10.4**

***Table 19.** Assessment of forking at 150, 180 and 210 day harvests*

		W1	W2	Winch (1&2)	Spray + Winch	D1	D2	D3	D4	Drip (all)
150 days	No. of roots	99	66	**165**	**112**	142	124	142	149	**557**
	% forked	35.4%	30.3%	**33.3%**	**17.0%**	14.8%	25.0%	18.3%	14.8%	**18.0%**
	Av. depth (cm)	14.3	16.0	**15.2**	**18.3**	12.1	13.7	19.0	16.0	**15.2**
	Min. depth (cm)	5.0	5.5	**5.3**	**9.5**	4.0	5.0	5.0	5.5	**4.9**
	Max. depth (cm)	30.0	36.5	**33.3**	**34.5**	25.0	29.0	35.0	29.0	**29.5**
180 days	No. of roots	109	68	**177**	**110**	98	135	130	141	**504**
	% forked	30.3%	41.2%	**34.5%**	**28.2%**	14.3%	18.5%	20.8%	22.7%	**19.4%**
	Av. depth (cm)	16.0	14.1	**15.1**	**16.4**	16.9	15.0	14.0	13.9	**15.0**
	Min. depth (cm)	5.5	7.0	**6.3**	**6.0**	8.5	4.0	2.0	5.0	**4.9**
	Max. depth (cm)	31.0	30.0	**30.5**	**31.0**	29.0	31.0	24.0	29.5	**28.4**
210 days	No. of roots	117	82	**199**	**96**	124	129	122	145	**520**
	% forked	34.2%	34.1%	**34.2%**	**25.0%**	12.9%	21.7%	18.9%	23.4%	**19.4%**
	Av. depth (cm)	14.3	15.7	**15.0**	**13.8**	13.0	14.2	14.3	16.1	**14.4**
	Min. depth (cm)	5.0	8.0	**6.5**	**9.0**	2.0	3.0	7.5	6.0	**4.6**
	Max. depth (cm)	35.0	26.5	**30.8**	**30.0**	26.0	28.0	24.0	30.0	**27.0**
Total number of roots		325	216	**541**	**318**	364	388	394	435	**1581**
Average % forked		33.2%	35.2%	**34.0%**	**28.3%**	14.0%	21.6%	19.3%	20.2%	**18.9%**
Average depth (cm)		14.9	15.3	**15.1**	**16.2**	14.0	14.3	15.8	15.3	**14.9**
Average Min. depth (cm)		5.2	6.8	**6.0**	**8.2**	4.8	4.0	4.8	5.5	**4.8**
Average Max. depth (cm)		32.0	31.0	**31.5**	**31.8**	26.7	29.3	27.7	29.5	**28.3**

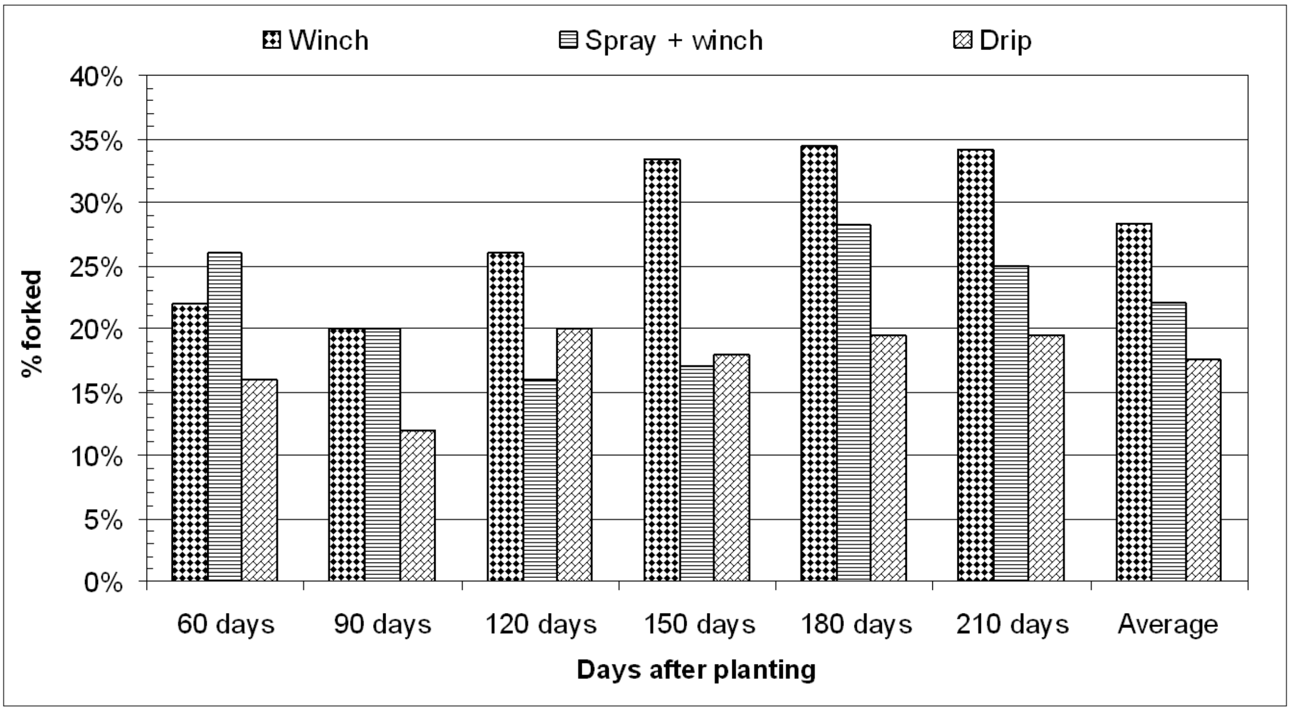

***Figure 5.** Percentage of forked roots for winch, sprayline + winch and drip irrigation*

Bolting

Bolting is the premature occurrence of flower stems and lowers the value of the root whilst also making it woody and difficult to process. The first two bolted plants were noticed on 12 February in D2 and D4, 60 days after planting, they flowered on 25 February 73 days after planting.

The number and percentage of bolted plants were assessed in several ways. The number of bolters was counted in the six 10 m plots used to assess germination in each of the winch, sprayline plus winch, drip at 45 cm and drip at 40 cm. This was done at 120, 150, 180 and 215 days after planting. The bolted plants were pulled out and removed from the field after counting. For each irrigation method the percentage of bolters is higher in the more stressed T2 treatment than for T1. The results are shown in Table 21.

Before the bolting count scheduled for 120 days after planting, on 13 April, I did four counts of bolted plants, selecting a starting point at random and then counting the number of bolters in 100 consecutive plants. The results are shown in Table 20.

Table 20. *Number (%) of bolters in 100 continuous plants chosen at random*

Date	Days after planting	Winch	Spray + Winch	D1	D2	D3	D4	Total bolted (300 plants)	Percentage
15/3/2002	91	0%	1%				0%	**1**	**0.3%**
22/3/2002	98	4%	2%			3%		**7**	**2.3%**
28/3/2002	104	2%	4%		0%			**6**	**2.0%**
5/4/2002	112	7%	1%	1%				**9**	**3.0%**

Table 21. *Number and percentage of bolted plants in 10 m emergence plots*

	Day 120 (12/4/02)		Day 150 (13/5/02)		Day 180 (12/6/02)		Day 215 (17/7/02)		Totals	
Irrigation type	**No. of plants**	**Percent bolted**	**No. of plants**	**Percent bolted**	**No. of plants**	**Percent bolted**	**No. of plants**	**Percent bolted**	**Total bolted**	**Percent bolted**
Winch										
Winch 1 (T1)	155	5.2%	147	2.2%	146	0%	146	0%	**9**	**5.8%**
Winch 2 (T2)	89	10.1%	80	0%	80	0%	80	0%	**9**	**10.1%**
Total winch	**244**	**7.0%**	**227**	**0.4%**	**226**	**0.0%**	**226**	**0.0%**	**18**	**7.38%**
Spraylines										
Total Spraylines	**210**	**6.7%**	**196**	**1.5%**	**193**	**0.0%**	**193**	**0.0%**	**17**	**8.10%**
Drip 40 cm										
D1 (T1)	82	4.9%	78	2.6%	78	0%	78	0%	**6**	**7.3%**
D2 (T2)	167	6.6%	156	1.9%	156	0%	156	0%	**14**	**8.4%**
Total Drip 40 cm	**249**	**6.0%**	**234**	**2.1%**	**229**	**0.0%**	**229**	**0.0%**	**20**	**8.03%**
Drip 45 cm										
D3 (T1)	124	3.2%	120	0.8%	119	0.8%	119	0%	**6**	**4.8%**
D4 (T2)	133	8.3%	127	0.8%	126	0.8%	120	0%	**8**	**6.0%**
Total Drip 45 cm	**257**	**3.9%**	**247**	**0.8%**	**245**	**0.8%**	**243**	**0.0%**	**14**	**5.45%**

At 120 days after planting all bolted plants were counted and removed from the field. Table 22 shows the results of this procedure. The estimated number of plants in each block was determined using the average plant population for the trial of 40% and the total length of row in each area. The highest percentage of bolters was 3.8% in D2. The winch area averaged 2.2%, the sprayline area 2.5% and the drip area 3.2%. Bolting overall was 2.5% of the estimated total population.

Table 22. *Number and percentage of bolted plants in the whole area120 days after planting*

Area		Number bolted	Estimated number of plants	Estimated percentage
Winch area	South Buffer	544	25 728	2.1%
	Winch 2	565	23 040	2.5%
	Middle buffer	509	19 200	2.7%
	Winch 1	461	23 040	2.0%
	North Buffer	298	19 200	1.6%
	Total	**2 377**	**110 208**	**2.2%**
Sprayline area	South Buffer	267	11 880	2.2%
	Sprayline	463	15 840	2.9%
	North Buffer	275	12 936	2.1%
	Total	**1 005**	**40 656**	**2.5%**
Drip area	Drip 1 (T1, 40 cm)	283	11 152	2.5%
	Drip 2 (T2, 40 cm)	421	11 152	3.8%
	Drip 3 (T1, 45 cm)	378	10 496	3.6%
	Drip 4 (T1, 45 cm)	306	10 496	2.9%
	Dry north end	29	1 024	2.8%
	Total	**1 417**	**44 320**	**3.2%**
Grand total		**4 799**	**195 184**	**2.5%**

Because the large number of plants removed could affect yields and root size, Orafti requested that we use 10 row 20 m blocks in each trial area for future bolting assessment. The number of plants in the block assumes the trial average plant population of 40%. The results are shown in Table 23.

In these plots the highest percentage of bolters was 3.9% in D2. The winch average was 2.7%, 3.4% for the sprayline plot and an average of 2.5% in the drip blocks. The overall average was 2.7%.

Table 23. *Number and percentage of bolted plants in 10 row 20 m plots*

	Day 150		Day 180		Day 215		Total	Percent
	Number bolted	Estimated %age	Number bolted	Estimated %age	Number bolted	Estimated %age	bolted	bolted
Winch								
Winch 2	13	1.6%	8	1.0%	3	0.4%	**24**	**3.0%**
Winch 1	15	1.9%	3	0.4%	1	0.1%	**19**	**2.4%**
Winch total	28	1.8%	11	0.7%	4	0.3%	**43**	**2.7%**
Sprayline								
	13	1.6%	7	0.9%	7	0.9%	**27**	**3.4%**
Drip								
D1 (T1, 40 cm)	12	1.5%	3	0.4%	1	0.1%	**16**	**2.0%**
D2 (T2, 40 cm)	20	2.5%	4	0.5%	7	0.9%	**31**	**3.9%**
D3 (T1, 45 cm)	14	1.8%	4	0.5%	2	0.3%	**20**	**2.5%**
D4 (T1, 45 cm)	9	1.1%	4	0.5%	1	0.1%	**14**	**1.8%**
Drip total	55	1.7%	15	0.5%	11	0.4%	**81**	**2.5%**
Grand total	**96**	**1.7%**	**33**	**0.6%**	**22**	**0.4%**	**151**	**2.7%**

The number of bolted plants was also noted at each harvest, the results are shown in Table 24. The most bolters were in W1 with 5.2%, the winch average was 4.3%, sprayline 2.8% and the drip average was 2%. Overall average from the harvest plots was 2.6%.

Table 24. *Assessment of bolting at 150, 180 and 210 day harvests*

Harvest		W1	W2	Winch (1&2)	Spray + winch	D1	D2	D3	D4	Drip (all)	Total
150 days	No. of plants	99	66	**165**	**112**	142	124	142	149	**557**	**834**
	No. bolted	3	3	**6**	**3**	1	3	2	2	**8**	**17**
	% bolted	3%	4.5	**3.6%**	**2.7%**	0.7%	2.4%	1.4%	1.3	**1.4%**	**2.0%**
180 days	No. of plants	109	68	**177**	**110**	98	135	130	141	**504**	**791**
	No. bolted	9	1	**10**	**3**	1	8	1	2	**12**	**25**
	% bolted	8.3%	1.5%	**5.6%**	**2.7%**	1.0%	5.9%	0.8%	1.4%	**2.4%**	**3.2%**
210 days	No. of plants	117	82	**199**	**96**	124	129	122	145	**520**	**815**
	No. bolted	5	2	**7**	**3**	3	3	3	3	**12**	**22**
	% bolted	4.3%	2.4%	**3.5%**	**3.1%**	2.4%	2.3%	2.5%	2.1%	**2.3%**	**2.7%**
Total number of plants		325	216	**541**	**318**	364	388	394	435	**1581**	**2440**
Total number bolted		17	6	**23**	**9**	5	14	6	7	**32**	**64**
Total percent bolted		5.2%	2.8	**4.3%**	**2.8%**	1.4%	3.6%	1.5%	1.6%	**2.0%**	**2.6%**

Figure 6 shows the percentage of bolting in the three irrigation types at 120, 150, 180 and 215 days after planting. Most of the bolting had occurred by day 120.

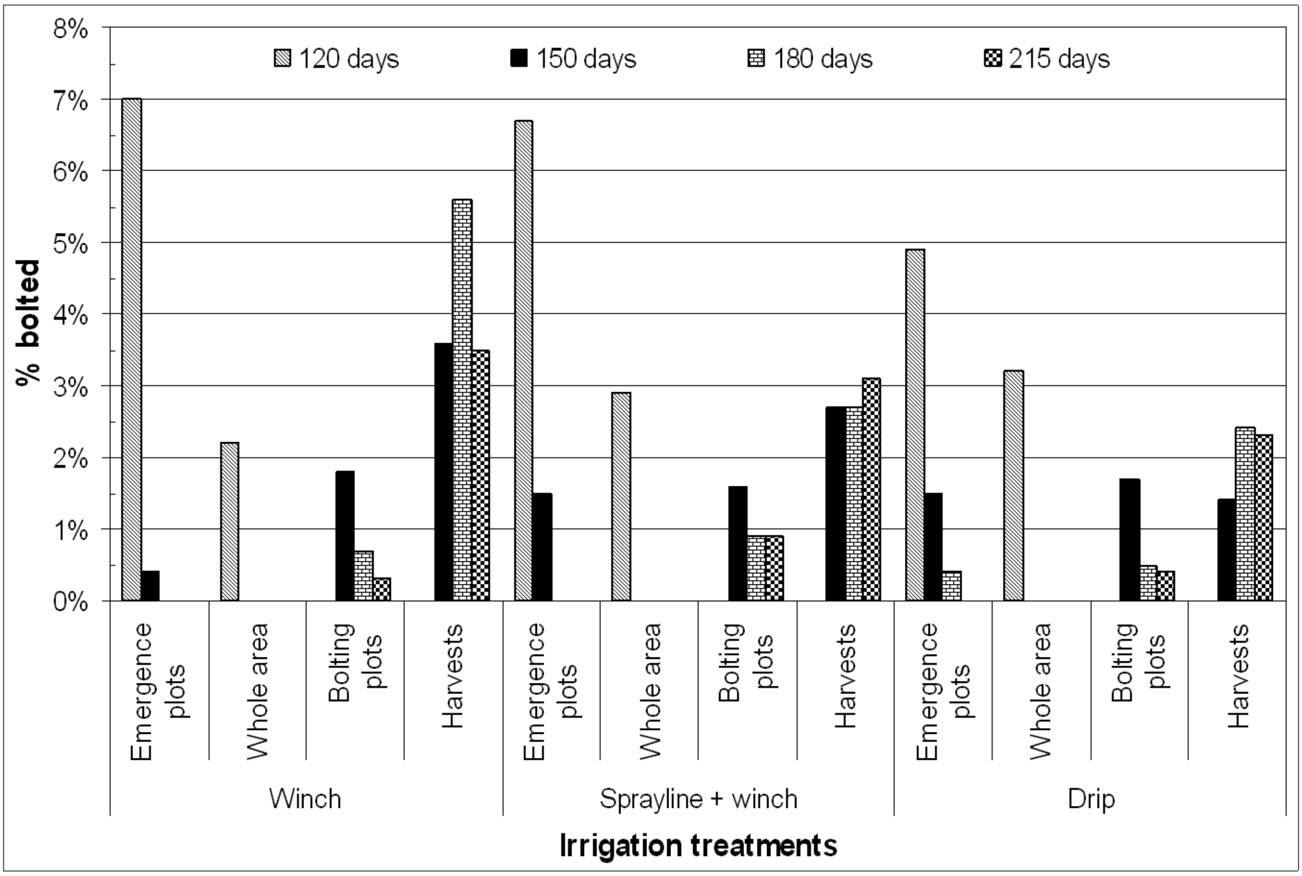

Figure 6. *Percentage bolting in winch, sprayline plus winch and drip irrigation*

Table 24 shows the percentage bolting for each method of irrigation for each area assessed and the overall average. The emergence plots had the highest percentage of bolters, averaging from 6.8% to 8.1%. All other counts indicated an average ranging from 2% to 4.3%. The number of plants in the emergence plots and harvested plots was known, the numbers in the bolting plots and whole area was assumed to be 40%, the average population from the emergence plots on 1 February and at the 120 day bolting count.

Table 24. *The percentage bolting for each method of irrigation for each area assessed*

Irrigation method	Emergence plots	Whole area	Bolting plots	Harvests
Winch	7.4%	2.2%	2.7%	4.3%
Sprayline + winch	8.1%	2.5%	3.4%	2.8%
Drip	6.8%	3.2%	2.5%	2.0%

The method of irrigation did not appear to have a major influence on bolting, however the T2 regime of moderate stress did have a higher percentage of bolters than T1. Irrigation was the same for all blocks until 31 January and changed to T1 and T2 treatments on 1 February, 49 days after planting. All blocks were stressed while the pumps were broken down between 13 and 19 February, day 61 to 67 after planting for the drip and sprayline blocks and 21 February for the winch blocks.

It is possible that this period of stress when them maximum temperature was above 30°C every day, was responsible for much of the bolting. Most of the bolting had occurred by day 120 after planting and almost no bolting occurred after day 150. Based on the whole area count plus the bolting plot counts, over the entire block there would have been between 5% and 6% of plants bolted.

Insects

Insect damage was either damage to foliage or damage to roots, with the exception of crickets which chewed holes in the drip tape.

Foliage damage

Foliage damage was generally minor and chemical control of insects was not considered necessary. Grasshoppers were occasionally seen in the crop, as were the odd heliothis grub *Helicoverpa* spp., and Rutherglen bug *Nysius vinitor*, however the damage they caused was barely noticeable. Two insects that did appear in large numbers were silverleaf whitefly which sucks sap from the plant and red shouldered leaf beetle that eat the leaf.

Silverleaf whitefly (SLW), *Bemisia tabaci*, was noticed in the crop on 8 January, after a heavily infested block of tomatoes upwind from the chicory block was slashed out. Up until that time SLW had only been seen on bellvine plants within the chicory block. Both adult and nymph SLW suck sap from the plant. Silverleaf whitefly did not appear on the small ‘depth of planting’ plot that was upwind from the tomato block.

Silverleaf whitefly built up to very high levels at times, whilst at other times, for example after rain, adult levels were low. SLW nymphs were present on the underside of most lower prostate leaves, but numbers were lower on the upright leaves. Sooty mould grew on some leaves on the honeydew the SLW produced.

There was some death of lower leaves, but whether this was caused by the feeding of the SLW, or a natural response of the chicory plant as lower leaves were shaded is not known.

Large numbers of ladybirds bred up on the chicory plants exerting some natural biological control on the numbers of SLW present. It was decided not to apply chemicals in an attempt to control SLW because they are generally not very effective and would kill the beneficials in the crop. Orafti wants to limit chemical use as much as possible.

There were very few SLW present when the root forking assessment was made on 11 April.

Red shouldered leaf beetle, *Monolepta australis*, is a swarming, leaf eating beetle that breeds on grass roots. It appeared on 21 February in the 40 cm drip area and gradually spread over the whole trial area, though there were fewer in the winch area. The adult beetles eat the leaf blade and also chew on the leaf stalk. Whilst a few plants were skeletonised when many beetles settled on them, most had only minor damage and quickly grew new leaf. The overall damage caused by these beetles was not considered to be enough to require the application of a pesticide. Very few beetles were present when the root forking assessment was made on 11 April.

Root damage

Almost all root damage was caused by white grubs which live in the soil. The majority of these were humus grubs, *Dasyganathus dejeani*, or *Dasyganathus trituberculatus* which are common in trash blanketed cane fields. They are found at shallow depths in the soil. Some damage was caused by Childers cane grubs, *Antitrogus parvulus*, which are found deeper in the soil and will therefore chew on the mid to lower parts of the roots. These beetles were identified by Dr Peter Allsop from the Bureau of Sugar Experiment Station, Bundaberg.

The damage caused by white grubs was generally shallow and did not appear to be of concern. In a very few instances it appeared that a growth crack or secondary rot had started where the root was damaged.

A small amount of damage appeared to be caused by wireworms, larvae of the click beetle (family Elateridae), or false wireworms, *Gonocephalum* spp. but none were found to confirm this. No nematode damage was found. Table 25 is a summary of root damage caused by insects for each irrigation treatment at each harvest.

Table 25. *Summary of the insect root damage for each irrigation treatment at each harvest*

Irrigation treatment	Average number of plants per 10 m	Percent insect damaged roots	Average number of plants per 10 m	Percent insect damaged roots	Average number of plants per 10 m	Percent insect damaged roots	Total number of roots	Total insect damaged roots	Percent insect damaged roots
	150 day harvest		**180 day harvest**		**210 day harvest**		**All harvests**		
W 1	33.0	16.2%	36.3	35.8%	39.0	36.8%	325	98	30.2%
W 2	22.0	9.1%	22.7	27.9%	27.3	36.6%	216	55	25.5%
Winch average	**27.5**	**12.6%**	**29.5**	**31.9%**	**33.2**	**36.7%**	**270.5**	**76.5**	**27.8%**
Spray + winch	**37.3**	**8.9%**	**36.7**	**28.2%**	**32.0**	**39.6%**	**318**	**79**	**24.8%**
Drip 1	47.3	9.9%	32.7	20.4%	41.3	29.8%	364	71	19.5%
Drip 2	41.3	11.3%	45.0	15.6%	43.0	25.6%	388	68	17.5%
Drip 3	47.3	7.7%	43.3	23.1%	40.7	43.4%	394	94	23.9%
Drip 4	49.7	10.7%	47.0	17.0%	48.3	29.0%	435	82	18.9%
Drip average	**46.4**	**9.9%**	**42.0**	**19.0%**	**43.3**	**32.0%**	**395.3**	**78.8**	**19.9%**
Total roots	**834**	**10.4%**	**791**	**23.3%**	**815**	**33.9%**	**2440**	**547**	**22.4%**

The percentage of roots damaged by insects increased at each harvest and could be expected to increase the longer roots were in the ground. Overall the highest percentage of damage was to the winch area, an average of 27.8%, followed by the sprayline area at 24.8% and the drip area averaged 19.9%.

Damage to drip tape

Crickets caused severe damage to the irrigation drip tape both before it was first used and afterwards. Chlorpyrifos was injected into the drip lines twice to reduce the damage and joiners used to repair the damage.

Disease

On 10 April plant virologist Denis Persley inspected the chicory block and found no evidence of any viral diseases.

On 16 May a yellowing, stunted, bolted plant was sent to Denis Persley to check for disease. It was subsequently sent to Karen Gibbs in Darwin who used a molecular test to identify the problem as belonging to the tomato big bud group. Big bud is a phytoplasma spread by leafhoppers which move into crops in dry conditions. It is sporadic and spreads very little within a crop.

On 22 May plant pathologist Heidi Martin inspected the chicory block and found no sign of disease.

Symptoms consistent with disease were observed in a very small percentage of plants in the trial. Sample plants were sent to DPI Plant Pathologists Bob Davis and Heidi Martin at Gatton for assessment and diagnosis.

Dark brown, circular leaf lesions (5 to 10 mm diameter) were present on the leaves of a very few plants. Isolations from these tissues, placed on potato dextrose agar, recovered *Alternaria* consistently. *Alternaria* is a fungus commonly associated with foliar diseases on a wide range of plant species and is a likely candidate pathogen for this symptom on chicory.

Isolations from root tissues yielded no consistent pathogenic organisms. *Fusarium oxysporum* appeared as a brown discolouration on a few roots and was frequently associated with cracks in the plant roots, indicating that it was likely to be a secondary breakdown organism and not a primary pathogen. It did not generally penetrate far below the skin and the root remained firm. *Sclerotium* was also infrequently found superficially on several roots. This organism is a common soil-borne fungus and is normally a pathogen associated with stressed, mature plants.

Three roots from the 150 day harvest had small black 'dots' on them which were identified as *Rhizoctonia* spp. sclerotes.

Trichoderma was recovered in isolations relatively consistently. It was also frequently found on harvested roots, particularly the 210 day harvest which was not washed to remove soil. *Trichoderma* is a soil-borne fungus and would not be pathogenic, but it is noteworthy since it is favoured by soils with a high organic matter and is utilised as a biological control agent against soil-borne plant pathogens in a suite of crops.

Isolations, particularly of root tissues, were frequently hampered by the presence of secondary breakdown organisms. Feeding damage from insects, for example white grubs, favoured the development of secondary rots. *Erwinia* soft rot was severe in some instances, making isolation of the primary pathogen extremely difficult. It was not noticed however during harvesting or root assessment, so appears to have developed whilst packaged for transport.

In four samples, leaf collapse was accompanied by severe grey/brown discolouration of the internal root tissue, extending from the root tips to the plant crown. Examination of thin tissue sections under x 100 magnification, revealed the presence of abundant bacterial ooze streaming from the edges of the tissue. In these cases, affected tissue was macerated in a few drops of sterile water and the macerate was streaked onto plates of nutrient agar. Creamy white gram-negative bacterial colonies were consistently recovered from these samples. This was consistent with *Ralstonia* spp. (*Pseudomonas*). *Ralstonia* spp. causes bacterial wilt in some tomato blocks in this district and is believed to have been found on this research station when it was a tomato farm in the early 1980's. These symptoms were only noticed in a small area at the southern end of the winch block.

Harvests and yields

Harvests were taken at 150, 180 and 210 days after planting. Plots were sited to give an overall coverage of each block. Each plot position was determined in the office before being marked out in the field to avoid bias. The roots were dug by hand using garden forks, spades, a pick and at times a crowbar. The soil was wet for the fist two harvests and dry for the third one.

Three roots, small, medium and large, were taken from plot one of each treatment on each harvest date. They were taken to Crop Tech Laboratories for preparation before being sent to Belgium for inulin extraction. The results of these tests showed that the percentage of carbohydrates was similar to results achieved in Australia in 2001 but the DP inulin (chain length) is on average about 10% lower, the reasons are unknown. There was very little difference between irrigation methods.

Some chicory plants produce a collar at the top of the root where the top has grown like a short stem. These collars are hard and undesirable in the processing plant. Very few plants produced collars and the total weight of collars per block, as a percentage of the weight of the root plus collar, ranged from only 0.1% to 0.3%.

A few roots were bent and some were blunt, that is they did not taper off but were comparatively short and rounded at the end. Many roots had the ends broken during harvest particularly the last harvest. They were considered to be broken if the size of the broken end was more than about 6 mm across. Figure 7 shows the percentage of broken, blunt and bent roots for each treatment and each harvest.

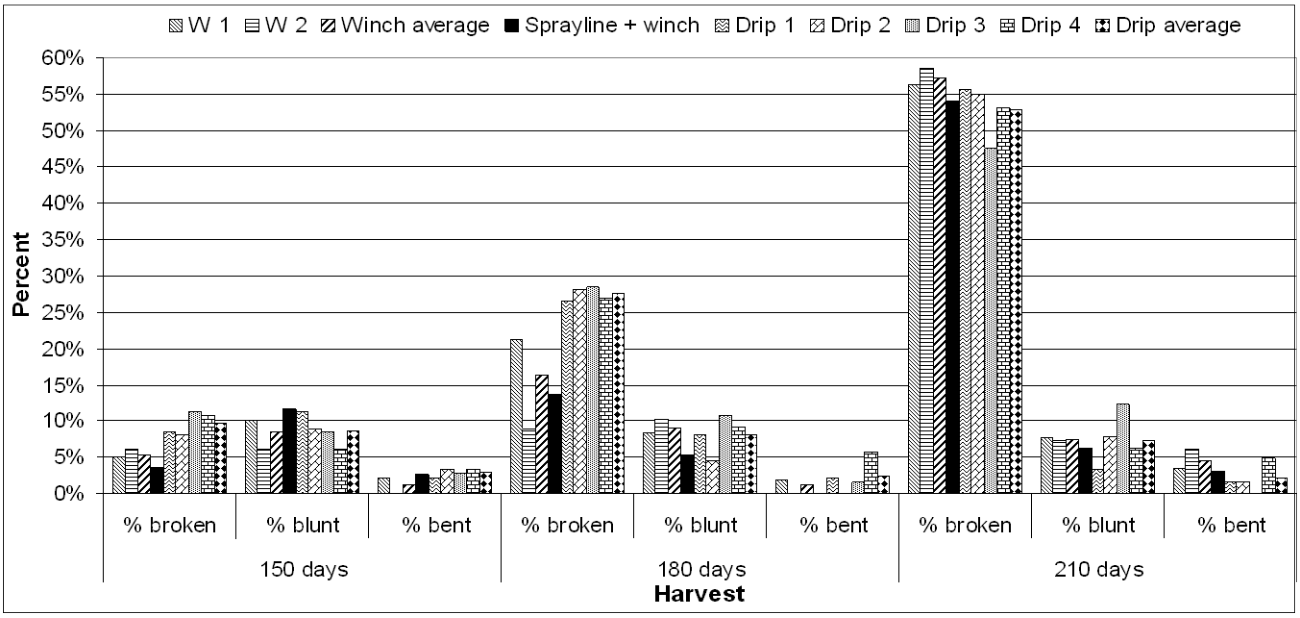

Figure 7. Percentage of broken, blunt and bent roots for each treatment and each harvest

The number of broken, blunt and bent roots has a significant effect on the average length of roots. Figure 8 shows that the average root length was frequently shorter for the 180 and 210 day harvests, when it was expected to increase.

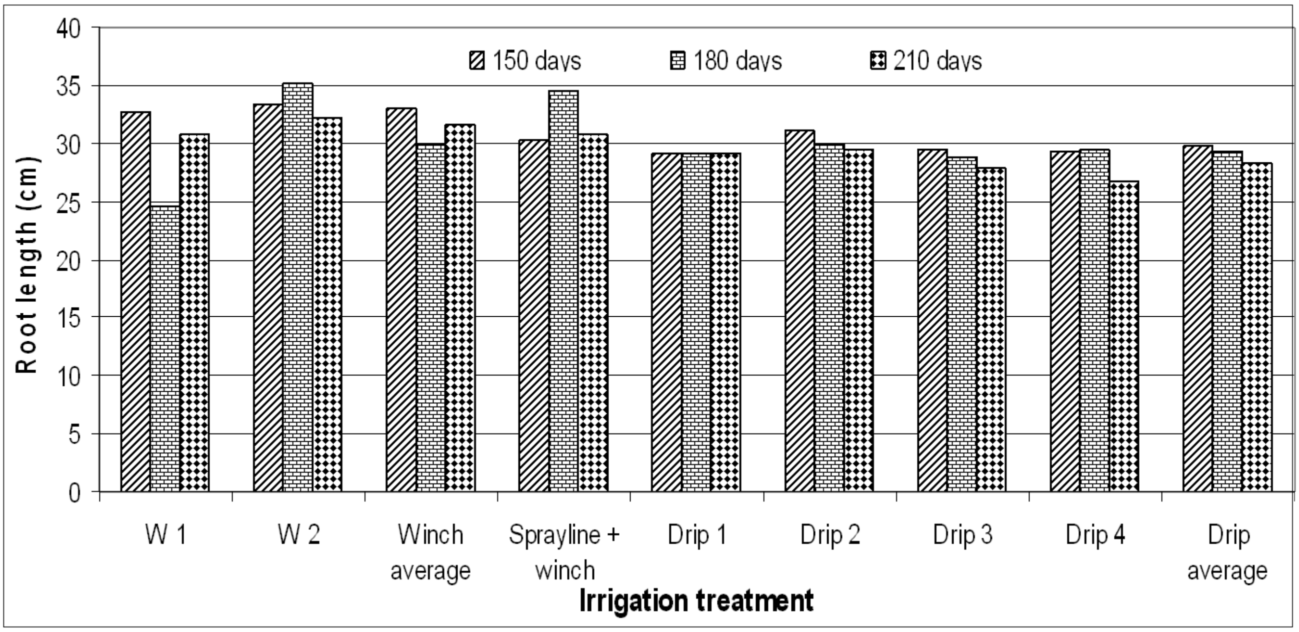

Figure 8. Average length of roots for each treatment and each harvest

Growth cracks and hollow centres are often the result of uneven growth in most plants and large roots of many root crops are also often hollow. The number of roots with growth cracks and hollows increased with each harvest. Most of the growth cracks healed over but in some instances, secondary rots such as *Fusarium* spp. developed around the growth crack, however they caused little root breakdown. Table 26 shows that both growth cracks and hollow roots were more common in the winch and sprayline treatments than the drip treatments. Treatment 2, which exerted more stress on the plants than T1, also had the most growth cracks and hollow roots, as expected, except for D3 which had slightly more growth cracks than D4.

Figure 9 shows the average percentage for the three harvests of roots with growth cracks and hollows.

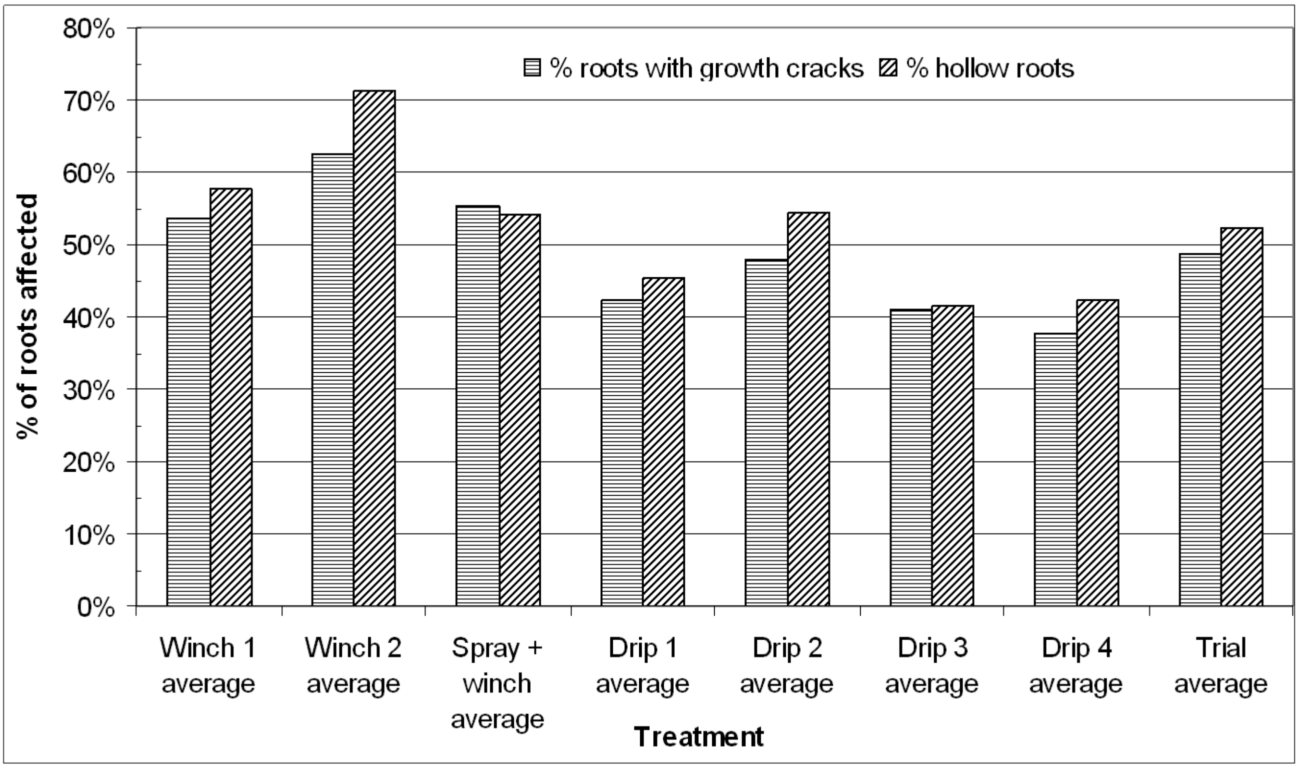

Figure 9. *Average percentage for three harvests of roots with growth cracks and hollows*

Hard fibres are not wanted in the processing plant. The presence of hard fibres in the roots was assessed by inserting a fingernail into the fibrous area of the root. Only nine out of 2,377 roots assessed (0.38%) were considered to have hard fibres, of these six were from plants that had bolted, and one was from a plant that redshouldered leafeating beetles had defoliated.

The yield of roots in tonnes per hectare (t/ha) and the average weight of each root increased at each harvest, whilst the weight of top growth was generally similar for the first two harvests and decreased at the last harvest. Top growth of each plant, averaged over the three harvests, was 292 g and 301 g respectively for winch 1 and 2, compared to 181 g for the sprayline/winch area and 206 g for each plant in the drip blocks. The winch and sprayline plus winch blocks produced the longest and largest roots at the final harvest but also had the fewest roots per plot allowing more space per plant. Some roots produce side roots from the main root that are thicker than the hair roots and may reduce the size and inulin content of the main root and break off during harvest.

Table 26 summarises these results as averages for each irrigation treatment for the three harvests.

***Table 26**. Summary of irrigation treatment averages for the three harvests*

Plot	Average % of possible plants	% with side roots	Average root length (cm)	Average plant weight (g)						% roots with growth cracks	% hollow roots
				Top		Collar		Root			
				Average weight	t/ha	Collar	% collar	Average weight	t/ha		
Winch 1	36.1%	36.3%	29.4	292.0	22.91	23.4	0.11%	460.1	37.0	53.5%	57.8%
Winch 2	24.0%	31.9%	33.6	300.9	16.07	17.7	0.11%	505.1	27.3	62.5%	71.3%
Sprayline + winch	35.3%	30.2%	31.8	180.7	14.56	36.6	0.31%	412.0	31.5	55.3%	54.1%
Drip 1	40.4%	21.7%	29.2	200.0	19.50	20.0	0.17%	314.1	30.5	42.3%	45.3%
Drip 2	43.1%	27.1%	30.2	243.6	25.58	48.6	0.29%	361.1	38.0	48.0%	54.4%
Drip 3	43.8%	21.6%	28.8	190.9	18.14	22.2	0.16%	308.8	28.5	41.1%	41.6%
Drip 4	48.3%	18.9%	28.5	189.3	20.12	34.4	0.30%	280.5	29.9	37.7%	42.3%
Average of all treatments	**38.7%**	**26.0%**	**30.2**	**228.2**	**19.55**	**29.0**	**0.21%**	**377.4**	**31.8**	**48.6%**	**52.4%**

The number of hairy roots was also recorded. These were roots with a lot of fine roots attached to the main root, most roots had very few or none of these fine roots noticeable after harvest. There were very few hairy roots at the 210 day harvest, when the soil was very dry. The other harvests were made in wet soil, the 150 day harvest was one week after the soil was irrigated to field capacity and the 180 day harvest after 187 mm in the previous eight days. The irrigation method did not appear to have much affect on root hairiness. Table 27 shows the percentage of hairy roots for each harvest.

***Table 27.** The percentage of hairy roots for each harvest*

	150 day harvest		180 day harvest		210 day harvest	
	Roots	% hairy	Roots	% hairy	Roots	% hairy
Winch 1	99	10.1%	109	7.3%	117	0.0%
Winch 2	66	4.5%	68	20.6%	82	0.0%
Winch average	**82.5**	**7.9%**	**88.5**	**12.4%**	**99.5**	**0.0%**
Sprayline + winch	**112**	**4.5%**	**110**	**11.8%**	**96**	**0.0%**
Drip 1	142	2.1%	98	11.2%	124	0.8%
Drip 2	124	7.3%	135	13.3%	129	1.6%
Drip 3	142	9.2%	130	7.7%	122	3.3%
Drip 4	149	2.7%	141	9.9%	145	3.4%
Drip average	**139.25**	**5.2%**	**126**	**10.5%**	**130**	**2.3%**
Total	**834**	**5.6%**	**791**	**11.1%**	**815**	**1.5%**

Tables 28, 29 and 30 show details of each plot harvested including the number of plants harvested; percentage with side roots, growth cracks and hollow roots; average root length and weight; weight of the plant tops and collar, and yields per hectare. All plants from the 150 and 180 day harvests were washed to remove dirt and mud. The soil at the 210 day harvest was very dry and roots only required brushing.

Table 28. *Summary of harvest 150 days after planting*

Plot	Plants per 10 m (%)	% with side roots	Av. root length	Plant weight (g)						% roots with growth cracks	% hollow roots
				Top		Collar		Root			
				Av. weight	t/ha	Collar (g)	% collar	Av. weight	t/ha		
W 1 - 150 -1	39	43.6%	35.6	317.3	27.5	10	0.09%	285.9	24.78	53.8%	46.2%
W 1 - 150 -2	31	51.6%	32.3	369.8	25.5	0	0.00%	339.5	23.38	38.7%	51.6%
W 1 - 150 -3	29	44.8%	30.3	352.1	22.7	0	0.00%	364.8	23.51	37.9%	55.2%
Total plants	***99***										
W 1 average	**33.00**	**46.5%**	**32.7**	**346.42**	**25.2**	**3.33**	**0.03%**	**330.05**	**23.89**	**44.4%**	**50.5%**
W 2 - 150 -1	32	40.6%	31.5	351.3	24.9	50	0.47%	333.8	23.74	46.9%	50.0%
W 2 - 150 -2	21	33.3%	34.2	396.6	18.5	0	0.00%	373.2	17.42	57.1%	71.4%
W 2 - 150 -3	13	46.2%	34.2	496.7	14.4	0	0.00%	415.9	12.02	53.8%	84.6%
Total plants	***66***										
W 2 average	**22.00**	**39.4%**	**33.3**	**414.86**	**19.3**	**16.67**	**0.16%**	**374.33**	**17.72**	**51.5%**	**63.6%**
Spray - 150 - 1	56	39.3%	31.0	256.6	31.9	24	0.18%	237.5	29.55	42.9%	48.2%
Spray - 150 -2	22	54.5%	28.3	213.7	10.5	32	0.63%	230.4	11.26	54.5%	40.9%
Spray - 150 -3	34	23.5%	31.5	0.0	0.0	0	0.00%	318.0	24.03	52.9%	52.9%
Total plants	***112***										
Spray average	**37.33**	**37.5%**	**30.3**	**156.77**	**14.1**	**18.67**	**0.27%**	**261.94**	**21.61**	**48.2%**	**48.2%**
D 1 - 150 -1	41	29.3%	28.9	229.1	23.5	20	0.25%	197.6	20.26	46.3%	31.7%
D 1 - 150 -2	43	23.3%	27.6	244.7	26.3	15	0.13%	266.3	28.62	41.9%	46.5%
D 1 - 150 -3	58	24.1%	30.8	189.1	27.4	0	0.00%	172.0	24.94	22.4%	31.0%
Total plants	***142***										
D 1 average	**47.33**	**25.4%**	**29.1**	**220.96**	**25.7**	**11.67**	**0.13%**	**211.94**	**24.60**	**35.2%**	**35.9%**
D 2 - 150 -1	52	42.3%	29.0	274.0	35.6	0	0.00%	250.5	32.56	57.7%	46.2%
D 2 - 150 -2	33	36.4%	31.3	386.8	31.9	59	0.48%	373.8	30.84	66.7%	66.7%
D 2 - 150 -3	39	28.2%	33.0	259.1	25.3	0	0.00%	249.0	24.28	33.3%	46.2%
Total plants	***124***										
D 2 average	**41.33**	**36.3%**	**31.1**	**306.63**	**30.93**	**19.67**	**0.16%**	**291.09**	**29.23**	**52.4%**	**51.6%**
D 3 - 150 -1	56	14.3%	29.3	214.2	26.7	44	0.39%	202.2	25.16	26.8%	37.5%
D 3 - 150 -2	42	28.6%	28.0	231.8	21.6	45	0.49%	219.6	20.49	35.7%	47.6%
D 3 - 150 -3	44	11.4%	31.1	197.8	19.3	0	0.00%	185.4	18.12	31.8%	34.1%
Total plants	***142***										
D 3 average	**47.33**	**17.6%**	**29.5**	**214.59**	**22.5**	**29.67**	**0.29%**	**202.37**	**21.26**	**31.0%**	**39.4%**
D 4 - 150 -1	51	23.5%	28.9	182.3	20.7	0	0.00%	163.8	18.56	25.5%	33.3%
D 4 - 150 -2	41	34.1%	27.0	270.6	24.7	70	0.73%	232.8	21.21	46.3%	43.9%
D 4 - 150 -3	57	14.0%	32.2	206.4	26.1	128	1.16%	191.9	24.31	17.5%	43.9%
Total plants	***149***										
D 4 average	**49.67**	**22.8%**	**29.3**	**219.78**	**23.8**	**66.00**	**0.63%**	**196.18**	**21.36**	**28.2%**	**40.3%**
% population	**39.71%**	**30.5%**								**39.9%**	**45.2%**

Table 29. *Summary of harvest 180 days after planting*

Plot	Plants per 10 m (%)	% with side roots	Av. root length	Plant weight (g)						% roots with growth cracks	% hollow roots
				Top		Collar		Root			
				Av. weight	t/ha	Collar (g)	% collar	Av. weigh	t/ha		
W 1 - 180 -1	46	19.6%	35.8	332.3	33.97	34	0.19%	398.7	40.75	50.0%	47.8%
W 1 - 180 -2	19	52.6%	32.6	360.0	15.20	0	0.00%	534.2	22.56	63.2%	73.7%
W 1 - 180 -3	44	22.7%	5.4	331.5	32.42	25	0.11%	500.0	48.89	56.8%	59.1%
Total plants	***109***										
W 1 average	**36.33**	**26.6%**	**24.6**	**341.27**	**27.19**	**19.67**	**0.10%**	**477.64**	**37.40**	**55.0%**	**56.9%**
W 2 - 180 -1	39	33.3%	37.6	337.0	29.21	0	0.00%	414.4	35.92	66.7%	71.8%
W 2 - 180 -2	13	30.8%	34.8	346.8	10.02	0	0.00%	436.5	12.61	69.2%	76.9%
W 2 - 180 -3	16	25.0%	33.2	0.0	0.00	0	0.00%	488.5	17.37	50.0%	75.0%
Total plants	***68***										
W 2 average	**22.67**	**30.9%**	**35.2**	**227.93**	**13.08**	**0.00**	**0.00%**	**446.49**	**21.97**	**63.2%**	**73.5%**
Spray - 180 - 1	28	14.3%	35.4	317.3	19.74	10	0.08%	420.8	26.18	57.1%	35.7%
Spray - 180 -2	47	27.7%	35.1	283.7	29.63	25	0.14%	381.2	39.81	40.4%	44.7%
Spray - 180 -3	35	25.7%	33.1	6.8	0.53	238	1.77%	377.8	29.38	60.0%	65.7%
Total plants	***110***										
Spray average	**36.67**	**23.6%**	**34.5**	**202.59**	**16.63**	**91.00**	**0.66%**	**393.27**	**31.79**	**50.9%**	**49.1%**
D 1 - 180 -1	30	26.7%	29.6	229.1	17.18	0	0.00%	329.0	24.67	43.3%	60.0%
D 1 - 180 -2	26	26.9%	29.1	262.2	17.04	30	0.37%	312.2	20.29	26.9%	50.0%
D 1 - 180 -3	42	21.4%	29.0	195.2	20.50	39	0.32%	289.5	30.39	47.6%	52.4%
Total plants	***98***										
D 1 average	**32.67**	**24.5%**	**29.2**	**228.81**	**18.24**	**23.00**	**0.23%**	**310.19**	**25.12**	**40.8%**	**54.1%**
D 2 - 180 -1	37	21.6%	30.6	289.0	26.74	0	0.00%	383.9	35.51	54.1%	54.1%
D 2 - 180 -2	54	14.8%	28.5	241.0	32.54	78	0.54%	265.2	35.81	35.2%	51.9%
D 2 - 180 -3	44	29.5%	30.7	229.3	25.22	60	0.46%	296.5	32.62	40.9%	54.5%
Total plants	***135***										
D 2 average	**45.00**	**21.5%**	**29.9**	**253.11**	**28.16**	**46.00**	**0.33%**	**315.23**	**34.65**	**42.2%**	**53.3%**
D 3 - 180 -1	59	30.5%	27.6	201.1	26.36	0	0.00%	291.8	38.26	45.8%	44.1%
D 3 - 180 -2	41	24.4%	28.6	202.4	18.44	7	0.06%	273.6	24.93	39.0%	34.1%
D 3 - 180 -3	30	30.0%	30.6	305.3	20.35	0	0.00%	397.9	26.53	56.7%	60.0%
Total plants	***130***										
D 3 average	**43.33**	**28.5%**	**28.9**	**236.24**	**21.72**	**2.33**	**0.02%**	**321.10**	**29.90**	**46.2%**	**44.6%**
D 4 - 180 -1	50	22.0%	29.4	231.9	25.77	8	0.06%	290.5	32.27	46.0%	40.0%
D 4 - 180 -2	40	20.0%	28.5	268.6	23.88	31	0.25%	313.4	27.86	42.5%	57.5%
D 4 - 180 -3	51	21.6%	30.2	209.5	23.75	17	0.11%	291.5	33.03	43.1%	41.2%
Total plants	***141***										
D 4 average	**47.00**	**21.3%**	**29.4**	**236.69**	**24.46**	**18.67**	**0.14%**	**298.43**	**31.05**	**44.0%**	**45.4%**
% population	**37.67%**	**24.8%**								**47.8%**	**52.2%**

Table 30. *Summary of harvest 210 days after planting*

Plot	Plants per 10 m (%)	% with side roots	Av. root length	Plant weight (g) Top Av. weight	Top t/ha	Collar (g)	Collar % collar	Root Av. weight	Root t/ha	% roots with growth cracks	% hollow roots
W 1 - 210 -1	39	43.6%	29.8	162.0	14.04	21	0.11%	502.8	43.58	46.2%	61.5%
W 1 - 210 -2	37	16.2%	33.1	205.4	16.89	23	0.10%	600.8	49.40	62.2%	64.9%
W 1 - 210 -3	41	48.8%	29.5	197.3	17.97	98	0.39%	614.0	55.94	70.7%	68.3%
Total plants	***117***										
W 1 average	**39.00**	**36.8%**	**30.8**	**188.2**	**16.30**	**47.33**	**0.20%**	**572.53**	**49.64**	**59.8%**	**65.0%**
W 2 - 210 -1	29	24.1%	31.2	258.7	16.67	66.00	0.34%	662.1	42.67	55.2%	72.4%
W 2 - 210 -2	25	28.0%	32.7	231.5	12.86	0.00	0.00%	639.6	35.53	72.0%	72.0%
W 2 - 210 -3	28	28.6%	33.1	289.7	18.02	43.00	0.20%	782.0	48.66	85.7%	82.1%
Total plants	***82***										
W 2 average	**27.33**	**26.8%**	**32.3**	**260.0**	**15.85**	**36.33**	**0.18%**	**694.57**	**42.29**	**70.7%**	**75.6%**
Spray - 210 - 1	31	32.3%	30.7	182.1	12.54	0	0.00%	593.9	40.92	71.0%	58.1%
Spray - 210 -2	36	27.8%	31.6	166.9	13.36	0	0.00%	553.7	44.30	66.7%	63.9%
Spray - 210 -3	29	27.6%	29.8	199.3	12.84	0	0.00%	594.7	38.32	69.0%	79.3%
Total plants	***96***										
Spray average	**32.00**	**29.2%**	**30.7**	**182.8**	**12.91**	**0.00**	**0.00%**	**580.76**	**41.18**	**68.8%**	**66.7%**
D 1 - 210 -1	33	15.2%	29.2	223.8	18.47	5	0.03%	501.5	41.37	69.7%	48.5%
D 1 - 210 -2	55	14.5%	28.6	98.9	13.60	62	0.34%	335.3	46.11	34.5%	45.5%
D 1 - 210 -3	36	16.7%	29.6	128.3	11.55	9	0.06%	423.7	38.13	61.1%	55.6%
Total plants	***124***										
D 1 average	**41.33**	**15.3%**	**29.2**	**150.3**	**14.54**	**25.33**	**0.14%**	**420.17**	**41.87**	**51.6%**	**49.2%**
D 2 - 210 -1	57	12.3%	28.3	134.3	19.13	134	0.57%	411.8	58.68	52.6%	57.9%
D 2 - 210 -2	35	40.0%	31.2	234.7	20.54	88	0.43%	582.5	50.97	51.4%	68.6%
D 2 - 210 -3	37	27.0%	28.9	143.8	13.31	18	0.11%	437.1	40.43	43.2%	48.6%
Total plants	***129***										
D 2 average	**43.00**	**24.0%**	**29.4**	**170.9**	**17.66**	**80.00**	**0.37%**	**477.11**	**50.02**	**49.6%**	**58.1%**
D 3 - 210 -1	54	16.7%	26.8	105.2	12.63	104	0.49%	392.1	47.06	46.3%	50.0%
D 3 - 210 -2	46	15.2%	30.2	95.8	9.79	0	0.00%	304.3	31.11	39.1%	26.1%
D 3 - 210 -3	22	31.8%	26.8	164.7	8.05	0	0.00%	512.0	25.03	68.2%	50.0%
Total plants	***122***										
D 3 average	**40.67**	**18.9%**	**27.9**	**121.9**	**10.16**	**34.67**	**0.16%**	**402.80**	**34.40**	**47.5%**	**41.0%**
D 4 - 210 -1	49	12.2%	25.8	134.9	14.69	16	0.08%	391.4	42.62	46.9%	44.9%
D 4 - 210 -2	55	12.7%	28.1	107.8	13.17	7	0.04%	312.6	38.20	40.0%	32.7%
D 4 - 210 -3	41	12.2%	26.6	91.6	8.35	33	0.24%	336.7	30.67	36.6%	48.8%
Total plants	***145***										
D 4 average	**48.33**	**12.4%**	**26.8**	**111.4**	**12.07**	**18.67**	**0.12%**	**346.89**	**37.17**	**41.4%**	**41.4%**
% population	**38.81%**	**22.6%**								**54.0%**	**55.0%**

Table 31 shows the average number of plants, root weight and yield for the three harvests.

Table 31. *Average number of plants, root weight and yield for the three harvests*

	Winch 1	Winch 2	Spray + winch	Drip 1	Drip 2	Drip 3	Drip 4
150 days							
Average plant number	33.0	22.0	37.3	47.3	41.3	47.3	49.7
Average root weight	330.1 g	374.3 g	261.9 g	211.9 g	291.1 g	202.4 g	196.2 g
Yield (t/ha)	23.9 t	17.7 t	21.6 t	24.6 t	29.2 t	21.3 t	21.4 t
180 days							
Average plant number	36.3	22.7	36.7	32.7	45.0	43.3	47.0
Average root weight	477.6 g	446.5 g	393.3 g	310.2 g	315.2 g	321.1 g	298.4 g
Yield (t/ha)	37.4 t	22.0 t	31.8 t	25.1 t	34.7 t	29.9 t	31.1 t
210 days							
Average plant number	39.0	27.3	32.0	41.3	43.0	40.7	48.3
Average root weight	572.5 g	694.6 g	580.8 g	420.2 g	477.1 g	402.8 g	346.9 g
Yield (t/ha)	49.6 t	42.3 t	41.2 t	41.9 t	50.0 t	34.4	37.2 t

On 14 August, 243 days after planting, some roots were dug with a three point linkage digger supplied by Orafti agronomist Mr Vincent Severin. It was a similar design to the diggers used on the harvesters. We wet the soil the previous day because it was extremely dry. The digger worked quite effectively. Vincent selected some of the roots that were dug and we assessed them for length, weight, cross section at the widest point, cross section of broken end, growth cracks and hollow roots. Plots were dug in the 40 cm and 45 cm drip areas and the winch 2 area. Table 32 shows the results.

Table 32. *Assessment of roots dug with the mechanical digger*

Plots	No. of roots	Root cross section	Break diameter	Root		Growth cracks	Hollow roots
				Length	Weight		
Winch	29	49.89 cm^2	1.64 cm	27.4 cm	561.7 g	58.6%	65.5%
Drip 40 cm rows	77	44.56 cm^2	1.73 cm	28.7 cm	464.6 g	35.1%	52.0%
Drip 45 cm rows	66	48.24 cm^2	1.80 cm	27.6 cm	475.1 g	41.6%	50.6%

Crop removal (postharvest cleanup)

Because the chicory root dehydrates quickly it was decided to attempt to get the roots onto the soil surface and let the hot, windy, dry spring weather desiccate them. On 11 - 12 September 2002, a ripper with three tines on the front and two tines behind them was passed through the crop along the rows. A cutter bar was attached to the three front tines to lift the roots.

The tines of the ripper became blocked by the top growth of the plant, particularly any flower stems present. To reduce this problem the tops were slashed off just above ground level. The ripper and cutter bar were then very effective in popping up the roots without serious blockages. After ripping a set of duck feet tines were passed across the block at right angles to the row direction and this dragged the roots up onto the soil surface. The roots quickly shrivelled and became rubbery and on

30 September a rotary hoe was used with the rear flap up to chop up the roots and throw them back onto the soil surface. Chopping up the roots with the rotary hoe speeded up the breakdown process and almost no regrowth occurred.

A small area was left for observation but it was later decided to remove it. This area we rotary hoed, one shallow pass and one to the full depth of the rotary, however regrowth occurred from almost all roots. It has since received applications of glyphosate and Basta® (glufosinate-ammonium), to try to destroy it.

Gross margin/whole farm analysis

Gross margins

The gross margins and whole farm analysis were done as a pre-trial theoretical gross margin/whole farm analysis and a post trial actual gross margin/whole farm analysis. The results of the pre-trial analysis were sent to Orafti on completion in August 2001. The report is attached as Appendix II.

Gross margins were done for the three methods of irrigation used in the trial, winch only, spray line and winch, one drip tape per two rows and also for one drip tape per row. The price used to determine gross income in the gross margins, $400/t, was designed to be an 'overall break even price'. This will cover fixed and capital costs but not financial costs. The gross margins are as follows:

- Winch only $13 037 per hectare
- Sprayline and winch $13 230 per hectare
- Drip - one tape per two rows $12 079 per hectare
- Drip - one tape per row $10 738 per hectare

Post trial analysis

Table 33 shows the gross margin results from the trial treatment blocks using the average yield for each block at the 210 day harvest and a price of $90 per tonne. At that price it will not be economically viable to manually control weeds, so land preparation will need to ensure that there will be no weeds that cannot be controlled by herbicides.

The whole farm analysis includes a wage to the owner of $30 000 per year. If the grower does the work listed in the gross margins it could be considered as part of his wage, whereas if he employs someone to do this work it is a cost to the chicory crop. To account for this and the cost of manual weed control each gross margin shows the following alternatives:

- Includes labour and manual weeding
- Includes labour and no manual weeding
- Includes manual weeding but no labour
- Includes no labour and no manual weeding

Table 33. *Gross margin results from trial treatment blocks at $90 per tonne*

	Winch 1	Winch 2	Spray + winch	Drip 1	Drip 2	Drip 3	Drip 4
Yield t/ha	49.6	42.3	41.2	41.9	50.0	34.4	37.2
Growing + cleanup costs							
Labour & manual weeding	$5 245.91	$5 437.31	$5 132.35	$6 317.98	$6 341.98	$6 302.98	$6 248.38
Labour & no manual weeding	$3 509.91	$3 701.31	$3 396.35	$4 581.98	$4 605.98	$4 566.98	$4 512.38
No labour & manual weeding	$4 036.31	$4 227.71	$4 034.75	$5 395.38	$5 419.38	$5 380.38	$5 325.78
No labour & no manual weeding	$2 300.31	$2 491.71	$2 298.75	$3 659.38	$3 683.38	$3 644.38	$3 589.78
Harvest costs	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00	$400.00
Gross margin $ per ha							
Actual for this block							
Labour & manual weeding	–$1 181.91	–$2 030.31	–$1 824.35	–$2 946.98	–$2 241.98	–$3 606.98	–$3 300.38
Labour & no manual weeding	$554.09	–$294.31	–$88.35	–$1 210.98	–$505.98	–$1 870.98	–$1 564.38
No labour & manual weeding	$27.69	–$820.71	–$726.75	–$2 024.38	–$1 319.38	–$2 684.38	–$2 377.78
No labour & no manual weeding	$1 763.69	$915.29	$1 009.25	–$288.38	$416.62	–$948.38	–$641.78
Break even yield t/ha							
Labour & manual weeding	62.73	64.86	61.47	74.64	74.91	74.48	73.87
Labour & no manual weeding	43.44	45.57	42.18	55.36	55.62	55.19	54.58
No labour & manual weeding	49.29	51.42	49.28	64.39	64.66	64.23	63.62
No labour & no manual weeding	30.00	32.13	29.99	45.10	45.37	44.94	44.33
Break even price $/t							
Labour & manual weeding	$113.83	$138.00	$134.28	$160.33	$134.84	$194.85	$178.72
Labour & no manual weeding	$78.83	$96.96	$92.14	$118.90	$100.12	$144.39	$132.05
No labour & manual weeding	$89.44	$109.40	$107.64	$138.31	$116.39	$168.03	$153.92
No labour & no manual weeding	$54.44	$68.36	$65.50	$96.88	$81.67	$117.57	$107.25
Gross margin $/ML water							
Labour & manual weeding	–$242.00	–$318.00	–$384.00	–$567.00	–$400.00	–$729.00	–$817.00
Labour & no manual weeding	$114.00	–$46.00	–$19.00	–$233.00	–$90.00	–$378.00	–$387.00
No labour & manual weeding	$6.00	–$128.00	–$153.00	–$389.00	–$236.00	–$542.00	–$589.00
No labour & no manual weeding	$361.00	$143.00	$212.00	–$55.00	$74.00	–$192.00	–$159.00

Tables 34, 35, 36 and 37 show the gross margin results from these blocks at different yields with and without labour and manual weeding. The full gross margin and whole farm analysis is attached as Appendix III.

Table 34 shows the gross margin results from the trial blocks at different yields when labour is included and weeds are controlled manually by hoeing or wick wiping. All irrigation methods deliver a loss.

Tables 34 and 36 show that at $90 per tonne manual weed control is not an economically viable option.

Table 34. *Gross margins based on costs from trial blocks with labour and manual weeding*

	Gross margin $ per hectare, @ $90 per tonne						
Yield t/ha	**Winch 1**	**Winch 2**	**Spray + winch**	**Drip 1**	**Drip 2**	**Drip 3**	**Drip 4**
30 t/ha	–$2 946	–$3 137	–$2 832	–$4 018	–$4 042	–$4 003	–$3 948
35 t/ha	–$2 496	–$2 687	–$2 382	–$3 568	–$3 592	–$3 553	–$3 498
40 t/ha	–$2 046	–$2 237	–$1 932	–$3 118	–$3 142	–$3 103	–$3 048
45 t/ha	–$1 596	–$1 787	–$1 482	–$2 668	–$2 692	–$2 653	–$2 598
50 t/ha	–$1 146	–$1 337	–$1 032	–$2 218	–$2 242	–$2 203	–$2 148
55 t/ha	–$696	–$887	–$582	–$1 768	–$1 792	–$1 753	–$1 698
60 t/ha	–$246	–$437	–$132	–$1 318	–$1 342	–$1 303	–$1 248

Table 35 shows the gross margin results from these blocks at different yields when labour is included and weeds are not manually controlled. Only the winch 1 and sprayline plus winch methods deliver a positive gross margin at 45 t/ha.

Table 35. *Gross margins based on trial block costs with labour but no manual weeding*

	Gross margin $ per hectare, @ $90 per tonne						
Yield t/ha	**Winch 1**	**Winch 2**	**Spray + winch**	**Drip 1**	**Drip 2**	**Drip 3**	**Drip 4**
30 t/ha	–$1 210	–$1 401	–$1 096	–$2 282	–$2 306	–$2 267	–$2 212
35 t/ha	–$760	–$951	–$646	–$1 832	–$1 856	–$1 817	–$1 762
40 t/ha	–$310	–$501	–$196	–$1 382	–$1 406	–$1 367	–$1 312
45 t/ha	$140	–$51	$254	–$932	–$956	–$917	–$862
50 t/ha	$590	$399	$704	–$482	–$506	–$467	–$412
55 t/ha	$1 040	$849	$1 154	–$32	–$56	–$17	$38
60 t/ha	$1 490	$1 299	$1 604	$418	$394	$433	$488

Table 36 shows the gross margin results from these blocks at different yields when labour is not included and weeds are manually controlled. Each irrigation method delivers a loss at 45 t/ha and only winch 1 and sprayline plus winch show a very small positive gross margin at 50 t/ha.

Table 36. *Gross margins based on trial block costs with no labour and manual weeding*

	Gross margin $ per hectare, @ $90 per tonne						
Yield t/ha	**Winch 1**	**Winch 2**	**Spray + winch**	**Drip 1**	**Drip 2**	**Drip 3**	**Drip 4**
30 t/ha	–$1 736	–$1 928	–$1 735	–$3 095	–$3 119	–$3 080	–$3 026
35 t/ha	–$1 286	–$1 478	–$1 285	–$2 645	–$2 669	–$2 630	–$2 576
40 t/ha	–$836	–$1 028	–$835	–$2 195	–$2 219	–$2 180	–$2 126
45 t/ha	–$386	–$578	–$385	–$1 745	–$1 769	–$1 730	–$1 676
50 t/ha	$64	–$128	$65	–$1 295	–$1 319	–$1 280	–$1 226
55 t/ha	$514	$322	$515	–$845	–$869	–$830	–$776
60 t/ha	$964	$772	$965	–$395	–$419	–$380	–$326

Table 37 shows the gross margin results from these blocks at different yields when neither labour nor manual weed control are included. Winch and sprayline plus winch deliver a positive gross margin at 35 t/ha and all irrigation methods are positive at 50 t/ha. Figure 10 shows this graphically.

Table 37. *Gross margins based on trial block costs with no labour and no manual weeding*

	Gross margin $ per hectare, @ $90 per tonne						
Yield t/ha	**Winch 1**	**Winch 2**	**Spray + winch**	**Drip 1**	**Drip 2**	**Drip 3**	**Drip 4**
30 t/ha	$0	–$192	$1	–$1 359	–$1 383	–$1 344	–$1 290
35 t/ha	$450	$258	$451	–$909	–$933	–$894	–$840
40 t/ha	$900	$708	$901	–$459	–$483	–$444	–$390
45 t/ha	$1 350	$1 158	$1 351	–$9	–$33	$6	$60
50 t/ha	$1 800	$1 608	$1 801	$441	$417	$456	$510
55 t/ha	$2 250	$2 058	$2 251	$891	$867	$906	$960
60 t/ha	$2 700	$2 508	$2 701	$1 341	$1 317	$1 356	$1 410

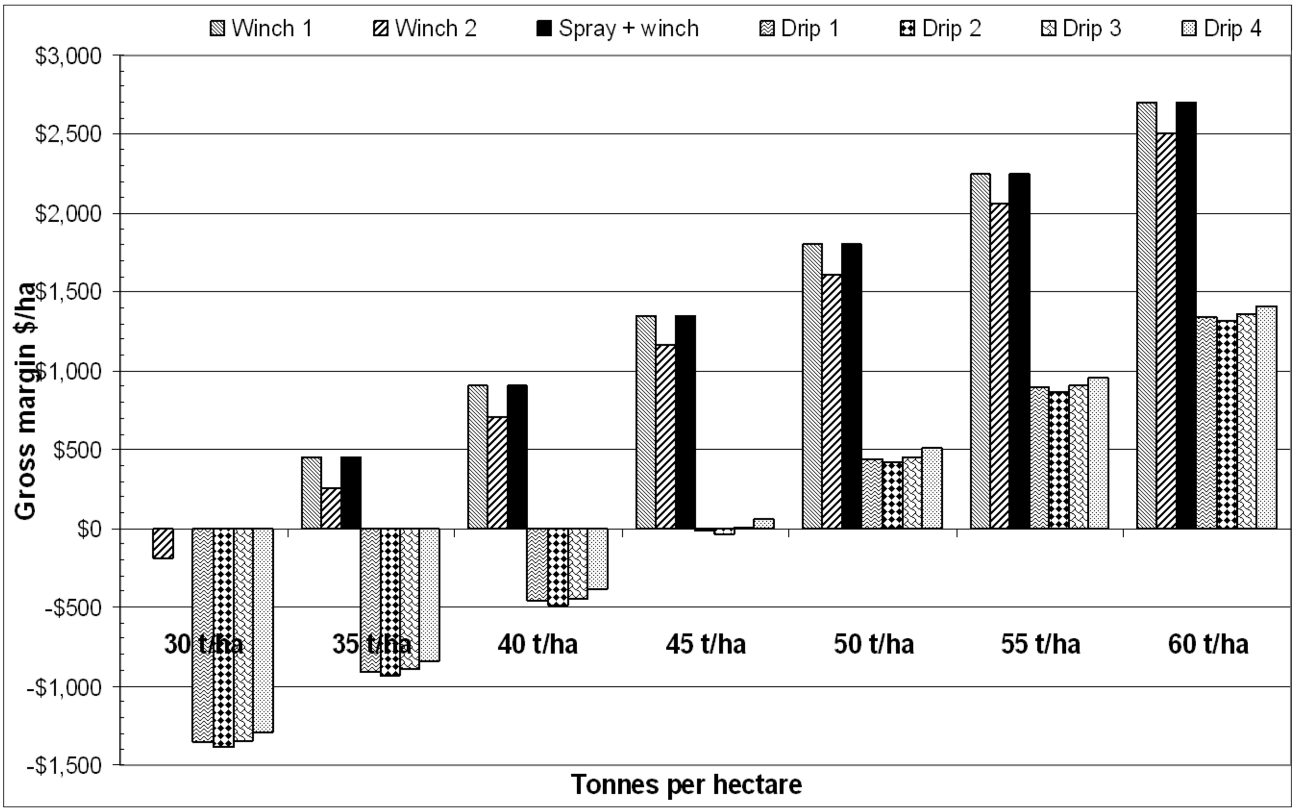

Figure 10. *Gross margins at $90 /t with no labour and no manual weed control included*

Table 37 and Figure 10 show that if the grower does most of the work required as part of the $30 000 wage allowed for in the whole farm analysis, and with no manual weed control, a satisfactory gross margin can be achieved for winch and sprayline plus winch irrigation methods at yields above 45 t/ha.

Figure 11 compares the break-even price at different yields, based on the costs from the trial blocks, with and without manual weed control and with and without labour costs. Only crops under the line at $90 deliver a positive gross margin. All other crops will lose money.

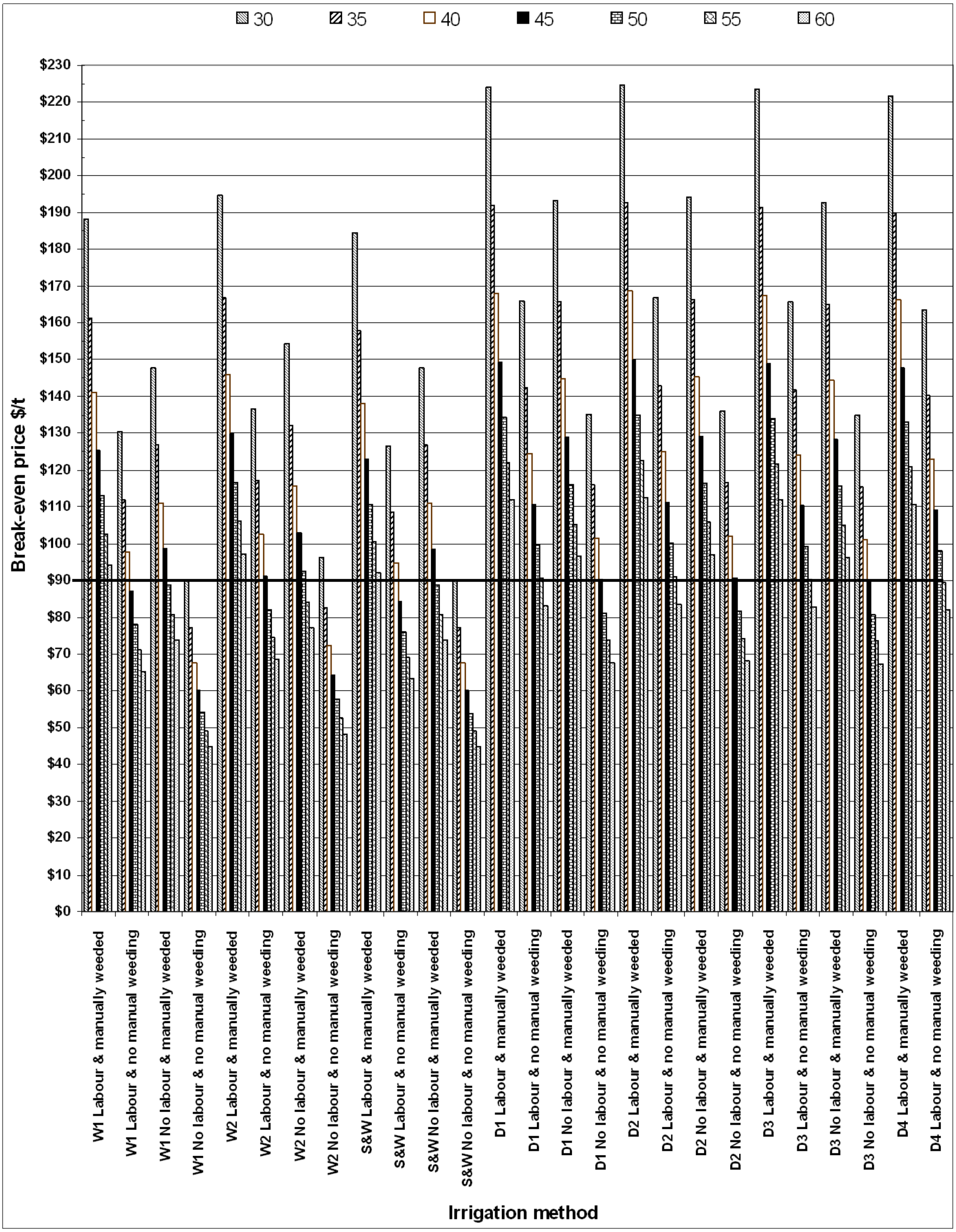

Figure 11. *Break-even price, at different yields, based on the costs from the trial blocks*

The sprayline plus winch method of irrigation had the highest gross margin at any yield. Table 38 shows the gross margins and break even price ($0 gross margin), using this method of irrigation at 45 t/ha as used in the pre-trial gross margins and 50 t/ha. It also shows the break even yield ($0 gross margin). Because the 41.2 t/ha yield was achieved at a plant population of only 32% it is felt that yields of above 50 t/ha would be quite achievable when the plant population reached 80% or higher as could be expected under normal conditions.

Table 38. *Gross margins, break even prices and break even yields using the sprayline plus winch*

Assumptions	Gross margin at:		Break even price		Break even yield at $90 per tonne
	45 t/ha	50 t/ha	$/t at 45 t/ha	$/t at 50 t/ha	
Includes labour and manual weeding	–$1 482	–$1 032	$122.94	$110.65	61.47 t/ha
Includes labour and no manual weeding	$254	$704	$84.36	$75.93	42.18 t/ha
Includes manual weeding but no labour	–$385	$65	$98.55	$88.70	49.28 t/ha
Includes no labour and no manual weeding	$1 351	$1 801	$59.97	$53.98	29.99 t/ha

Whole farm analysis

The whole farm analysis (in Appendix III) assessed the affect of including chicory in rotation with sugar cane. It shows that increased chicory yields improve the whole farm budget as shown in Tables 39, 40, 41 and 42. These tables show the yield achieved in the trial, an average yield of 45 t/ha and a yield of 50 t/ha which is considered to be easily achievable under normal conditions.

Table 39 shows the farm fixed costs, operating return and return on assets at different chicory yields when labour and manual weed control in chicory are included.

Table 39. *Farm fixed costs, operating return and return on assets at different chicory yields, includes labour and manual weed control in chicory*

Item	Chicory @ 41.2t/ha	Chicory @ 45t/ha	Chicory @ 50t/ha
Total farm gross margin	–$14 749	–$9 619	–$2 869
Less fixed costs	$64 198	$64 198	$64 198
Operating return	–$78 947	–$73 817	–$67 667
Total farm assets*	$600 000	$600 000	$600 000
Return on assets	–13.2%	–12.3%	–11.2%

*includes land, buildings, machinery

Table 40 shows the farm fixed costs, operating return and return on assets at different chicory yields with labour included but no manual weed control in chicory.

Table 40. *Farm fixed costs, operating return and return on assets at different chicory yields, with labour but no manual weed control in chicory*

Item	Chicory @ 41.2t/ha	Chicory @ 45t/ha	Chicory @ 50t/ha
Total farm gross margin	$11 291	$16 421	$23 171
Less fixed costs	$64 198	$64 198	$64 198
Operating return	–$52 907	–$47 777	–$41 027
Total farm assets*	$600 000	$600 000	$600 000
Return on assets	–8.8%	–8.0%	–6.8%

*includes land, buildings, machinery

Table 41 shows the farm fixed costs, operating return and return on assets at different chicory yields with no labour included and weeds manually controlled in chicory.

Table 41. *Farm fixed costs, operating return and return on assets at different chicory yields, with no labour and weeds manually controlled in chicory*

Item	Chicory @ 41.2t/ha	Chicory @ 45t/ha	Chicory @ 50t/ha
Total farm gross margin	$34 391	$39 521	$46 271
Less fixed costs	$64 198	$64 198	$64 198
Operating return	–$29 807	–$24 677	–$17 927
Total farm assets*	$600 000	$600 000	$600 000
Return on assets	–5.0%	–4.1%	–3.0%

*includes land, buildings, machinery

Table 42 shows the farm fixed costs, operating return and return on assets at different chicory yields with no labour and the chicory is not manually weeded.

Table 42. *Farm fixed costs, operating return and return on assets at different chicory yields, no labour included and weeds in chicory are not manually controlled*

Item	Chicory @ 41.2t/ha	Chicory @ 45t/ha	Chicory @ 50t/ha
Total farm gross margin	$60 431	$65 561	$72 311
Less fixed costs	$64 198	$64 198	8 113
Operating return	–$3 767	$1 363	$7 513
Total farm assets*	$600 000	$600 000	$600 000
Return on assets	–0.6%	0.2%	1.4%

*includes land, buildings, machinery

Table 42 shows that a positive return on assets at $90 /t for chicory relies on a chicory yield of at least 45 t/ha, chicory not being manually weeded and the grower doing the labour required on the farm. However growing sugar cane only gives a total farm gross margin of $45 292, a negative operating return of –$18 906 and a negative return on assets of –3.2% when labour costs are not included. This is worse than growing a 50 t/ha crop of manually weeded chicory. Table 43 shows the minimum yield that must be achieved if a chicory crop is to be included as a rotation crop instead of leaving the ground fallow. It shows that under normal conditions a chicory crop could be expected to improve the whole farm budget provided that no manual weed control is required, and would probably also do so if the chicory was manually weeded and no other labour costs were included. These figures are based on a high manual weeding cost of $1736 per hectare.

Table 43. *Break-even yield required to make chicory production worthwhile*

Assumptions	**Break-even yield to make chicory production worthwhile**
Includes labour and manual weeding	61.5 t/ha
Includes labour and no manual weeding	42.2 t/ha
Includes manual weeding but no labour	49.3 t/ha
Includes no labour and no manual weeding	30.0 t/ha

Discussion

This project was designed to assess the agronomic requirements of chicory production in the subtropics. Major agronomic factors investigated were;

- land preparation;
- planting and plant emergence;
- irrigation;
- weed control;
- root forking;
- plant bolting;
- insect and disease activity;
- yields under different irrigation methods and regimes;
- post harvest cleanup;
- gross margins for chicory and a whole farm analysis for growing chicory in rotation with sugar cane.

Land preparation

Chicory is a very small seeded crop which is direct seeded into the soil. Orafti plan to grow chicory in rotation with sugar cane so there will be one chicory crop in a block after four or five years of sugar cane. They also want the cane to be green harvested to increase the amount of organic matter in the soil. Whilst this is good cultural practice it does add to the difficulty of preparing soil to plant small seed at an even depth of about 10 mm into a plough out sugar cane block.

Orafti plan to plant with a six row seeder, or multiples of six, and harvest with a six row harvester. It is therefore essential that the seed is planted at a uniform depth into a level soil so that the harvester is able to remove the tops without either leaving too much top on the root or damaging the roots.

Land preparation for this trial required more workings than anticipated as well as two applications of water, because of the very dry conditions and lack of subsoil moisture. Despite these conditions it was possible to prepare a seedbed suitable for chicory after a green harvested sugar cane crop. The time of year and seasonal conditions will affect the time required to prepare a seedbed but it certainly can be done.

Land preparation is perhaps the key to profitable chicory production. Good land preparation will improve the chance of getting a high, uniform plant population and therefore a high yield. Thorough, well planned land preparation will also reduce the amount of nutgrass and weed seed in the block before planting, reducing the cost of weed control as well as the negative effect weeds have on the crop. Well prepared soil is also likely to reduce the number of forked and bent roots.

Depth of planting trials

In Belgium chicory is planted at no more than 5 mm deep, however Queensland conditions are hotter and the surface soil dries out quickly. The depth of planting plots showed that in warm Queensland conditions chicory seed will emerge from at least 20 mm deep in red ferrosol (Australian soil classification), Euchrozem (great soil group) soil. Emergence was better in the plots at 10 to 20 mm deep than at 5 mm because the soil dried out near the surface but retained its moisture deeper down. The soil is also cooler as depth increases, this is an advantage for hot weather plantings but higher soil temperature is likely to be an advantage for winter plantings.

These results obtained may be different in a winter planting when the soil is colder and does not dry out as quickly, so although deeper plantings were successful in late spring and early summer in red ferrosol soil these tests need to be repeated under cooler conditions and different soil types.

Deeper planting has the added advantage that it is not necessary to get the soil quite as fine at the surface because soil contact with the seed and moisture will be better at greater depth. Deeper planting also decreases erosion risks because the soil does not need to be as fine.

Plant emergence

Soil temperatures were very high at planting and during seed germination and emergence, and the monthly average maximum temperature at 100 mm did not fall below 32.5°C until March. These conditions combined with strong, dry northerly winds made it extremely difficult, even with 35 mm of rain within three days of planting, to maintain soil moisture in the top 10 mm of soil where the seeds were planted. Some seed appeared to have started to germinate then died.

The overall emergence of around 40% was very disappointing and unexpected after averaging between 70% and 95% in the pre-trial depth of planting plots. We thought that with the 35 mm of steady rain just after planting the seed would have emerged quickly and that there would be no opportunity to assess differences in emergence for the different irrigation methods.

The low emergence percentage and losses caused by storms makes it difficult to assess the effect of the irrigation methods on plant emergence. At seven days spraylines were the best with drip slightly better than winch but at 21 days drip at 40 cm rows was the best followed by drip at 45 cm rows, then winch and sprayline. By harvest time the drip treatments were best, averaging 42% over 36 plots, compared to 35% for the spraylines over nine plots and 30% for the winch over 18 plots.

Maintaining moisture in the top 10 mm of the soil is critical. However it will be difficult and use excessive amounts of water with either winch or drip irrigation when the drip tape is 20 to 22.5 cm away from the seed. Spraylines or a drip tape within 10 cm of each row would be the most water efficient and easy to control way of maintaining the soil moisture, however the drip option is currently too expensive.

Irrigation

This trial assessed three methods of irrigation, winch (travelling irrigator), sprayline plus winch and drip irrigation at two row spacings. Irrigation was scheduled with the aid of an Enviroscan®, and two types of tensiometers were also compared with the Enviroscan®.

Winch irrigation

Winches are an easy way to apply water but produce large, heavy water droplets that are not conducive to the emergence of small seeds and cause soil compaction. Water distribution can be very uneven, depending on the direction and intensity of the wind and water loss from wind and evaporation can be high. It is also difficult to apply small amounts of water often, for example daily, with a winch, although the newer turbo winches appear to be better at this than the older models. However even with these difficulties it is possible to produce a chicory crop using a winch.

The winch irrigated blocks were lusher and produced more top growth than other plots and the soil was more compacted making it more difficult to dig. Roots were heavier, longer, had more growth cracks and were more likely to be hollow than roots from other irrigation methods.

Sprayline plus winch irrigation

This combined method of irrigation gave the best financial results and used the least water except for the 45 cm row T2 drip block. Spraylines were by far the easiest and most water efficient method of maintaining surface soil moisture. Distribution was better than the winch but was still affected by wind and there would be some evaporation losses. Droplets were smaller than from the winch and soil compaction was less noticeable.

The use of spraylines throughout the cropping period, or a low pressure travelling boom with sprinklers, would probably be the most practical method of irrigating chicory. The combination of spraylines until the crop is well established and leaves protect the soil and then a winch was the best method tested.

Drip irrigation

Drip irrigation was tested at two row spacings, 40 cm and 45 cm. One drip tape was placed between two rows so the water had to travel 20 to 22.5 cm before reaching the row line. This trial did not achieve the water savings expected from drip irrigation, partly because of the cricket damage and because of the onion pattern of water distribution produced in the soil by drip irrigation. The onion pattern is where the water ‘bulges out’ under the soil, so to wet the soil surface and the seeds in the row it has to travel further than the distance from the drip tape to the row.

This meant that a lot of soil had to be wet up, both laterally and vertically, before the water reached the seed, so much more water was used than the small amount required to keep the soil around the seed moist. To wet the soil around the seed it was sometimes necessary to irrigate for eight to nine hours just after planting and when the plants were small. Pulsing, several short irrigations at close intervals, did not seem to help on the red soil. This may in part be because the soil was worked as deeply as possible to break a hard pan that would impede root growth. Water rarely spread past the chicory rows so the interrow that did not have a drip tape in it remained dry, this was very noticeable at harvest.

The cost of drip tape and the lack of water savings expected made the drip method of irrigation economically unviable. However compared to other methods of irrigation there were some advantages in using drip irrigation, as follows:

- the percentage emergence was higher;
- the average percentage of root forking was lower;
- fewer side roots were produced;

- the average percentage of insect damage was slightly lower;
- the average percentage of growth cracks and hollows was lower;
- the average root weight at the 210 day harvest was more suited to factory requirements at 412 g, compared to 581 g for the sprayline plus winch and 634 g average for the winch;
- drip irrigation is not affected by wind and evaporation losses are low;
- large areas of crop can be irrigated as required, at any time, by just turning on the pump.

Whilst drip is not economically viable at present, for the reasons above it is worth investigating how it can be made an economically viable alternative irrigation method.

Soil moisture monitoring

Enviroscan®

Most horticultural plants draw most of their water requirements from close to the soil surface where the majority of their roots are and extract it from progressively deeper down as the soil near the surface dries out. The Enviroscan® shows that chicory takes water fairly evenly over the full depth of the root so as the root grows the depth from which water is used increases, to in excess of 50 cm. Therefore, unlike most other plants, the depth at which water is being extracted is not an indication of drying soil closer to the soil surface or plant stress.

Because of this apparent ability to draw water from the entire length of the root, the Enviroscan® summed graph should be a good guide to the plant’s water usage and irrigation requirements.

Tensiometers

Tensiometers are easy to use and are much cheaper and ‘grower friendly’ than the Enviroscan®. The Jetfill® tensiometers are easy to read and instantly show soil water tension, an indication of the availability of the soil water. Soilspec® tensiometers are individually cheaper than Jetfill® type tensiometers once the electronic reader is purchased. You need to have the reader with you to read them but you can download the readings to a computer to develop a graph which shows a history of soil water tension and gives an indication of the soil water availability at different depths throughout the crop.

Tensiometers appear able to give a reasonable, ‘farmer friendly’ guide to when to irrigate chicory but some calibration would be necessary on different soil types to determine when irrigation is required. A water tension greater than 30 centibars could probably be used in the later stages of the crop.

Weed control

Dry conditions during land preparation meant most weeds didn’t germinate until after planting and irrigation.

The crop had to be kept free of weeds, particularly in the early stages where the chicory grows slowly and is easily over grown by weeds. There was an option to use cultivators but this couldn’t be done in the rows with a drip tape between them and would not remove weeds within the plant row. Fusilade could have been used but it would only control the early stages of grass weeds and not broad leaf weeds such as bellvine which was plentiful. For these reasons we decided hand hoeing weeds was the most effective option but it is also the most expensive in terms of labour.

Nutgrass was a major problem in the drip areas, particularly D1, D2 and D3. Hoeing was ineffective but using 50/50 glyphosate/water in wick wipers proved very effective in killing both the main plant and some of the side plants down the chain of nuts. If that method had not been successful that part of the trial would have been abandoned.

Weed control is going to be a critical part of any chicory crop and weeds will be very difficult to control mechanically, especially in the early stages of the crop, because the young chicory plants are so small that they are easily smothered. Finding suitable chemical herbicides and registering them for use is therefore very important. Any herbicide used in chicory must also be assessed to determine its residual effect on sugar cane and vegetable crops which are widely grown in the Bundaberg and Childers areas.

Reducing the amount of weed seed in the block to very low levels before planting will be the key to weed free chicory crops.

Summary of the BSES herbicide trial

The poor crop germination made measuring the effect of herbicide treatments on chicory growth difficult. Visual crop damage and weed control assessments indicate that:

- The Treflan® at 1.5 and 3 L/ha treatments provided good control of monocotyledons (grasses) with no visual damage to the crop. Plant count results indicate that it had no effect on chicory germination. Further trials are needed to be certain of this result.
- Spinnaker® treatments provided good control of dicotyledons and nutgrass without any visual crop damage.
- The 100 g/ha rate of Sempra® controlled the nutgrass but caused slight leaf necrosis to the chicory, the crop appeared to recover quickly. The 50 g/ha rate only suppressed the nutgrass and caused slight leaf necrosis.
- Dual Gold®, Broadstrike® and Kerb® treatments were not effective at controlling monocotyledon weeds and only suppressed the dicotyledon weeds during the spray period. These weeds quickly recovered after spraying ceased. They were all applied at below the recommended rate and may have controlled weeds at higher rates.

Treflan®, Spinnaker® and Sempra® are worth further investigation for efficacy on the weeds found in the Bundaberg region, their effect on chicory and their residual effect on sugar cane and vegetable crops.

Forking

Forked roots are more likely to break during harvest, reducing yield and inulin content. The average of assessments from 60 to 210 days showed the winch blocks produced 28% forked roots, the sprayline plus winch 22% and the drip block averaged 18%. For the 210 day harvest the figures were 34%, 25% and 19% respectively. It appears from these figures that the irrigation method affects the amount of forking.

The average depth at which forking occurred was similar for all treatments so the irrigation method did not influence the depth of forking.

Bolting

The first two bolters occurred 60 days after planting and most bolting had occurred by 120 days after planting. All obvious bolters were removed from the entire trial area 120 days after planting and most of the remaining bolters had occurred by 150 days after planting. The irrigation method did not appear to influence percentage of bolters, however the moderate stress treatment, T2, did show a higher percentage of bolters. All blocks were stressed while the pumps were broken down 61 to 69 days after planting. All the T1 blocks were almost due to be irrigated when the pumps became inoperable.

It seems probable that this period of stress, combined with maximum temperatures over 30°C during this period, may have triggered the bolting.

There was a wide variation in plant types throughout the block, so it is possible that within the plant population there may also be a large variation in susceptibility to bolting.

Bolting is bought on by stress and the past year has been abnormally hot and dry in the Bundaberg region. It should not be assumed that the amount of bolting that occurred under these conditions would be repeated under the normal weather conditions in this region.

Insects and disease

In this trial neither insects nor disease appeared to be a major problem in chicory. No pesticide chemicals were applied to the block.

Insects

There was a major infestation of silverleaf whitefly but the effects of this are unknown. In sweetpotatoes, similar infestations slow down plant growth so that it takes longer for roots to grow, but do not appear to reduce yield if plants are harvested later than normal.

White grubs (cane grubs and humus grubs) caused some surface damage to roots, the level of damage increasing the longer the roots were in the ground. This damage generally healed over but sometimes growth cracks appeared to originate from the damaged area and in some instances secondary disease infections occurred, usually caused by *Fusarium* spp. that appeared as firm brown discoloured areas.

Red shouldered leaf beetles did severe damage to the foliage of some plants whilst having little affect on other plants. New foliage grew on the damaged plants once the beetles had gone.

Crickets were a major problem with the drip tape that was used but thicker tape would eliminate them as a problem.

Disease

Very little disease appeared in the crop, the most concerning was the occurrence of a few plants with bacterial wilt. This is not a common disease on cane farms but does occur on some farms, particularly if they have grown tomatoes. A few roots had secondary infections, usually caused by *Fusarium* spp. but these roots did not appear to rot or break down. *Trichoderma* was found on many roots but is not considered a problem and in fact may give the roots some protection from other diseases.

Harvests and yields

Yields increased at each harvest. Root weight increased rapidly between harvests and at 210 days, roots from the winch and sprayline plus winch treatments were larger than desired by the factory. Root breakage was much higher at the 210 day harvest but this was probably due to the very dry soil. Average root length was slightly lower for the last harvest due to the increase in breakage but generally did not vary much over the three harvests or different irrigation methods.

Crop removal (postharvest cleanup)

After harvesting, use an implement for example tines, to lift any roots or pieces of root onto the soil surface and allow them to desiccate in the sun.

Gross margin analysis

The trial showed that the best gross margin at any yield is returned by the sprayline plus winch method of irrigation followed by winch T1 and winch T2. For this reason whole farm profitability was based on using the sprayline plus winch irrigation method for chicory. Because the 41.2 t/ha yield was achieved at a plant population of only 32% it is felt that yields of above 50 t/ha would be quite achievable when the plant population reached 80% or higher as could be expected under normal conditions.

The cost of weed control is high because of the high cost, $1736 per hectare, of hand hoeing weeds and wick wiping nutgrass. Under normal conditions, with good weed control in the land preparation stage, this cost could be expected to be considerably lower. The gross margins include a no manual weed control alternative but this assumes that weeds were either not present or could be removed by herbicides. Because an allowance has been made in the whole farm analysis for a $30 000 wage to the grower, the gross margins also include alternatives for with and without labour for growing the crop.

Table 37 and Figure 10 (page 54) show that if the grower does the work required to grow chicory and with no manual weed control, a satisfactory gross margin can be achieved for winch and sprayline plus winch methods at a yield of 45 t/ha. More detail is provided in Appendix III.

Factors affecting profitability of chicory production

There are five key factors that will affect the profitability of chicory in the Bundaberg region. They are the plant population; yield; weed control; land preparation and water supply.

1. A high, uniform plant population is dependant on good land preparation, frequent applications of small amounts of water until the plants are well established and weather conditions that are not excessively hot and windy.

2. Yield, particularly of suitably sized roots, is to a large extent dependant on a high plant population.

3. Weed control is expensive, particularly if manual labour is required to remove weeds, and weeds can outgrow chicory in the early stages, reducing the plant numbers and uniformity. A suitable herbicide would be very beneficial but thorough land preparation is the best option. Manual weed control is not a viable option at the suggested price of $90 per tonne.

4. Land preparation is perhaps the key to profitable chicory production. Good land preparation will improve the chance of getting a high, uniform plant population and therefore a high

yield. Thorough, well planned land preparation will also reduce the amount of weed seed in the block before planting, reducing the cost of weed control as well as the negative effect weeds have on the crop. Well prepared soil is also likely to reduce the number of forked and bent roots.

5. An adequate water supply is required to produce an economically viable chicory crop in the Bundaberg region. This will be assured with the promised construction of the Paradise dam on the Burnett river and a return to normal seasons.

Some savings could perhaps have been made in land preparation if weather conditions had been more suitable but that may be false economy. There may be some savings to be made in water application but these would be a small percentage of overall costs.

Competing crops

There is an increasing interest in the Bundaberg region in alternatives to sugar cane production and/or other crops to grow in rotation with sugar cane. Peanuts are currently being grown by some farmers as a result of demand from processors and industrial hemp may also provide competition for chicory in the future.

Farmers are currently easily achieving a gross margin of $1000 /ha (range $800 to $1500) for peanuts.

Whole farm profitability

The whole farm analysis (Appendix III) assesses the benefits of including chicory in rotation with sugar cane. Table 42 (page 57) shows that a positive return on assets at $90 /t for chicory relies on a chicory yield of at least 45 t/ha, chicory not being manually weeded and the grower doing the labour required on the farm. A yield of 44 t/ha delivers a 0% return on assets.

However growing sugar cane only gives a total farm gross margin of $45 292, a negative operating return of –$18 906 and a negative return on assets of –3.2% when labour costs are not included. Table 43 (page 58) shows that under normal conditions a chicory crop could be expected to improve the whole farm budget provided that no manual weed control is required. It would probably also do so if the chicory was manually weeded and no other labour costs were included. These figures are based on a high manual weeding cost of $1736 per hectare.

Chicory production could therefore be expected to improve the whole farm profitability of a sugar cane farm.

Technology transfer

The contents of this report are confidential, they will be relayed to potential growers at Orafti's request if the chicory industry goes ahead as hoped.

Recommendations

- Ensure thorough land preparation to reduce the level of nutgrass and weed seeds and ensure a seed bed suitable for small seeds.

- Establish the crop with spraylines then use either spraylines or winch through the rest of the crop cycle.

- Screen for suitable herbicides, particularly for nutgrass and broad leaf weeds, but they should be considered as a backup to thorough land preparation, not an alternative. Their residual effect on following crops must also be tested.

Possible future work

- Review factors affecting the occurrence of bolting and grow chicory under controlled climate conditions to assess the effect of temperature on bolting.
- Test chicory varieties for susceptibility to bolting and select non-bolting plants from the populations.
- Further assess herbicides in chicory and their residual effect on following crops.
- Investigate planting depth in different soil types and seasons.
- Compare the T1 irrigation treatment with a treatment applying a percentage of the water required for T1, for example 50% as Orafti intended T2 to be.
- Assess ways of making drip irrigation economically viable for example using re-usable drip tape on each row.
- Assess the affect of planting on beds to increase available soil depth and reduce forking and bent roots.
- Assess the use of seed tape on plant emergence and establishment.
- Investigate the effect silverleaf whitefly has on yields.

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Appendices

The following Appendices are attached:

Appendix I

Final report, Chicory herbicide trial, 2002, Bundaberg, Australia

Appendix II

Pre-trial whole farm/gross margin analysis for chicory

Appendix III

Post-trial gross margin analysis for chicory and whole farm analysis for chicory and sugar cane