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Improving lettuce quality through adoption of sustainable production practices

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Agriculture Western Australia

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Improving lettuce quality through adoption of sustainable production practices.

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Agriculture Western Australia

Vegetable Industry National Levy

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Purpose

The project "Improving Lettuce quality through the adoption of sustainable production practices" aimed to improve the quality, yield, reliability and product uniformity of lettuce for domestic and export markets through adoption of sustainable management practices. Thus enhancing Australia's clean and green image on export markets and raising domestic consumer confidence in the product.

Acknowledgment

The authors of this report wish to thank the vegetable industry of Australia and the Horticultural Research and Development Corporation (HRDC) for their financial support for this project through the National Vegetable Industry Levy. Support for salaries, operating and infrastructure provided by Agriculture Western Australia is also acknowledged together with in-kind support from growers who participated in the study.

Logos

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1. Industry Summary

Approximately half of all the vegetable crops produced for domestic and export consumption in Western Australia are grown on light sandy soils of the Swan Coastal Plain. Typically these soils have low water and nutrient retention capability and readily leach nutrients, especially nitrogen and potassium. Fixed sprinkler irrigation is widely practiced by growers, and fertilisers, both poultry manure and chemical fertilisers are applied at high rates by world standards. Soil volumetric water holding capacity of around 10% dictates that in hot weather growers may irrigate many times per day to avoid crop water stress.

Approximately 80% of the state's lettuce (head and leaf types) are grown on these soils and most growers produce it year round. Prior to the commencement of this project, fertiliser and water use rates were known to be high for this crop, even when compared to other vegetable crops. Water is considered by growers to be relatively abundant and cheap on these soils because the Swan Coastal Plain overlays a huge reservoir of shallow ground water of good quality. Similarly, fertiliser is considered inexpensive compared to the value of the crop it produces. In the absence of reliable information on how much of these inputs to use in every case to ensure high yield and quality, there has been a natural tendency for growers to use 'more rather than less' if in doubt.

Considerable research work had been done during the 1980's and 1990's to better define the water and fertiliser requirements of vegetable crops including lettuce on these soils but the results of that work had not translated into adoption by commercial growers. This project set out to both improve the quality of the information available to growers on how to manage fertiliser and irrigation programmes for head (iceberg) lettuce, and to explore methods of getting this information to growers and adoption of improved practices. The project team took a holistic approach to the challenge of improving the efficiency of production of lettuce by also investigating the significance of pests and diseases in production of the crop and seeking to involve growers in the R&D process and practice where possible.

The main outputs from the research were determined to be:

- A yield maximising formula for irrigation and nitrogen management of iceberg lettuce was identified.
- Guideline standards for sap nitrate tests and soil moisture levels to verify performance of the formula were established.
- Significant loss of water and nutrients through leaching were shown to be an inevitable consequence of current production technology based on sprinkler irrigation and discontinuous fertiliser application.
- Potential for adoption of the new techniques and estimates of possible productivity gains were made by testing the formula in commercial crops.
- Pest and disease problems requiring further research work to improve industry productivity were identified.
- Grower participation in the research and development process was fostered and a greater industry coherence was established through ownership of the project.

Conclusions

There is considerable potential for productivity gains and more efficient use of inputs in the W.A. lettuce industry through a more systematic approach to fertiliser and water management. Planned programmes based on measurable levels of both inputs, backed up by regular testing using simple commercially available monitoring devices can deliver improved efficiencies.

Plant diseases are a significant cause of crop loss in winter, especially sclerotinia rot and big vein virus and there is a need for pest control to be practiced "year round". Extension techniques used in this project including newsletters, field days, commercial crop demonstrations and seminars did not lead to adoption of new production techniques. They were valuable in raising awareness of the techniques but it is expected that adoption of new fertiliser and irrigation practices, by individual growers would require close 1:1 support to customise the procedures to individual businesses. This type of support would require a 'consulting' approach on a 'case by case' basis.

2. *Technical Summary*

The project plan was to conduct critical research to define the irrigation and nitrogen nutrition requirements of iceberg lettuce in hot weather. The research aimed to produce more than a recipe or formula for use of these inputs but a set of standards by which objective tests could be measured while the crop was growing. This technique would ensure that future commercial crops could be kept on track to maximum production by regular monitoring and adjustment of water and nitrogen inputs. The measurements made were: evaporation using daily records from an A class pan evaporimeter and irrigation volumes applied, measured by rain gauges. Soil moisture was continuously monitored by placing tensiometers in the crop root zone. Nutrition was monitored by regularly testing plant sap nitrate levels using Merckoquant® sensitive strips and a RQFlex® colorimeter. Nutrient loss below the crop was measured in drainage lysimeters. All of these devices could be used to monitor the progress of commercial crops and guide their irrigation and nutrition programmes.

Two experiments comparing up to 35 combinations of irrigation and nitrogen rate were conducted in 1998 and 1999. These were followed by a series of on farm commercial demonstrations and monitoring to assess the potential for adoption of these new schedules. These were backed up by field days, a seminar for growers and quarterly newsletters on progress of the project. Pest monitoring was conducted weekly for 12 months on 3 properties and disease monitoring was conducted on up to 6 properties in the winters of 1998 and 1999. Key findings of the research were as follows:

Research

- Irrigation rates for maximum yield were around 110% to 140% evaporation replacement for much of the life of the crop with little margin for water saving below this rate without significant reduction in yield. The results were consistent in summer and autumn in two consecutive years.
- Nitrogen rates applied as chemical fertiliser on a 7 day schedule to transplanted crops gave maximum yields around 50 - 70 kg/ha N per week but there was scope for significantly reduced rates early in the life of the crop if small reductions in yield were accepted.
- Sap testing using inexpensive 'do-it-yourself' methods proved to be a reliable measure of plant performance as long as the crop was not water stressed. If it became so, sap nitrate levels were elevated and difficult to interpret. An optimum range from 390 - 600 ppm NO_3-N throughout the crop's life is proposed from the research.
- Soil moisture measurement using tensiometers was hard to interpret in this crop because of the difficulty of choosing a site and depth to locate the probes which was not affected by the sheltering effect of crop leaves. Despite this, a level of around –4kPa at 15 cm depth was associated with high yielding treatments that did not appear water stressed.
- All irrigation rates, from sub optimal to excessive resulted in through-drainage below the crop and the amount wasted was in direct proportion to irrigation rate applied. It seemed to be impossible to avoid some drainage on these soils. Water loss rates for optimal treatments were as high as 60%.
- Water loss through leaching resulted in nutrient loss below the root zone. This was shown to be as high as 40% for nitrate at optimal rates of irrigation and nitrogen.

Crop Monitoring

- Pests were present in and around commercial lettuce crops in every month of the year. Growers sprayed regularly to control them and there were few serious control problems. A pest of concern was the corn earworm (*Helicoverpa armigera*) which has become resistant to a wide range of pesticides used in lettuce crops in Eastern Australia in recent seasons. This was most prevalent in WA crops in late summer/early autumn.
- The most widespread and debilitating diseases were Sclerotinia rot (caused by the soil borne fungus Sclerotinia minor) and big vein virus which is also soil borne and highly persistent from year to year.
- Grower fertiliser programmes consistently resulted in sap nitrate levels which fell below the optimum levels in the last 3 to 5 weeks of the crop's life, possibly resulting in as much as 20% loss in yield by weight at harvest.
- Irrigation scheduling using evaporation replacement methods was difficult in commercial crops due to growers using water to prevent wind blown sand from damaging crops. The result was that more water was often applied to crops than the minimum needed to meet the crop's irrigation demand alone.

Grower Demonstrations

- Fertiliser schedules derived from research proved to be the equal or better than grower schedules for high yield. Sap testing could be used practically to guide regular applications. Sap testing required a level of attention to detail to be successfully used, which may be beyond many busy growers. It would be best done by a specialist or consultant to ensure meaningful, repeatable results.
- Growers did not adopt these techniques from demonstrations on farm alone and intensive 1:1 assistance in individual cases may be required to prove the value of the tests and effect adoption.

Future Research & Development

Future work needs to concentrate and proving the value of these guidelines in commercial practice through intensive case studies over an extended period where yield and quality changes are measured and verified. The guidelines need to be re-tested in winter crops for nitrate. Guidelines for phosphorus and potassium need to be developed and tested by employing similar research methods. Research needs to be conducted to minimise the impact of sclerotinia rot and big vein virus. Attention needs to be paid to the threat posed by *Heliothis armigera* and appropriate strategies developed to minimise the risk of pesticide resistance development.

Lettuce Cropwatch

3. Irrigation and Nutrition Research

3.1 Lettuce Irrigation and Nutrition research on sandy soils of the Swan Coastal Plain of Western Australia - Autumn 1998.

D.R Phillips, L. K Teasdale, S Kumar, D. G Gatter, T.C. Calder, and G.J. D'adhemar

Summary

A 'line source irrigator' was used to apply a continuum of irrigation rates to plots of transplanted 'iceberg' lettuce (cv Grande) treated with five rates of nitrogen fertiliser at Medina Research Centre in the autumn of 1998. Irrigation rates applied over the course of the experiments ranged from 50% pan evaporation replacement (Epan) to 200% Epan, superimposed over nitrogen rates from 15kg/ha/week N to 75kg/ha/week N, including a zero nitrogen control, in a split plot design.

The yield maximising combinations of crop irrigation and nitrogen rates were determined for each week of the crop's life from weekly sequential harvesting of plants within each treatment. The result was a yield maximising crop factor/nitrogen function for the life of the crop. Yield maximising treatments derived from the irrigation/nitrogen response surface were between 60 - 70kg/ha/wk N and an irrigation optimum average of 150% Epan over the life of the crop. Petiole sap analysis conducted weekly from 14 days after transplanting was used to determine a desirable nitrate nitrogen range for high yield and marketability throughout the growing cycle.

Measurements were taken during the life of the crop of leachate at a depth of 40 cm below the crop to determine the relative water and fertiliser use efficiency of the treatment combinations. These measurements showed production of a healthy and marketable lettuce crop resulted in some leaching. The highest yielding treatments resulted in 40 - 50% water loss over the life of the crop and 20% of the total amount of nitrogen applied leaching past the root zone.

Tensiometers were also used to monitor the soil moisture levels within the differing irrigation treatments over the life of the crop, to assess the potential of soil moisture measurement as an alternative tool to schedule irrigation. Tensiometers (Irrometer® LT) proved to be suitable as monitoring devices in the operating range -3 to -6 kPa.

Introduction

This research project investigated sustainable management practices that would improve the quality, yield, reliability and product uniformity of lettuce for domestic and export markets. The means of achieving this end was to combine crop monitoring, field research and 'in field' demonstration of improved practices to facilitate adoption. The short time frame for the study necessitated that the crop monitoring and field research overlapped in time.

Recommendations for lettuce nutrition (Graham, 1994) and irrigation (Lantzke 1995) on Coastal Plain soils were available but had not been widely adopted by growers. These recommendations were based on limited research and had not been thoroughly tested. Irrigation recommendations used evaporation replacement principles (crop factor or Epan) and did not take account of recent advances in soil moisture monitoring technology. Similarly, nutrition recommendations for nitrogen were based on a 'universal' recommended rate per hectare and did not include monitoring techniques or guidelines to allow tactical adjustment of fertiliser rates and timings during the life of the crop.

Continuously recording tensiometers, specifically designed for sandy soils (Irrometer® LT) were available at the start of the project. Plant tissue analysis and rapid sap testing for nitrate was available from fertiliser merchandisers but adequate standards for interpretation of results had not been developed. A hand held digital colorimeter suitable for rapid 'in field' sap testing (RQflex meter®) was also available.

A'line source' irrigation layout was available at Medina Research Centre (35 km south of Perth WA) which allowed detailed testing of irrigation and nutrition strategies on a field scale.

Lettuce was chosen as a target crop for this study because:

- Previous irrigation and nutrition research had been conducted on the Swan Coastal Plain
- The crop is almost exclusively grown on sandy soils in Western Australia

- It is an important crop in the vegetable industry, with 14,000 tonnes produced in 1996, valued at $8 million in Western Australia and $70 million nationally.
- Typically, growers used high rates of fertiliser and water to produce the crop and there was a high potential for adverse environmental effects. The most obvious being pollution of shallow groundwater aquifers used for irrigation and other purposes.
- There was a high potential for new technologies to provide savings in inputs and costs.

The main aims of this experiment were:

1. To develop irrigation scheduling guidelines for 'iceberg' lettuce grown on sandy soils.
2. To test the hypothesis that there is an interaction between irrigation and nitrogen response of lettuce.
3. To test the suitability of tensiometers as a soil moisture monitoring device on sandy soils and develop relevant standards for using these devices to monitor and schedule irrigation.
4. To derive sap nitrate standards for the life of the crop which maximises yield and quality of lettuce.
5. To test nitrogen fertiliser strategies for lettuce in the absence of pre planting poultry manure with the potential to maintain crop yield and quality while reducing unwanted leaching.

Materials and Methods

A split-plot design was used with main plots having 5 levels of nitrogen and the subplots having 7 rates of irrigation. There were four replicates of the 35 treatments. Refer to Table 1 for treatments.

Table 1: Treatments.

Nitrogen Treatment (kg N/ha/wk)	*Irrigation Treatments (% Epan Replacement)*
0 kg/ha	200
15 kg/ha	175
35 kg/ha	150
55 kg/ha	125
75 kg/ha	100
	75
	50

Iceberg lettuce, cultivar Grande was used in this experiment. The soil type for the site was grey-phase Karrakatta sand on the Agriculture Western Australia Medina Research Centre. Grey phase Karrakatta sands are characteristically well drained soils, have a low nutrient retention and water holding ability and a pH between 6 - 7. The experiment was planted on the 5 March 1998.

Site preparation and transplanting

The major and minor element requirements of all treatments were met by broadcasting 3000kg/ha of Superphosphate® and 150kg/ha trace elements (Medina Mix) and rotary hoeing to the depth of 15 to 20 cm two days prior to planting. Magnesium and Potassium were applied throughout the life of the crop at a fixed rate for all treatments to a total of 350kg/ha Mg and 425kg/ha K. The trial site was fumigated with metham sodium at the rate of 500L/ha and irrigated for 7 days before transplanting. Each of the 1.2m beds were divided into plots 9m in length and 4 week old seedlings of cultivar Grande grown by a commercial seedling nursery were planted into the plots. The seedlings were planted 35cm apart in rows and the rows were 30cm apart with 3 rows per bed allowing 90 plants per treatment plot. Kerb WP® was applied at 3kg/ha with 3mm of irrigation immediately after transplanting (Refer to Figure 1).

Figure 1: Medina Research Centre Trial Site.

Irrigation

All the beds were irrigated 3 times per day for 3 days (total of 9mm per day - depending on the weather). The line source irrigation commenced after the 3rd day. The irrigation replacement was calculated from the previous day's evaporation and rainfall data collected at the Meteorology unit at the Medina Research Centre. Irrigation output in each of the four replicates was measured by the use of rain gauges placed in the centre of each planted bed (4 row groups in 1.5 m width separated by tractor wheelings) across the trial site (see photo of layout).

Fertiliser

The Nitrogen treatments commenced on day 10 after transplanting. Fertiliser was applied as a liquid solution by watering cans, drenched over the foliage and immediately washed off with water only (watering cans) at 7 day intervals. The four different rates were applied using 1mm equivalent total water application for the first 3 applications then 2mm for the last three applications (see photo of layout).

Potassium nitrate and ammonium nitrate were the nitrogen sources used, with all treatments receiving the same rate of potassium in the form of potassium nitrate. Refer to Table 2 for actual amounts applied in each treatment.

Table 2: Fertiliser rates applied to nitrogen treatments.

Treatment	*KNO_3 (kg/ha/wk)*	*NH_4NO_3 (kg/ha/wk)*
0 kg/ha	NIL	NIL
15 kg/ha	112	NIL
35 kg/ha	112	59
55 kg/ha	112	127
75 kg/ha	112	176

Leachate measurement

Six drainage lysimeters were buried at a depth of 40cm under the beds receiving the following treatments.

Table 3: Locations of drainage lysimeters.

Bed No	*Nitrogen Treatment*	*Irrigation Treatment*
120	55 kg/ha/wk	200
122	55 kg/ha/wk	150
123	55 kg/ha/wk	125
124	55 kg/ha/wk	100
125	55 kg/ha/wk	75
126	55 kg/ha/wk	50

The catchment surface area of these lysimeters was 40cm x 40cm. A 1 metre hose was attached to the two outlets at the bottom of the tank, the ends of which protruded slightly above the ground in the wheel tracks between the beds. The leachate collected in these tanks was pumped out each week using a small mechanical motor pump. The volume of leachate and the concentration of nitrogen in the leachate were measured at each date using a RQFlex® meter.

Yield measurements

Weekly harvests were conducted on all plots. 12 plants from each treatment (4 plants per row) were collected on the day before fertiliser treatment each week and fresh weights were recorded. Harvests were conducted on a weekly basis beginning on the17 March 1998. During the final harvest (21 April 1998) the lettuce heads (marketable/ unmarketable) and frames were weighed separately.

Lettuce sap analysis

Sap nitrates were analysed for all treatments within one replicate of the trial. This analysis was conducted on the same weekly cycle as sequential harvesting. Sap was extracted from 20 random petioles from wrapper leaves from the twelve harvested plants per plot. The nitrate levels were measured using the RQFlex® meter. The potassium and phosphorous content of the sap were also measured at the harvest dates 12, 19 and 47 days after transplanting.

Tensiometer monitoring

Soil moisture levels were monitored continuously throughout the life of the crop using continuously recording LT® tensiometers coupled to a data logger. Groups of tensiometers were sited at 15cm, 30cm and 45cm depths below the soil surface in 4 out of the 7 Irrigation treatments (65, 100, 140, 175% Epan Replacement). Data was downloaded onto a notebook computer at weekly intervals.

Data Recording

For each week during the life of the crop (5/3/98 - 21/4/98) the following were recorded:

1. Lettuce fresh weight.
2. Leachate volume.
3. Amount of nitrogen leached.
4. Petiole sap analysis results of nitrogen, phosphate and potassium.
5. Volume of water applied to plots.
6. Tensiometer soil moisture readings.

Results

Sequential harvests

A mathematical model was applied to calculate the combinations of nitrogen and irrigation, which maximised yield at each week during the crop's life. From this, a schedule of irrigation rates and nitrogen rates was produced for the life of the crop. The technique also allowed us to calculate how much fertiliser and water could be saved if a compromise was made and less than 100% yield was accepted at different stages of growth.

Harvest yields at 19 days after planting are shown in Figure 2. There was a significant difference between nitrogen treatments 15kg N/ha/wk and 35kg N/ha/wk ($p \leq 0.01$), but despite this difference there was no significant difference between all the irrigation treatments ($p \leq 0.126$). The calculated optimum combination of nitrogen and irrigation was 66kg/ha/wk and 150% Irrigation. (See Figure 2).

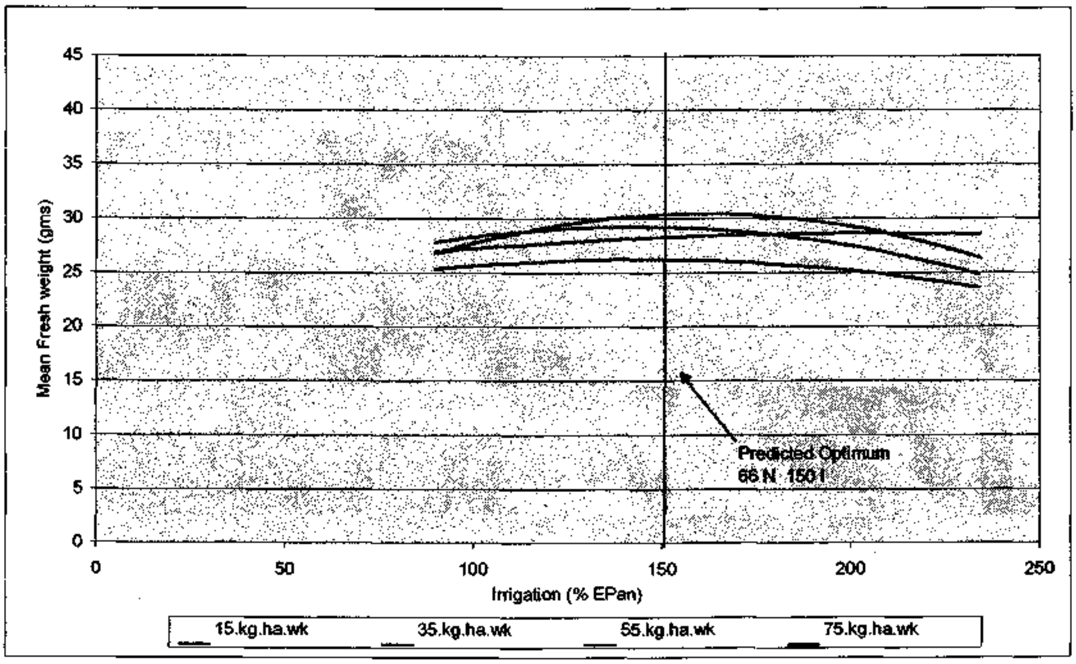

Figure 2: Yield response (mean fresh weight per plant - 12 whole plant tops) at 19 days after transplanting.

At 26 days after transplanting, there was a more substantial difference between the nitrogen treatments ($p \leq 0.001$). There was also a significant difference between the irrigation treatments ($p \leq 0.001$) at this harvest. The 15kg/ha/wk nitrogen rate showed a definite decline in yields and visually was lagging behind the other three treatments and the 35kg/ha/wk rate was declining rapidly at high irrigation rates. The calculated optimum combination of nitrogen and irrigation had increased to 75kg/ha/wk nitrogen and an irrigation rate of 164 % Epan. (Refer to Figure 3).

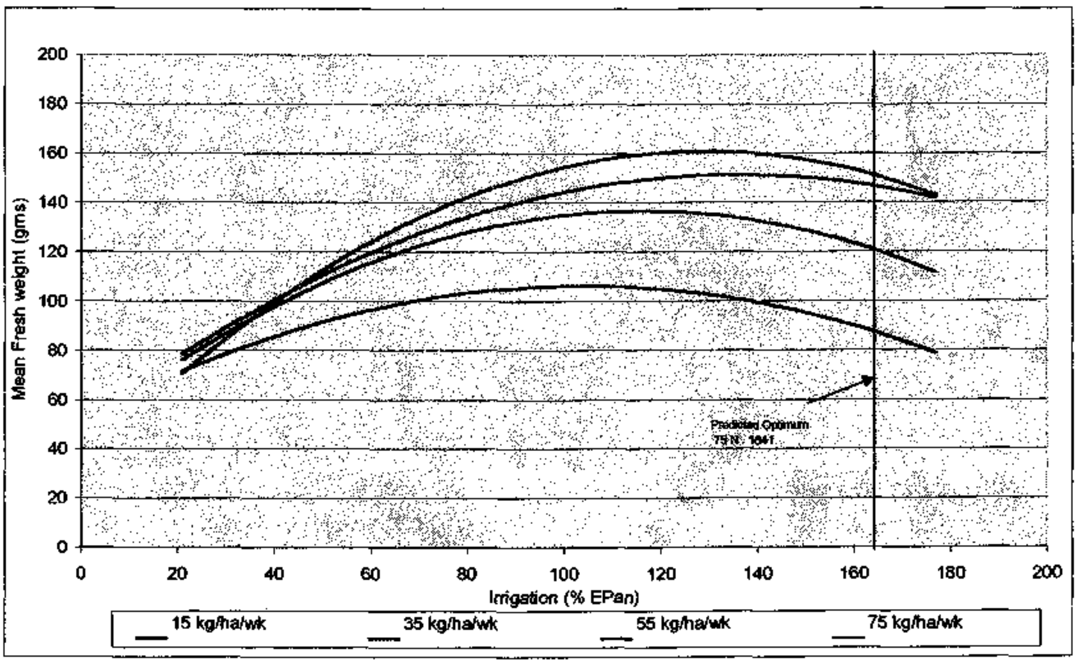

Figure 3: Yield response (mean fresh weight per plant - 12 whole plant tops) at 26 days after transplanting.

By 33 days after transplanting, there were still significant differences between all treatments ($p \leq 0.001$). The 15 kg/ha/wk rate fell further behind the other treatments and the 35kg/ha/wk nitrogen treatment also continued to decline at irrigation rates higher than the optimum. The calculated optimum combination of nitrogen and irrigation changed minimally on the previous week at 72kg/ha/wk nitrogen and 154% Irrigation (Refer to Figure 4).

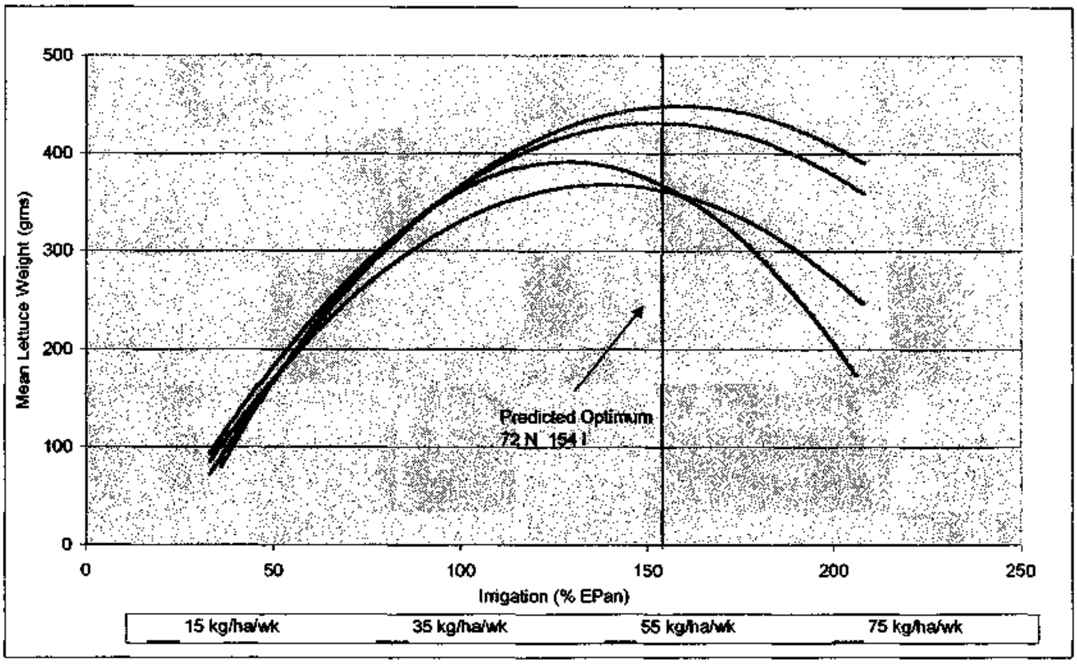

Figure 4: Yield response (mean fresh weight per plant - 12 whole plant tops) at 33 days after transplanting.

At 40 days after transplanting the previous trend in nitrogen response continued. A significant difference between the 15kg/ha and 35kg/ha treatments was noted ($p \leq 0.01$) and no significant difference between 35kg/ha, 55kg/ha and 75kg/ha ($p \leq 0.824$). Again, nitrogen treatments 15kg/ha/wk and 35kg/ha/wk declined significantly in yield when the irrigation rate was applied above the optimum levels, but also started to decline at the medium irrigation levels. The optimum irrigation and nitrogen rate was determined to be 72kg/ha/wk nitrogen and 157% irrigation (Refer to Figure 5).

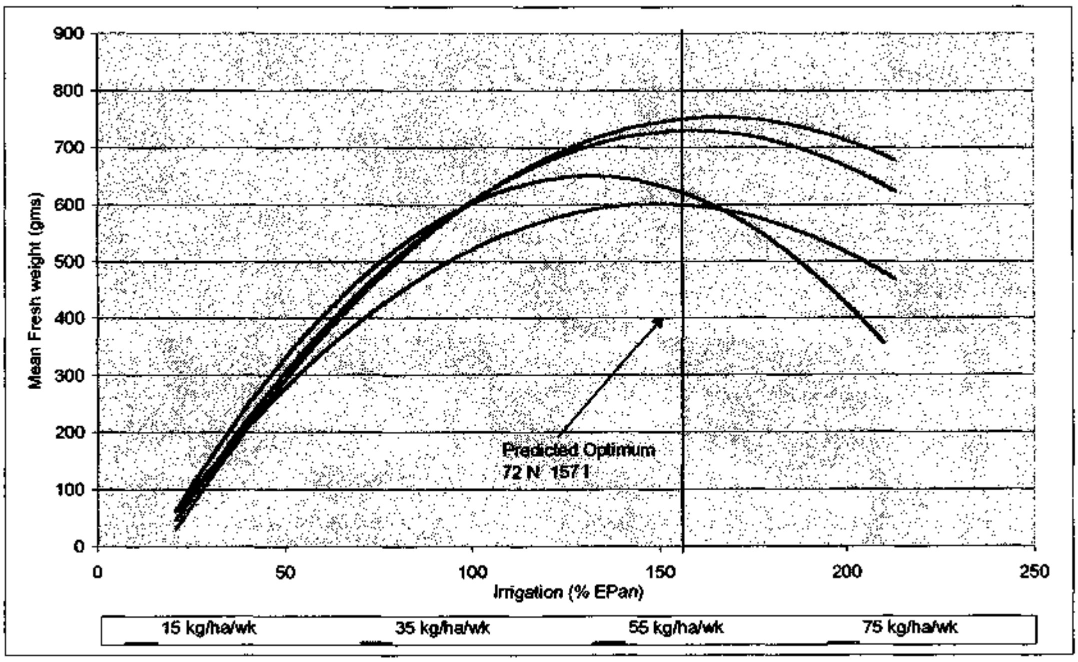

Figure 5: Yield response (mean fresh weight per plant - 12 whole plant tops) at 40 days after transplanting.

By final harvest at 47 days after transplanting (Figure 6), there was still a significant difference between all 4 nitrogen treatments ($p \leq 0.001$). Again, the 15kg/ha/wk nitrogen rate dropped away at the high rates of irrigation but also declined at the low to medium rates of irrigation, demonstrating the inadequacy of this treatment towards the end of the crop. The 35kg/ha/wk nitrogen treatment still dropped at rates higher than the predicted optimum, but also showed a slight decline for the two highest nitrogen treatments in the medium to low irrigation range. The calculated optimum combination of irrigation and nitrogen was determined to be 69kg/ha/wk nitrogen and 152% Irrigation (Figure 6).

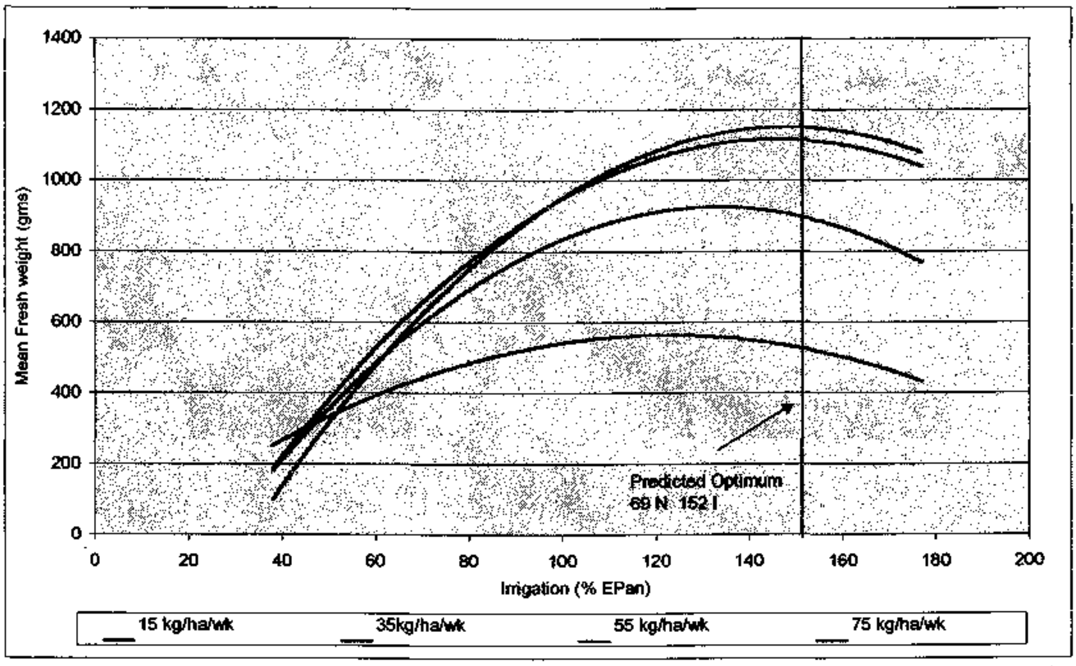

Figure 6: Yield response (mean fresh weight per plant – 12 whole plant tops) at 47 days after transplanting.

Optimum treatments

The optimum nitrogen and irrigation combinations at each week, which maximised yield, are shown in Table 4. To achieve maximum yield at harvest, nitrogen should be applied in a range of 60 - 70 kg/ha/wk over the life of the crop and an irrigation schedule of 150 - 160% Epan Replacement (Table 4).

Table 4: Nitrogen and irrigation rates for maximum yield at each harvest week.

Days after transplant	*19 days (24/3/98)*	*26 days (31/3/98)*	*33 days (7/4/98)*	*40 days (14/4/98)*	*49 days (21/4/98)*
Optimum Nitrogen (kg/ha)	66	75	72	72	69
Optimum Irrigation (% Epan Replacement)	150	164	154	157	152
Optimum Yield (g/head)	28	151	427	706	1089

There was some variability recorded within the trial site in irrigation rates applied to the trial plots. These rates varied from week to week and therefore the targeted irrigation rate was not achieved each week. The most variation was recorded in the first 3 weeks after transplanting. For example, 19 days after transplanting, treatment 1 was planned to receive 50% I. It actually received 94% I that week and in the week after that it only received 29% I and the other six treatments varied in proportion. This variability is thought to be a contributing factor in the higher optimum irrigation rate determined for 26 days after transplanting compared to the later weeks.

Rates of fertiliser and irrigation required to produce maximum yields may not be economically and environmentally justified. To test this hypothesis, rates of both inputs required to produce 95% of the maximum yield at each date of harvest were calculated from the response surface curves to see if significant savings could be made. These results are shown in Table 5.

Table 5: Nitrogen and irrigation rates for 95% maximum yield at each harvest week.

Days after transplant	*19 days (24/3/98)*	*26 days (31/3/98)*	*33 days (7/4/98)*	*40 days (14/4/98)*	*49 days (21/4/98)*
Nitrogen (kg/ha)	32	53	54	57	55
Irrigation (% Epan Replacement)	145	160	153	155	150
Yield (g/head)	26	127	405	670	1034

This proved that there was little yield tolerance at any date to reduced irrigation input, with a reduction of 2-5% in irrigation rate resulting in a 5% drop in yield. Nitrogen was less sensitive, with a 20 - 50% reduction in rate over the life of the crop and only resulting in 5% loss of total yield. Notably, the largest margin for reductions in nitrogen rate with minimal yield penalty were early in the life of the crop. The cumulative effects of the crop of these rate reductions each week cannot be predicted from the data generated by the response model.

Petiole sap analysis

Sap nitrate nitrogen (NO_3-N)

Petiole sap analysis was conducted weekly during the experiment to monitor the nitrate levels in the crop. An optimum range for sap nitrate was determined from these weekly readings which matched the optimum treatment combinations for maximum yield. (Table 6). The upper and lower range readings were based upon 10% confidence intervals from the absolute optimum levels at each week of testing. This optimum range is demonstrated graphically in Figure 7.

Table 6: Proposed sap nitrate-N range for maximum yield of lettuce.

Days after Transplanting	*19 Days*	*26 Days*	*33 Days*	*40 Days*	*49 Days*
Lower Range (mg/L (NO_3-N)	376	455	349	426	436
Upper Range (mg/L (NO_3-N)	459	556	426	521	533

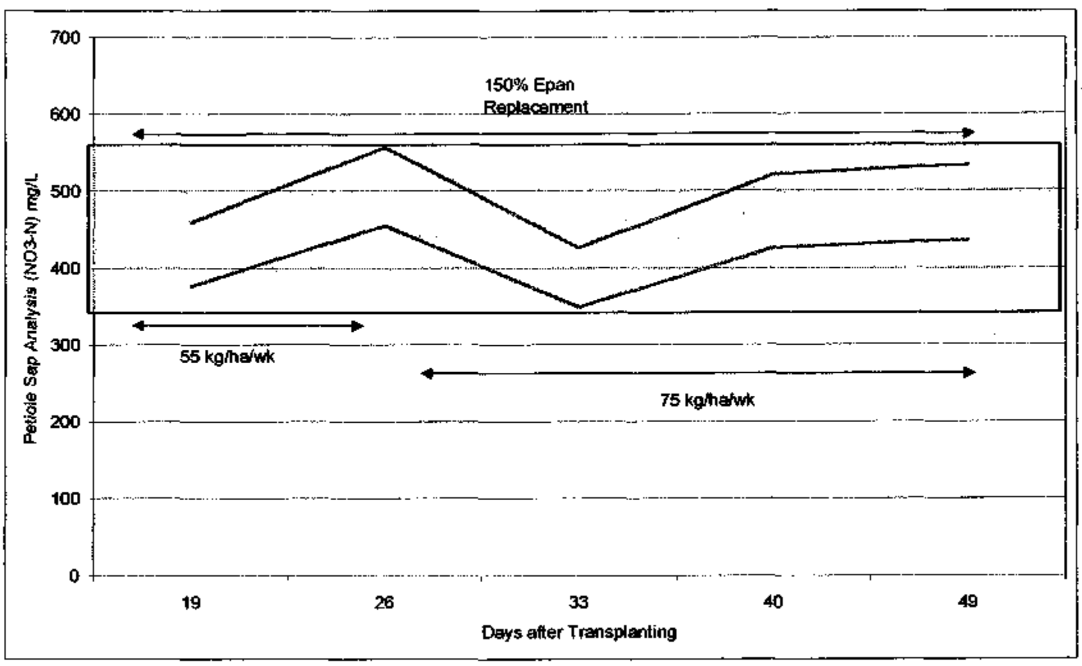

Figure 7: Proposed sap nitrate-N levels for maximum yields of lettuce.

Sap nitrate was sensitive to increasing nitrogen rates at all dates but even more so to water stress. This observation is illustrated in Figure 8 where the highest sap nitrate nitrogen readings were regularly recorded from the lowest irrigation rates (50% I and 75% I). The treatment combination which maximised yield at the 40 day harvest was 72kg/ha/wk N and 157% I. This was nowhere near the highest recorded levels for this week. The crop receiving 50% I was not healthy and not marketable despite recording the highest sap nitrate-N readings for this week.

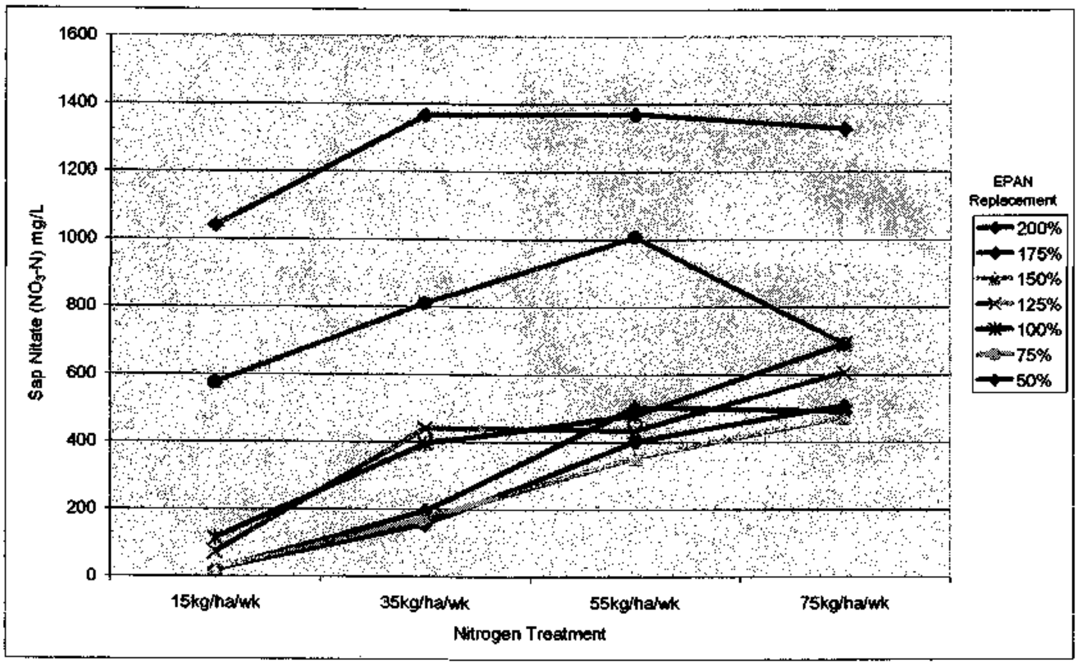

Figure 8: Sap nitrate-N, 40 days after transplanting for 7 rates of irrigation and 4 rates of nitrogen.

Throughout the course of the crop's life the sap nitrate-N levels were monitored for each nitrogen and irrigation treatment. Figure 9 shows how the sap nitrate-N levels fluctuated from week to week in the 75kg/ha/wk treatment with different irrigation treatments. From Figure 9 it can been seen that 150% I and 175% I are the irrigation treatments with the least fluctuation over the whole monitoring period. As this irrigation range was determined to be close to the yield maximising treatment for most of the crops life, the sap profile for this treatment (150% I) was considered to be a good estimate of the optimum for maximising yield throughout the life of the crop.

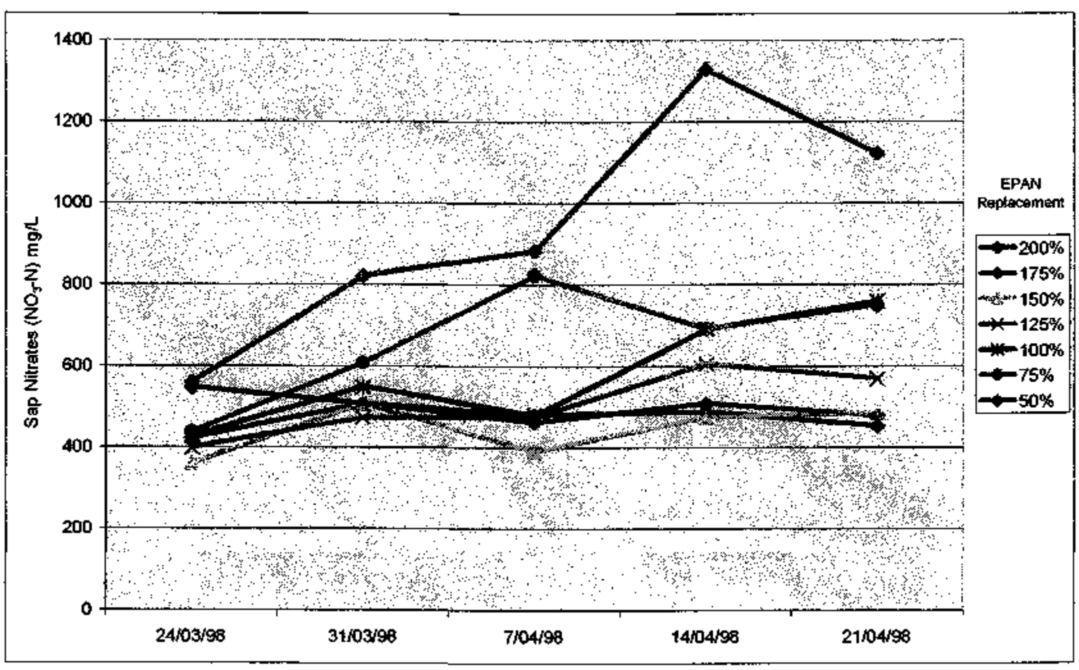

Figure 9 Sap NO_3-N levels over the life of the crop for treatment 75 kg/ha/wk N at all rates of irrigation.

Sap nitrate-N proved to be correlated with yield at most dates of harvest, (Figure 10), where most high yielding treatments recorded 200 - 400 mg/L (NO_3-N) and those recording above 400 mg/L had reduced yields. The sap nitrate test proved to be a useful tool for identifying water stress in plants when levels rose above 500 mg/L (NO_3-N) and this was associated with reduced yield.

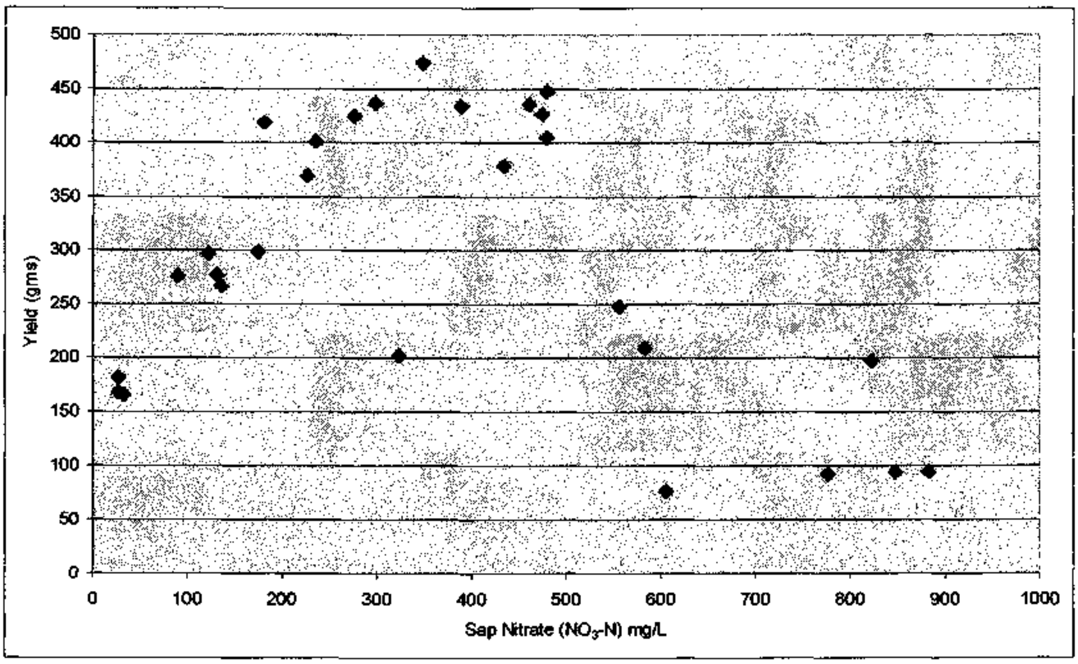

Figure 10: Relationship between sap nitrate-N and fresh weight yield of tops 33 days after transplanting.

<u>Phosphate and potassium sap analysis</u>

Petiole sap analysis for phosphate (PO_4^{3-}) and potassium (K^+) was also conducted during the trial to monitor the effects of the different treatments. These tests were conducted at the harvest dates 12, 19 and 47 days after transplanting.

At final harvest (47 days after transplanting), sap phosphate and irrigation treatments were shown to be poorly correlated (Figure 11). The majority of the treatments over the life of the crop recorded levels of 200 - 300 mg/L sap phosphate. Phosphorous was not considered to be a limiting factor in this experiment.

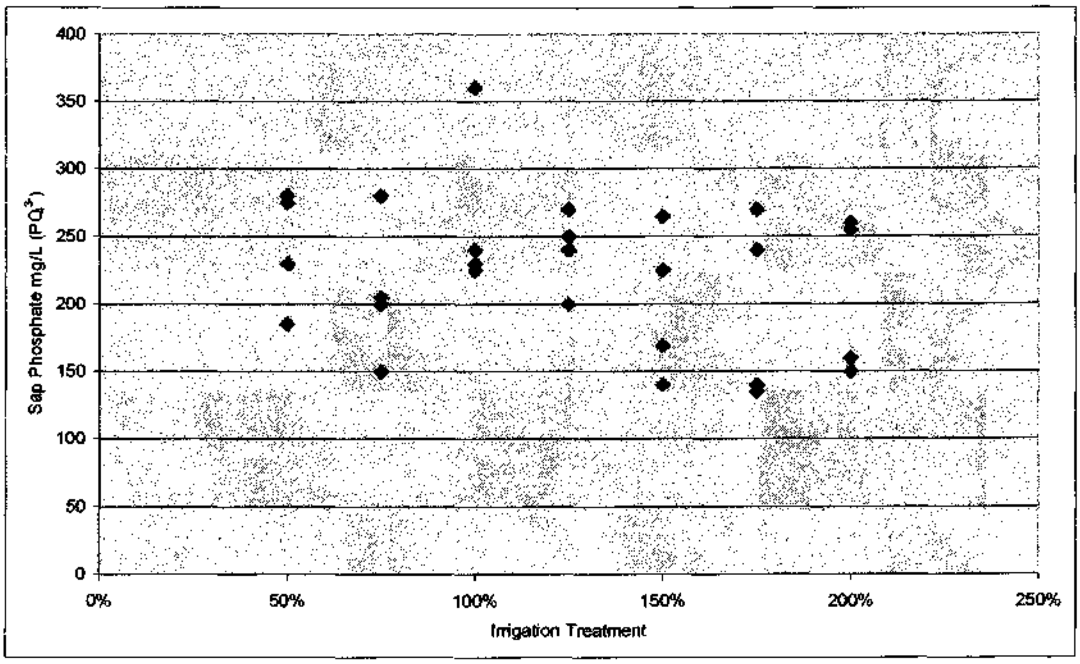

Figure 11: Effects of irrigation rate on sap phosphate levels at 47 days after transplanting.

Figure 12 shows the relationship between sap phosphate and nitrogen rate at harvest (47 days after transplanting). Nitrogen rate and sap phosphate levels were not correlated. The low data points represent the low irrigation rates of 75% I and 50% I and these occurred at all the nitrogen rates. This indicates that the nitrogen rate has little or no effect on the phosphorous uptake by the plant. The levels of phosphate recorded were very variable over the range of treatments applied.

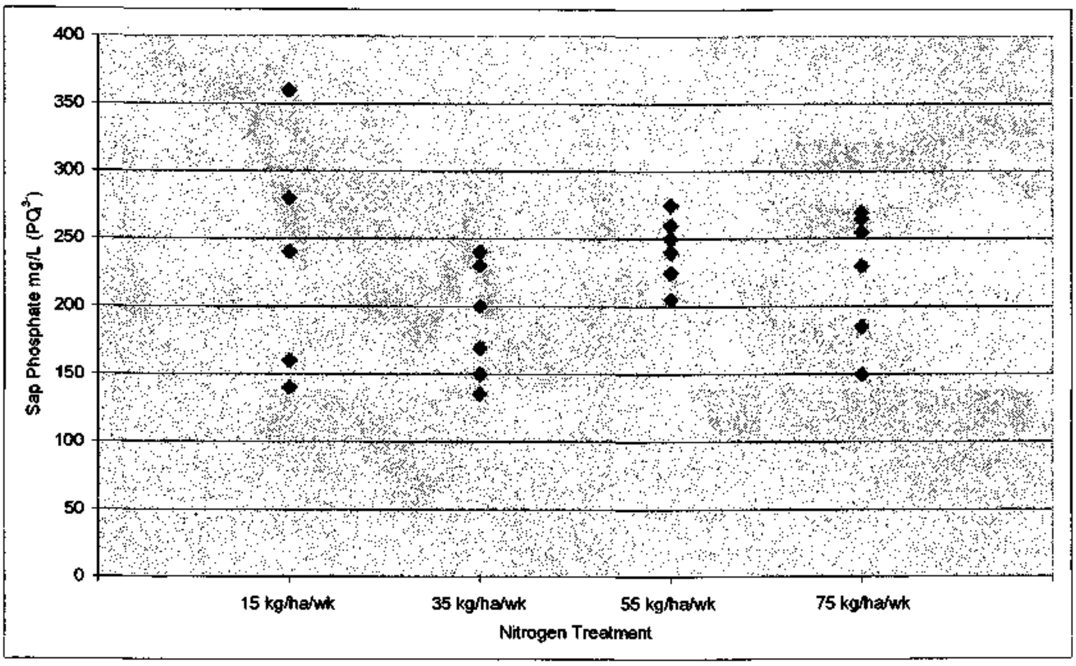

Figure 12: Effect of nitrogen rate on sap phosphate levels 47 days after transplanting.

Potassium levels in lettuce petiole sap were also recorded to monitor trends during crop growth. Figure 13 shows that sap potassium was variable at 47 days after transplanting at all rates of irrigation but with a weak trend towards higher levels in the lower irrigation rates, possibly reflecting leaching effects.

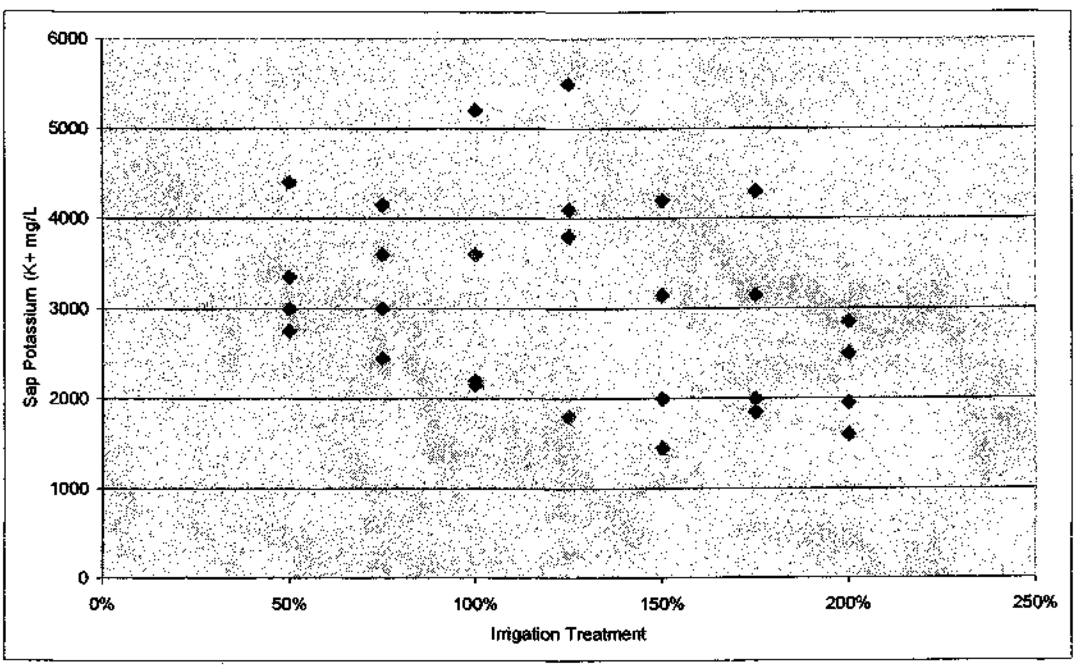

Figure 13: Effect of irrigation rate on sap potassium at 47 days after transplanting.

Figure 14 demonstrates the relationship between nitrogen treatment and sap potassium at 47 days after transplanting. There was a definite trend for sap potassium levels to fall with increasing nitrogen rate. The sap levels were highly variable however at the same rate of nitrogen, partly as a result of the effect of irrigation rate and leaching on the potassium sap levels. The results suggest that potassium uptake may have been similar for low and high nitrogen treatments but the concentration in plant sap was lower in larger healthier plants, and this may have been made worse by potassium leaching from the soil at high irrigation rates. Potassium was not, however considered a limiting factor to yield in this experiment. The results suggest that, to produce a healthy and marketable lettuce crop the sap potassium levels should be in the range of 2000 - 3700 mg/L (K^+).

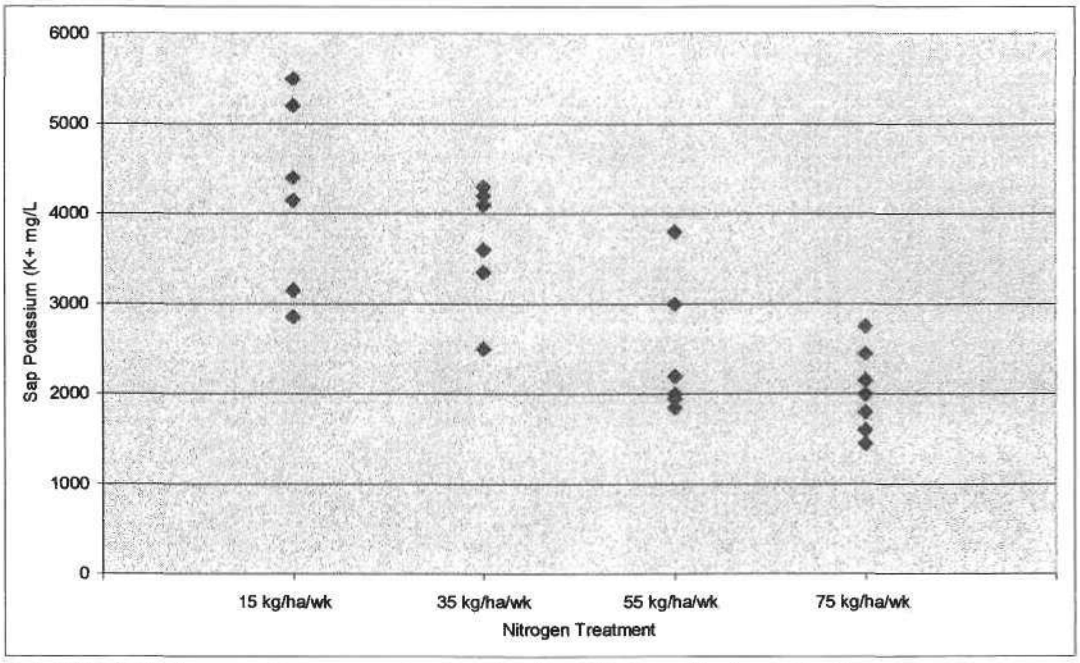

Figure 14: Effect of nitrogen rate on sap potassium levels at 47 days after transplanting.

Leachate measurement

Leachate was measured on a weekly basis from 12 days after transplanting. Figure 15 shows the volumes of irrigation applied and collected as leachate over the 6 irrigation treatments.

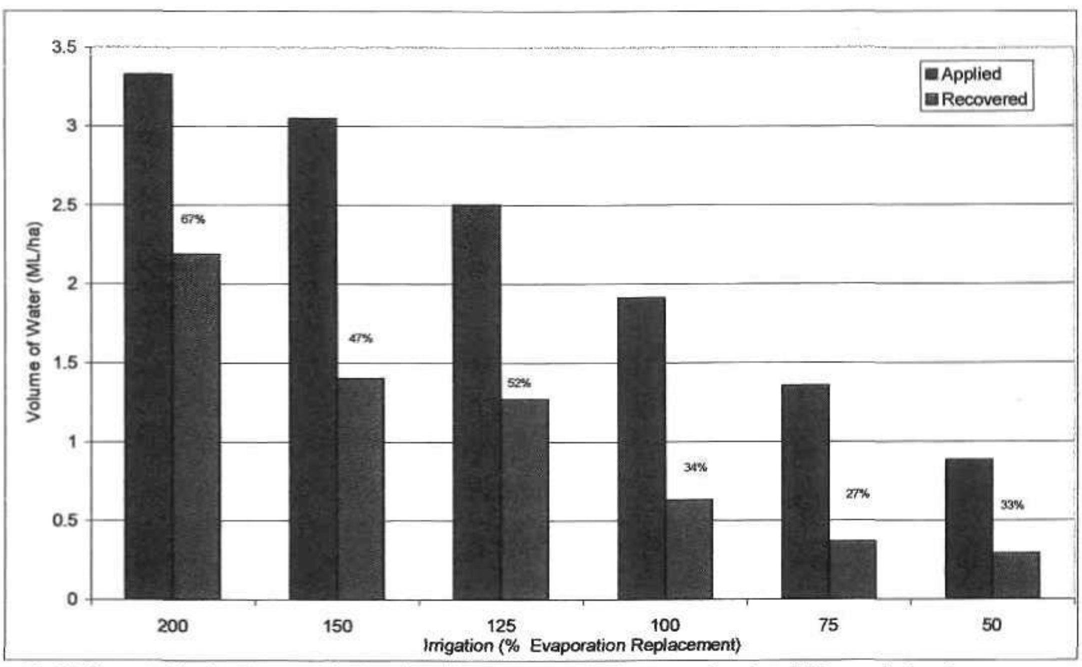

Figure 15: Volume of irrigation applied and collected in the lysimeters for the different irrigation treatments over the life of the crop.

All irrigation treatments leached some volume of water past the root zone. On these free draining sandy soils, through-drainage is rapid and unavoidable. As shown earlier the rates of 50% and 75% I were insufficient to grow a healthy and marketable lettuce crop. It is not surprising to discover that these two treatments recorded the lowest amount of leaching of 27% and 33% of the total water applied. At the other end of the irrigation scale, the 200% I treatment leached 67% of the total water applied. At irrigation rates below the 200% I the leaching percentages declined in direct proportion to the rate of irrigation applied. In the optimum range of

150%, I losses were recorded at 47% of the total amount of irrigation applied. The results suggest that losses of this order through leaching were inevitable on these Karrakatta sands to ensure that a marketable crop was produced. These results were obtained with a fixed watering schedule of two applications per day of variable duration depending on the previous day's evaporation.

It should also be noted that an expected result of through-drainage is the leaching of fertiliser and in particular highly soluble nitrate. Figure 16 shows that for all irrigation treatments some nitrogen leached past the root zone. The lower irrigation rates of 50 - 100% I leached 5 - 10% of the total amount of nitrogen applied, but as indicated by the yield results these treatments were sub-optimal. These irrigation rates leached more nitrate than the 100% rate possibly because fertiliser was not removed from the soil by poorly growing plants.

The highest irrigation rate leached 25% of the total nitrogen applied. This indicated that the plants only had access to approximately 75% or less of what was applied available to them. This treatment (200%) also produced sub-optimal yields due to excessive leaching. It is likely that even more nitrogen would have moved though the soil profile for all treatments after harvest was completed, but measurements of leachate ceased at harvest.

The yield maximising treatments in the optimal irrigation range of 150% I leached only 19% of the total amount of nitrogen applied. This treatment is the best compromise between higher yields and minimised water and nitrogen loss through leaching under the irrigation rates and application times.

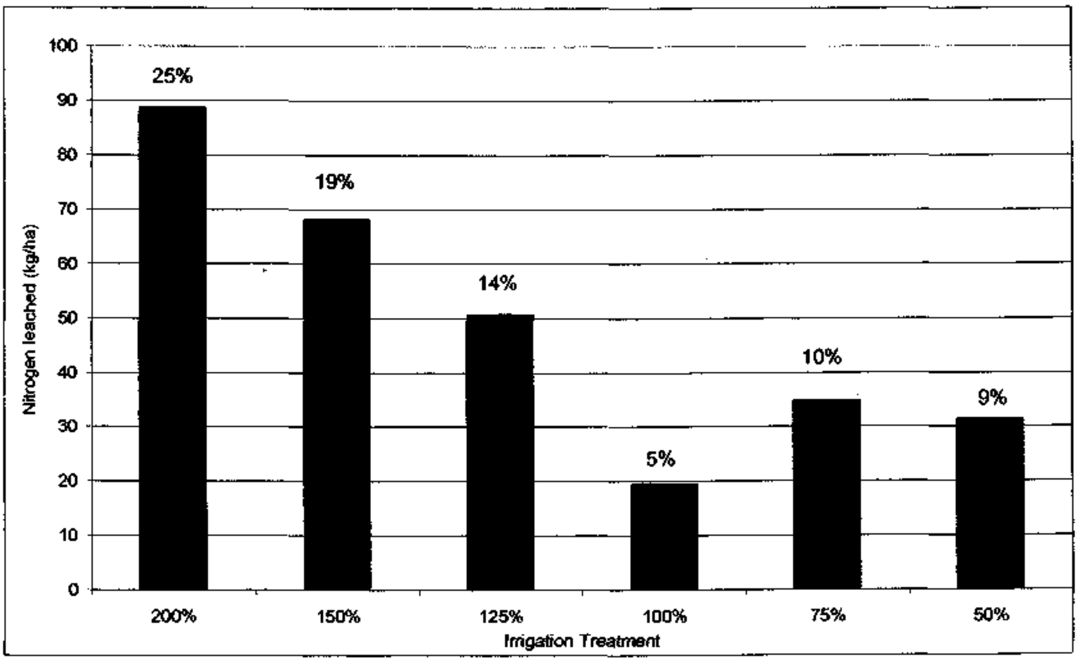

Figure 16: Amount of nitrogen leached over time vs irrigation treatment in the 55 kg/ha/wk treatment.

Soil moisture monitoring

Tensiometers were read on a weekly basis to monitor the soil moisture levels in 4 of the 7 Irrigation treatments over the life of the crop.

Figure 17 represents the tensiometer readings from the week of the 20 March 1998 to the 27 March 1998 at 100% I. This figure shows a typical wetting and drying cycle for an 8 day period at three depths in the soil. The soil is saturated at 0 kPa (centibars) and approaching early water stress at around -7 kPa (centibars). Irrigation events each day are shown by vertical spikes on the graph.

The 100% treatment represented in Figure 17 progressively became sub-optimal for lettuce production and the traces at all depths show that the soil is in a long term drying trend under this irrigation regime. The effect of under-irrigation is most marked at depth, where the 45cm zone was drying faster than the shallower zones. This suggests that the crop's roots were active at this depth, only 15 days after planting. By the end of this week, soil moisture levels were only being maintained in the 0-15cm zone by this irrigation treatment.

This soil monitoring technique has potential in commercial practice, because it allows the grower to see whether there is sufficient water in and around the root zone of the crop and whether there is a need to irrigate. This, in the long term, could be used as an efficient and manageable irrigation scheduling aid.

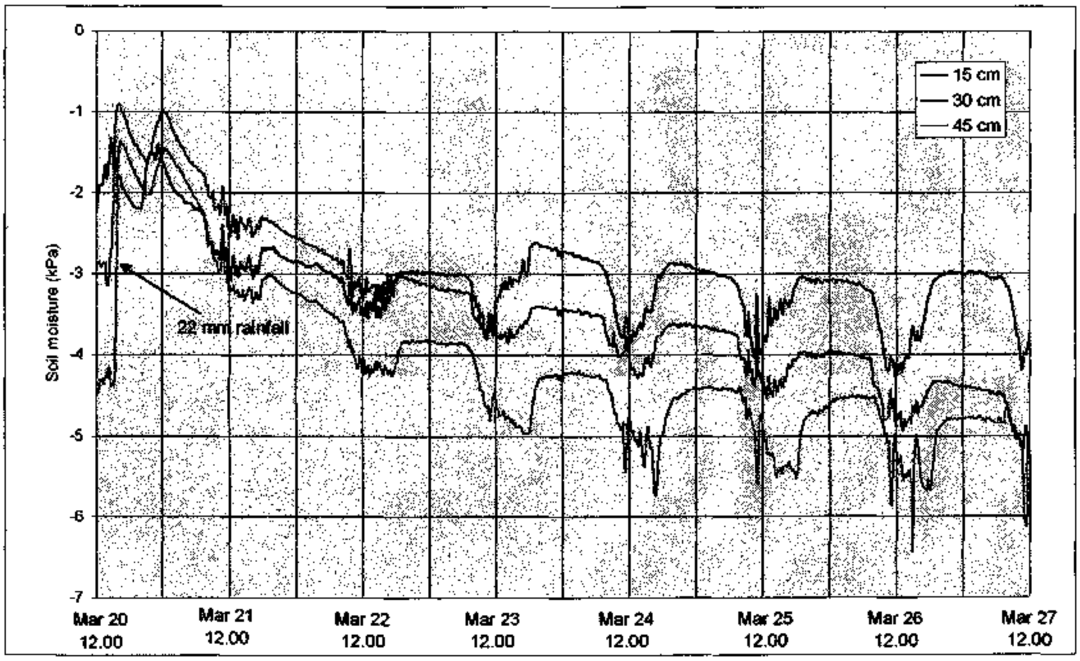

Figure 17: Soil moisture suction measured by tensiometers (Irrometer LT®) at depths of 15cm, 30cm and 45cm at 100% I (20 March 1998 - 27 March 1998).

Conclusion

The 'line source' irrigation technique used in this experiment provided the opportunity to predict the optimum combinations of irrigation and nitrogen fertiliser to maximise lettuce crop yield. The system and the method assumed overhead irrigation with sprinklers on a twice-daily basis and fertiliser applications on a weekly cycle applied as a liquid solution of nitrogen, potassium and magnesium. The results are applicable to an autumn transplanted 'iceberg' lettuce crop.

Taking into account these constraints, the yield maximising combinations of nitrogen and irrigation were consistently in the range 60-70 kg/ha/wk N with an average irrigation rate of 150% I. The law of diminishing returns applied strongly to the nitrogen response with up to 50% of the total nitrogen applied being required to gain the last 5% of yield increase in the weeks soon after planting. Closer to harvest, this effect decreased with a 20% increase in rate required to gain the last 5% of yield. This effect allowed for significant reductions in fertiliser rates if the grower could tolerate small reductions in yield.

Yield was far more sensitive to irrigation rate with small reductions in irrigation rate resulting in excessively large reductions in yield throughout the life of the crop. There was little opportunity for water savings below 125% I at most stages of growth.

Petiole sap analysis, conducted weekly, was used in conjunction with the yield data to determine an optimum sap nitrate range which would ensure maximum yield throughout the crop's life. This optimum range was determined to be 350 - 550 mg/l NO_3-N, over the life of the crop. Sap nitrate levels proved to rise in direct proportion to nitrogen rate applied but they were also highly sensitive to water stress, rising dramatically above the optimum range when irrigation rates were sub-optimal. Petiole sap analysis was a good indicator of water stress but levels were relatively less sensitive to marginally sub-optimal nitrogen rates. The technique was still useful to detect sub-optimal nitrogen application rates however.

The rapid sap testing device, the RQFlex® meter proved to be accurate and reliable and a useful tool to monitor crop performance rapidly when used in conjunction with the standards derived in this study. For this technique to be meaningful however, strict adherence to optimum irrigation practice, timing of sampling, sampling method and testing procedure is required. It would be best done in commercial practice by a specialist but could be used by a grower with attention to detail.

Potassium and phosphate levels in petiole sap were also measured to determine that they were not limiting to yield. The results suggested that neither of these elements was limiting. Sap levels of phosphate was not affected by nitrogen rate, but sap nitrate and potassium were negatively correlated. Low levels of irrigation were associated with slightly elevated sap potassium levels but had little effect on sap phosphate levels.

The adequate range for sap potassium was 2000 - 3700 mg/l and 300 - 400 mg/l for phosphate. Levels of both elements were highly variable at the same rate of irrigation or nitrogen and the 'adequate range' concept is appropriate for interpreting sap levels of these elements. Duplicate tests with the RQFlex® meter showed that the variation was not a result of analytical technique but real differences in sap levels between plots over time.

Leachate measurements were taken on a weekly basis to determine the efficiency of the nitrogen and irrigation treatments. Irrigation rates in the optimum range of 150% were shown to have leached around 47% of the water applied on these free draining sandy soils. Sub-optimal irrigation rates still leached a large amount of applied irrigation and these plots did not produce marketable standard plants. The conclusion was reached that some leaching is unavoidable on these free draining sandy soils with overhead sprinkler irrigation even for sub-optimal treatments.

Nitrate-N was also shown to be readily leached below the root zone for the optimal and higher irrigation rates. The 55 kg N/ha/wk treatment resulted in 19% of the total nitrogen applied leaching into the catchment lysimeter. Any treatments less than this optimum were unable to produce marketable yields and still showed evidence of leaching. The rate of the loss of nitrogen was in direct proportion to the amount of irrigation applied.

Tensiometers (Irrometer® LT) modified to continuously record soil moisture with a digital readout proved highly sensitive to changes in soil moisture status in the root zone of the crop. They demonstrated that soil moisture levels at all depths, from 0cm to 45cm (in the root zone) were sufficiently wet throughout the crop's life to avoid water stress to the crop. The recorded levels were consistently in the range –3 to –6 kPa. These levels could be considered desirable targets for growers to use to ensure optimal irrigation rates were being applied.

Tensiometers were considered to be suitable as a monitoring tool to ensure that irrigation schedules based on evaporation were doing what they should. They were considered to be of limited value as a scheduling tool in their own right on these soils due to the rapid fluctuation of soil moisture content during the course of a day and the narrow operating range between adequate soil moisture and the onset of water stress. This characteristic could result in many short term irrigations in the course of a day which could have implications for plant bacterial and fungal disease control. They were also subject to variation due to siting within the root zone and were sensitive to associated equipment failure such as damage to cabling by machinery.

3.2 Lettuce irrigation and nutrition research on sandy soils of the Swan Coastal Plain of Western Australia – Summer 1999.

D. R Phillips, L. K Teasdale, S Kumar, D. G Gatter, T Calder, and G D'adhemar.

Summary

A 'line source irrigator' was used to apply a continuum of irrigation rates to plots of transplanted 'iceberg' lettuce (cv. Kingsway) treated with five rates of nitrogen fertiliser at Medina Research Centre in the summer of 1998/99. Irrigation rates applied over the course of the experiment ranged from 65% pan evaporation replacement (Epan) to 190% Epan, superimposed on nitrogen rates from 40 kg/ha/week N to 70 kg/ha/week N in a split plot design.

The yield maximising combinations of crop irrigation and nitrogen rates were determined for each week of the crop's life, from weekly sequential harvesting of plants within each treatment. Yield maximising treatments derived from the irrigation/nitrogen response surface were between 50 - 60kg/ha/wk N and an irrigation rate range of 110 - 140% Epan, over the life of the crop. Petiole sap analysis conducted weekly from 14 days after transplanting was used to determine a desirable nitrate nitrogen (NO_3-N) range for high yield and marketability throughout the growing cycle.

Measurements of leachate were taken during the life of the crop at a depth of 40 cm to determine the relative water and fertiliser use efficiency of the treatment combinations. These measurements showed production of a healthy and marketable lettuce crop resulted in some leaching. The highest yielding treatments resulted in 60% water loss over the life of the crop and 40% of the total nitrogen applied leaching past the root zone.

Tensiometers were used to monitor the soil moisture levels within the differing irrigation treatments. This data was used to assess the potential of soil moisture measurement as an alternative tool for scheduling irrigation. Tensiometers, Irrometer® LT proved to be suitable as monitoring devices in the operating range -4 to -10 kPa. The soil moisture tension level at 15 cm depth below the crop, which was associated with maximum yield was about -4 kPa throughout.

Introduction

This research project investigated sustainable management practices that would improve the quality, yield, reliability and product uniformity of lettuce for domestic and export markets. The means of achieving this end was to combine crop monitoring, field research and 'in field' demonstration of improved practices to facilitate adoption. The short time frame for the study necessitated that the crop monitoring and field research overlapped in time.

Recommendations for lettuce nutrition (Graham, 1994) and irrigation (Lantzke 1995) on Coastal Plain soils were available but had not been widely adopted by growers. These recommendations were based on limited research and had not been thoroughly tested. Irrigation recommendations used evaporation replacement principles (crop factor or Epan) and did not take account of recent advances in soil moisture monitoring technology. Similarly, nutrition recommendations for nitrogen were based on a 'universal' recommended rate per hectare and did not include monitoring techniques or guidelines to allow tactical adjustment of fertiliser rates and timings during the life of the crop.

Continuously recording tensiometers, specifically designed for sandy soils (Irrometer® LT) were available at the start of the project. Also, plant tissue analysis and rapid sap testing for nitrate was available from fertiliser merchandisers but adequate standards for interpretation of results had not been developed. A hand held digital colorimeter suitable for rapid 'in field' sap testing (RQflex meter®) was also available.

A 'line source' irrigation layout was available at Medina Research Centre (35 km south of Perth WA) which allowed detailed testing of irrigation and nutrition strategies on a field scale. This facility was used in the autumn 1998 to derive optimum irrigation and sap nitrate guidelines and needed to be re-tested at a hotter time of the year.

Lettuce was chosen as a target crop for this study because:

- Previous irrigation and nutrition research had been conducted on the Swan Coastal Plain
- The crop is almost exclusively grown on sandy soils in Western Australia

- It is an important crop in the vegetable industry, with 14,000 tonnes produced in 1996, valued at $8 million in Western Australia and $70 million nationally.
- Typically, growers used high rates of fertiliser and water to produce the crop and there was a high potential for adverse environmental effects. The most obvious being pollution of shallow groundwater aquifers used for irrigation and other purposes.
- There was a high potential for new technologies to provide savings in inputs and costs.
- Raw poultry manure was widely used by growers as a fertiliser/soil conditioner on this crop and its use resulted in uncontrolled releases of high rates of nitrogen into the soil profile, which was largely unused by the crop and hence available for leaching into groundwater, potentially resulting in pollution of aquifers.

The main aims of this experiment were:

1. To develop irrigation scheduling guidelines for 'iceberg' lettuce grown on sandy soils.
2. To test the hypothesis that there is an interaction between irrigation and nitrogen response of lettuce.
3. To test the suitability of tensiometers as a soil moisture monitoring device on sandy soils and develop relevant standards for using these devices to monitor and schedule irrigation.
4. To derive sap nitrate standards for the life of the crop which maximises yield and quality of lettuce.
5. To re-evaluate the results obtained in 1998 for an autumn sown crop at a hotter time of the year.
6. To test nitrogen fertiliser strategies for lettuce in the absence of pre planting poultry manure with the potential to maintain crop yield and quality while reducing unwanted leaching.

Materials and Methods

A split-plot design was used with main plots having 4 levels of nitrogen plus 1 pre-planting rate of fowl manure and the subplots having 6 rates of irrigation. There were four replicates of the 30 treatments. Refer to Table 1 for treatments.

Table 1: Nitrogen and Irrigation treatments.

Nitrogen Treatment (kg N/ha/wk)	*Irrigation Treatments (% Epan Replacement)*
40 kg/ha	190*
50 kg/ha	175
60 kg/ha	140
70 kg/ha	100
30 m^3/ha poultry manure (pre-plant) then 50 kg/ha N	65

** Note that, although the 'line source' system was designed to give progressive increases in irrigation rate across the plots, in practice, the two highest rates of irrigation were little different, around 190% Epan. Below this rate, there was a progressive fall in irrigation rates across the plots as planned (see Table 1).*

Iceberg lettuce, cultivar Kingsway, was used in this experiment. The soil type on the trial site was grey-phase Karrakatta sand. Grey phase Karrakatta sands are characteristically well drained soils, have a low nutrient retention and water holding ability and a pH between 6 -7. The trial was transplanted using seedlings from a commercial nursery on the 11 February 1999.

Site preparation and transplanting

The major and minor element requirements of all treatments was met by broadcasting 3000 kg/ha of superphosphate® and 150kg/ha trace elements (Medina Mix) and rotary hoeing to the depth of 15 to 20 cm two days prior to planting. Potassium and magnesium were applied throughout the life of the crop at a fixed rate for all treatments to a total of 365 kg/ha K and 300 kg/ha Mg. The fowl manure treatment was broadcast and incorporated on 3 February, eight days before transplanting.

The trial site was fumigated with metham sodium at the rate of 500 L/ha and irrigated for 7 days before transplanting. Each of the 1.2m beds were divided into plots of 9 m length. Four week old seedlings of cultivar Kingsway WA were planted into the plots. The seedlings were planted 35 cm apart in the row and the rows were 30 cm apart with 3 rows per bed allowing 90 plants per treatment. Kerb® was applied at 3 kg/ha with 3 mm of irrigation immediately after transplanting.

Irrigation

All the beds were irrigated 3 times per day for 3 days (total of 9mm per day - depending on weather). The line source irrigation commenced after the 3rd day. The irrigation replacement was calculated from the previous day's evaporation and rainfall data was collected at the Meteorology unit at the Medina Research Centre. Irrigation output in each of the four replicates was measured by the use of rain gauges placed at 1.5m in intervals across the trial site.

Fertiliser

The Nitrogen treatments commenced on day 7 after transplanting. Fertiliser was applied as a liquid solution by watering cans drenched over the foliage and immediately washed off with water-only (watering cans) at 7 day intervals. The four different rates were applied using 1 mm equivalent of solution for the first 3 applications then 2 mm for the last three applications.

Potassium nitrate and ammonium nitrate were the nitrogen sources with all treatments receiving the same rate of potassium in the form of potassium nitrate. Refer to Table 2 for actual amounts applied in each treatment.

Table 2: Fertiliser rates applied to nitrogen treatments.

Treatment kg N /ha/wk	*KNO_3 (kg/ha/wk)*	*NH_4NO_3 (kg/ha/wk)*
40 kg/ha	158	57
50 kg/ha	158	87
60 kg/ha	158	116
70 kg/ha	158	145
30 m^3 poultry manure (pre-plant) then 50 kg/ha N	158	87

Leachate measurement

Ten drainage lysimeters were buried at a depth of 40 cm under the beds receiving the following treatments (Table 3). Five of these were already in place from the previous year and 5 new ones were installed prior to site preparation. These new lysimeters were placed in plots 64, 70, 74, 82 and 88.

Table 3: Lysimeter placements.

Bed No	*Nitrogen Treatment*	*Irrigation Treatment*
64	FM30 +50	140
70	40	140
73	60	190
74	60	190
75	60	175
76	60	140
77	60	100
78	60	65
82	50	140
88	70	140

The catchment surface area of these lysimeters was 40 cm x 40 cm. A 1 metre hose was attached to the two outlets at the bottom of the tank, the ends of which protruded slightly above the ground in the wheel tracks between the beds. The leachate collected in these tanks was pumped out each week using a small mechanical pump. The volume of leachate was measured at each date and the concentration of nitrate in the leachate was determined using a RQflex® meter.

Yield measurements

Weekly harvests were conducted on all plots (excluding the FM30 + 50kg/ha/wk which was half the length of the other plots and not randomised). Twelve plants from each treatment were collected on the day before fertiliser treatment each week and the fresh weights were recorded. Harvests were conducted on a weekly basis beginning on the 17 February, but excluding the 24 March. The FM30 + 50 kg/ha/wk treatment was only harvested at weeks 1,5 and 7. The final harvest plot size on the 31 March (week 7) was 24 plants. During the final harvest, lettuce heads (marketable/ unmarketable) and frames were weighed separately.

Lettuce sap analysis

Sap nitrates were analysed for all treatments within one replicate of the trial. This analysis was conducted on the same weekly cycle as sequential harvesting. Sap was extracted from 20 randomly selected petioles from wrapper leaves taken from the twelve harvested plants per plot. The nitrate levels were measured using the RQFlex® meter. The potassium and phosphorous content of the sap were also measured in weeks 3, 5 and 7.

Tensiometer records

Soil moisture levels were monitored continuously throughout the life of the crop using continuously recording LT® tensiometers coupled to a data logger. Four pairs of tensiometers were sited at 15 cm and 30 cm depths below the soil surface in 4 out of the 6 Irrigation treatments (65, 100, 140, 175% Epan replacement). Data was downloaded onto a notebook computer at weekly intervals.

Data Recording

For each week during the life of the crop (11/2/99 - 31/3/99) the following were recorded:
1. Lettuce fresh weight.
2. Leachate volume.
3. Amount of nitrate leached.
4. Petiole sap levels of nitrogen, phosphate and potassium.
5. Volume of water applied to plots.
6. Tensiometer soil moisture levels.

Results

Sequential harvests

A mathematical model was applied to calculate the combinations of nitrogen and irrigation, which maximised yield at each week during the crop's life. From this, a schedule of irrigation rates and nitrogen rates was produced for the life of the crop. The technique also allowed us to calculate how much fertiliser and water could be saved if a compromise was made and less than 100% yield was accepted at different stages of growth.

Harvest yields at 14 days after planting are shown in Figure 1. Only the 40 kg/ha rate of nitrogen was beginning to decline in yield at high rates of irrigation, the other three rates were not significantly different. Notably, yields at all N rates dropped at high rates of irrigation, suggesting a leaching effect. Despite the trend, there was no significant difference between all N treatments ($p \leq 0.110$). Even at this early stage of crop growth there was a significant difference between irrigation (I) treatments ($p \leq 0.001$). This indicates that irrigation schedules below 100% - 120% (I) will produce sub-optimal yields. The calculated optimum combination of nitrogen and irrigation was 56kg/ha N and 111% I (see Fig. 1).

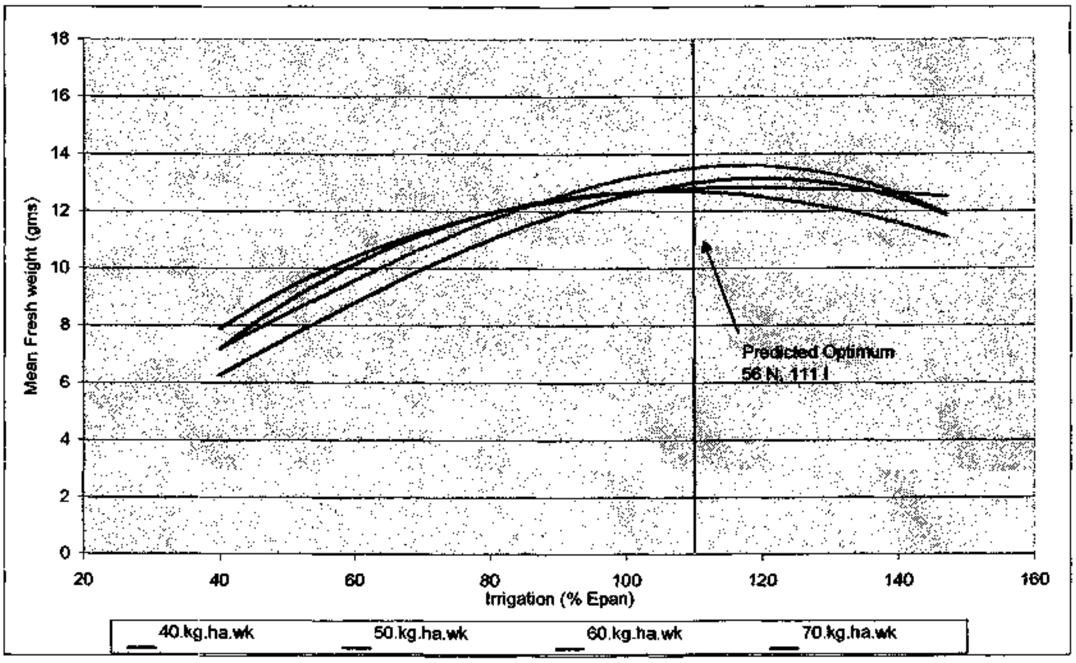

Figure 1: Yield response (mean fresh weight per plant – 12 whole plant tops) at 14 days after transplanting.

At 21 days after transplanting, the 40 kg/ha rate of nitrogen showed even more pronounced reduction in yield at high rates of irrigation compared with the two highest N rates. During this week it was found that there was a significant difference between all nitrogen and irrigation treatments ($p \leq 0.001$). The calculated optimum combination of nitrogen and irrigation had increased to 61kg/ha N and 132% I (see Fig. 2).

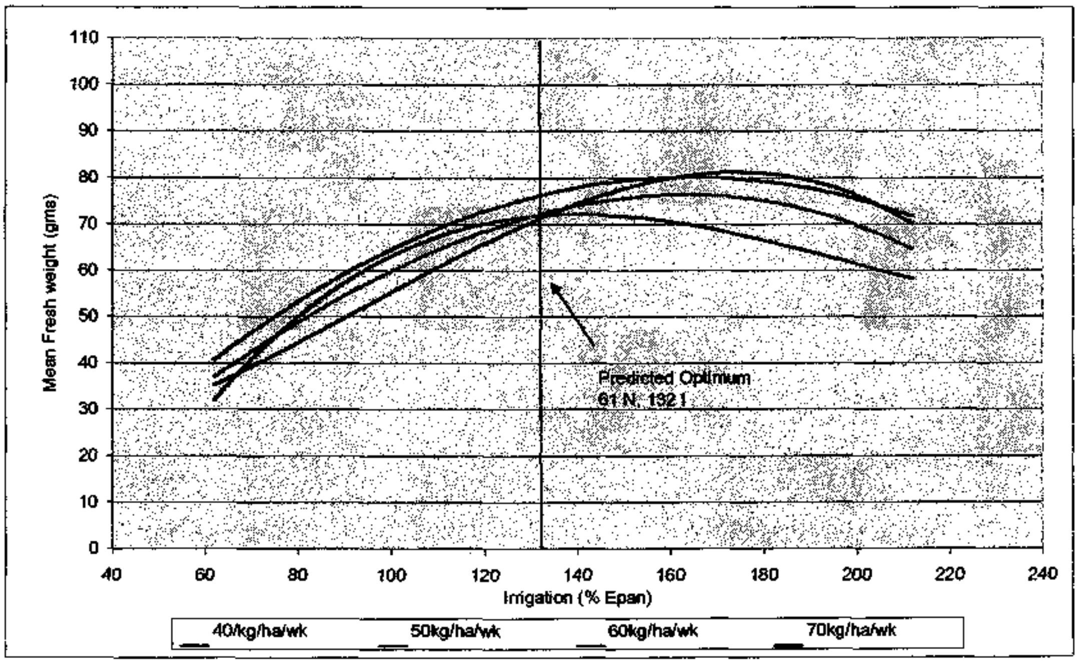

Figure 2: Yield response (mean fresh weight per plant –12 whole plant tops) at 21 days after transplanting.

By 28 days after transplanting, there were still significant differences between all treatments ($p \leq 0.001$). The 40 kg/ha rate of nitrogen fell further behind the other N rates at all rates of irrigation compared with the two highest N rates. The calculated optimum combination of nitrogen and irrigation changed little on the previous week at 61 kg/ha N and 135% I (see Fig. 3).

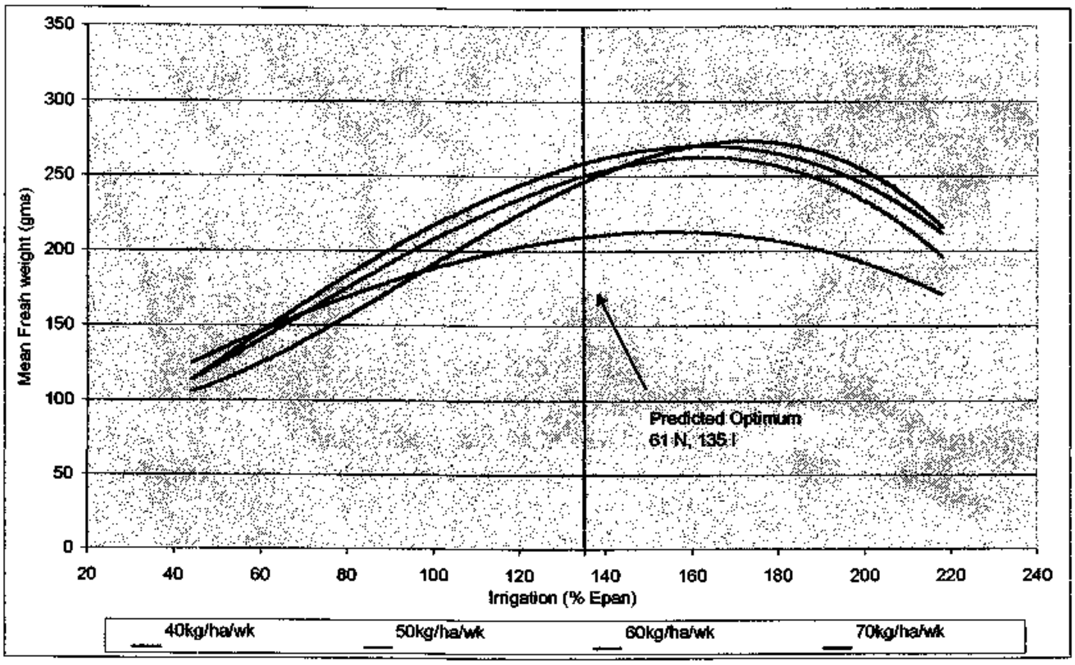

Figure 3: Yield response (mean fresh weight per plant – 12 whole plant tops) at 28 days after transplanting.

At 35 days after transplanting, the previous trend in nitrogen response continued with the optimum irrigation rate increasing slightly to 139% I. There was a significant difference between all treatments during this week ($p \leq 0.001$). At this date of harvest, the fowl manure plots were also harvested and showed higher yields than the other treatments at low irrigation rates and up to 140% Epan (Figure 4). There are a number of possible explanations for this, the most likely being that this treatment performed better than the others up to 14 days and the higher yields are a carry-over effect in drier treatments which were adequate when the crop was younger. It may also be the result of improved soil moisture holding capacity in these plots (not measured).

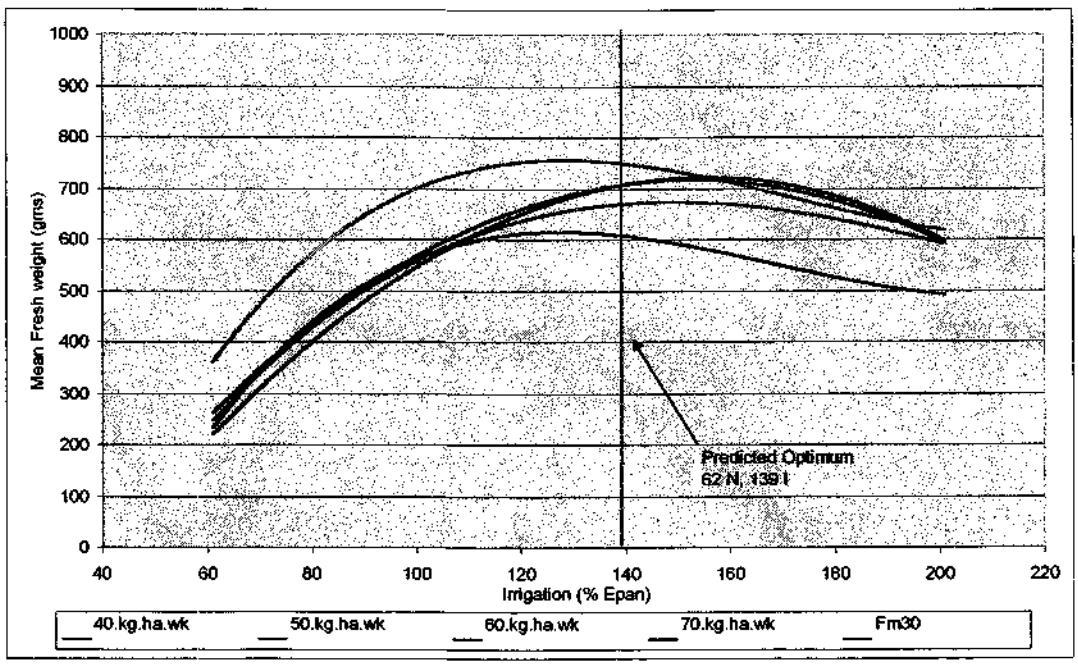

Figure 4: Yield response (mean fresh weight per plant – 12 whole plant tops) at 35 days after transplanting.

By final harvest at 49 days (Fig. 5), the differences between nitrogen treatments became less pronounced, with a calculated optimum of 33 kg/ha N and 122% I. The reasons for this drop in optimum rates are not clear but it could be the result of the onset of seed stem formation in all plots which increased plot to plot variability in weight. However, none of the plots had 'bolted' by harvest time. Analysis of variance showed that there was a significant difference between all treatments ($p \leq 0.001$).

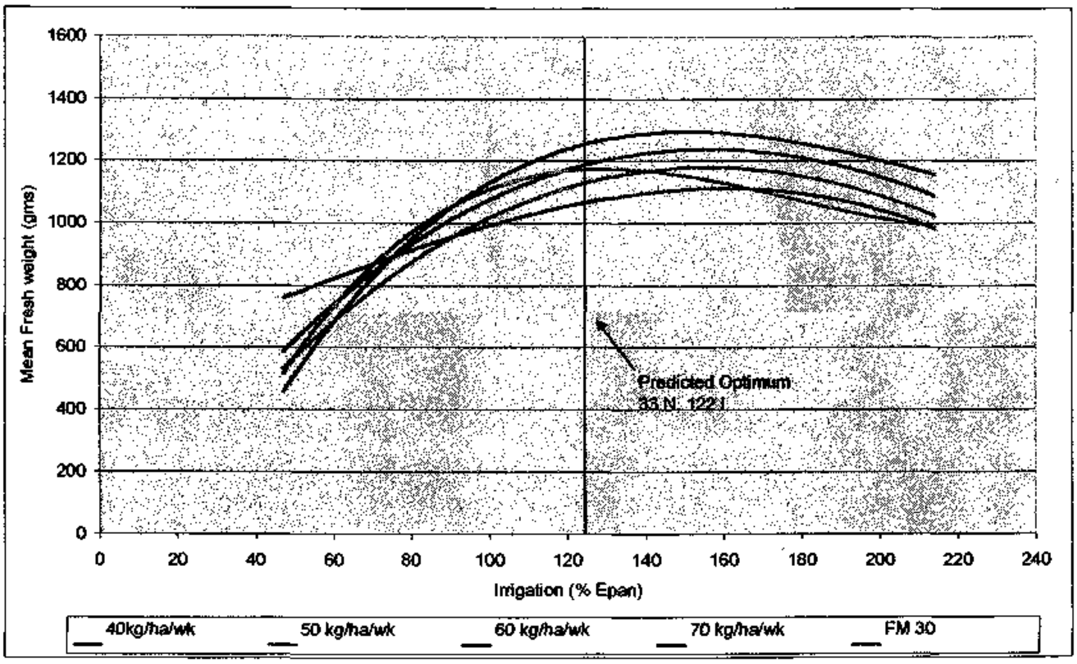

Figure 5: Yield response (mean fresh weight per plant – 24 whole plant tops) at 49 days after transplanting.

Optimum treatments

The optimum nitrogen and irrigation combinations at each week, which maximised yield are shown in Table 4. To achieve maximum yield at harvest, nitrogen should be applied in the range of 50 - 60 kg/ha/wk over the life of the crop and an irrigation schedule ranging from 110 - 140% Epan replacement (Table 4).

Table 4: Nitrogen and irrigation rates for maximum yield at each harvest week.

Days after transplant	*7-14*	*15-21*	*22-28*	*29-35*	*36-49*
Optimum nitrogen (kg/ha)	56	61	61	62	33
Optimum irrigation (% Epan replacement)	111	132	135	139	122
Optimum yield (g/head)	12	72	240	660	1180

There was large variability within the trial site in irrigation rate applied to the plots, and rates varied from north to south across the site. The target irrigation regimes were not achieved every week. The most notable variation in rates occurred in the first 3 weeks after planting. For example, in week 1, treatment 1 which was planned to receive 190% replacement only received about 145% and in week 2 it received 210% and all other treatments varied in proportion. After week 2, the rates were consistently close to the planned rates for all plots. It is expected that this may have contributed to an underestimation of the optimum irrigation rates in this experiment in the early weeks after planting.

Rates of fertiliser and irrigation required to produce maximum yield may not be economically or environmentally justified. To test this hypothesis, rates of both inputs required to produce 95% of maximum yield at each date of harvest were calculated from the response surface to see if significant savings could be made. The result of that analysis is shown in Table 5 and Table 6.

Table 5: Nitrogen and Irrigation rates for 95% maximum yield at each harvest week.

Days after transplanting	*7-14*	*15-21*	*22-28*	*29-35*
Nitrogen (kg/ha/wk)	42	49	52	49
Irrigation (% Epan replacement)	110	131	134	138
Yield (g/head)	11	68	228	627

Table 6: Potential irrigation and nitrogen rates (% of maximum), which together would result in 95% of maximum yield.

Days	*Nitrogen rate (% of optimum)*	*Irrigation rate (% of optimum)*	*Estimated yield (% of maximum)*
7-14	75%	98.5%	95%
15-21	80%	99.1%	95%
22-28	85%	99.1%	95%
29-35	80%	99.2%	95%

There proved to be little yield tolerance at any date to reduced irrigation input, with a reduction of 1-2% in irrigation rate resulting in a 5% drop in yield. Nitrogen was less sensitive, however, with a 25% reduction in rate up to 14 days resulting in only a 5% loss of yield and similar tolerances in subsequent weeks. The cumulative effect on the crop of these rate reductions each week cannot be predicted.

Petiole sap analysis

Sap nitrate nitrogen ($NO_3 - N$)

Petiole sap analysis was conducted weekly during the trial to monitor the nitrate, phosphate and potassium levels in the crop. An optimum range for sap nitrate was determined from these weekly readings which matched the nitrogen and irrigation treatments closest to the optimum treatment combinations for maximum yield (see Table 7). This optimum range is illustrated graphically in Figure 6. The lower end of the range is the absolute optimum level minus a 10% confidence level and the upper end is plus the 10% confidence level.

Table 7: Proposed sap nitrate-N range for maximum yield of lettuce.

Days after transplanting	*7-14*	*14-21*	*22-28*	*29-35*	*36-49*
Lower range NO_3 - N (mg/L)	390	450	450	370	500
Upper range NO_3 - N (mg/L)	480	550	550	460	600

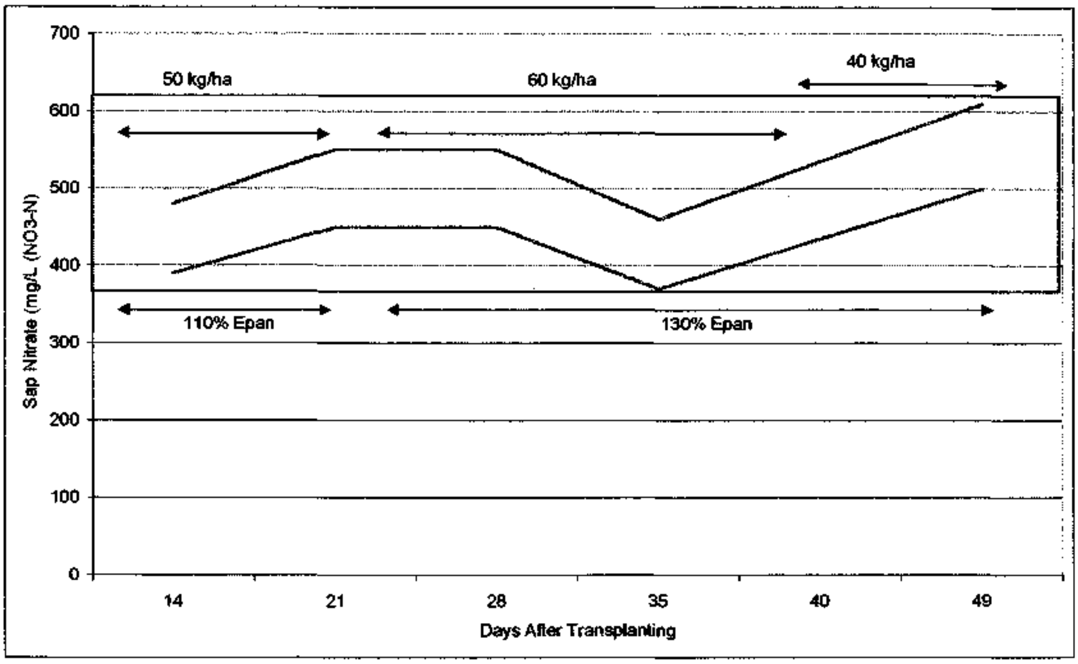

Figure 6: Proposed sap Nitrate-N range for maximum yield of lettuce.

Sap nitrate was sensitive to increasing nitrogen rate at all dates but even more so to water stress. This observation is illustrated in Figure 7 where the highest sap nitrate readings were consistently recorded from the lowest irrigation treatments (65%). The treatment combination which maximised yield at 14 days was approximately 60 kg/ha/wk N and 100% I. Surprisingly, this treatment did not give the highest sap nitrate level recorded. Although 65% I recorded the highest sap nitrate-N levels for this week, it did not produce healthy or marketable plants. The sap levels shown in Fig 7 suggest that even treatment 100% I may have mild water stress despite being close to the predicted yield maximising treatment.

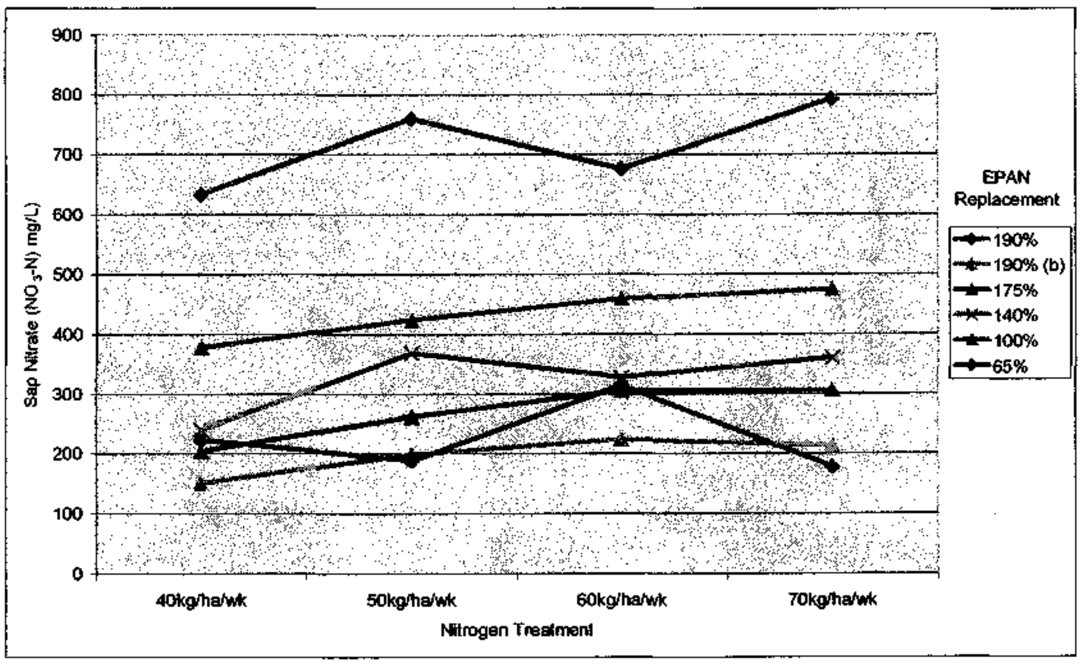

Figure 7: Sap nitrate-N, 14 days after transplanting for 6 rates of irrigation and 4 rates of nitrogen.

Week 3 harvest results (28 days after transplanting) also show interesting effects, where the predicted optimum was approximately 60 kg/ha/wk N and 140% I. Figure 8 shows that the same sap nitrate level was recorded from a high yielding treatment (190% I and 70 kg/ha/wk N) as for a low yielding water stressed treatment (65% I and 70 kg/ha/wk N). By this date, 100% I was clearly water stressed and yields had fallen away compared to the higher irrigation rates and this was reflected in the consistently high sap nitrate results. The sap nitrate levels for the other four irrigation treatments in Figure 8 sit closely together over the range of nitrogen rates, suggesting that they are not water stressed.

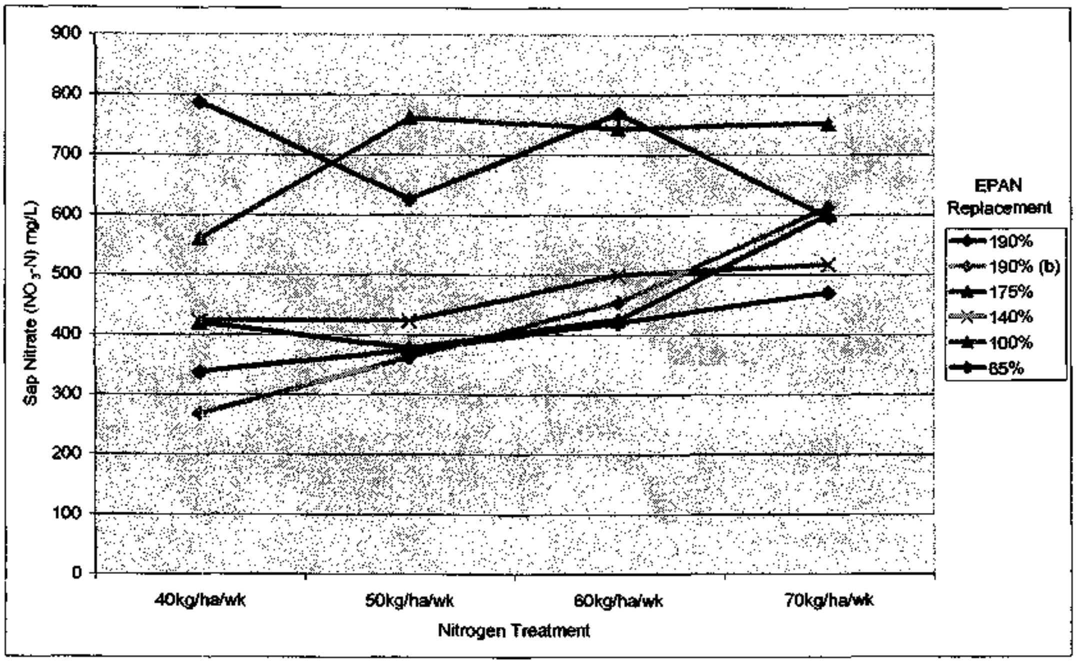

Figure 8: Sap nitrate-N, 28 days after transplanting for 6 rates of irrigation and 4 rates of nitrogen.

Throughout the crop's life the sap nitrate-N levels were monitored for each nitrogen and irrigation treatment. Figure 9 shows how the sap nitrate-N levels fluctuated from week to week in the 60 kg/ha/wk N treatment with the different irrigation treatments. From Figure 9 it can be seen that 140% I is the irrigation treatment with the least fluctuation over the whole monitoring period. As this irrigation treatment was determined to be close to the yield maximising treatment for the 3 middle weeks of the monitoring period it is also obviously sufficient for the first week. This irrigation rate was above the predicted optimum for the last week of the crop's life and hence the sap nitrate level should not be elevated by water stress. The sap profile for this treatment is thus considered to be a good estimate of the optimum for maximising yield up to 35 days and probably also to maturity.

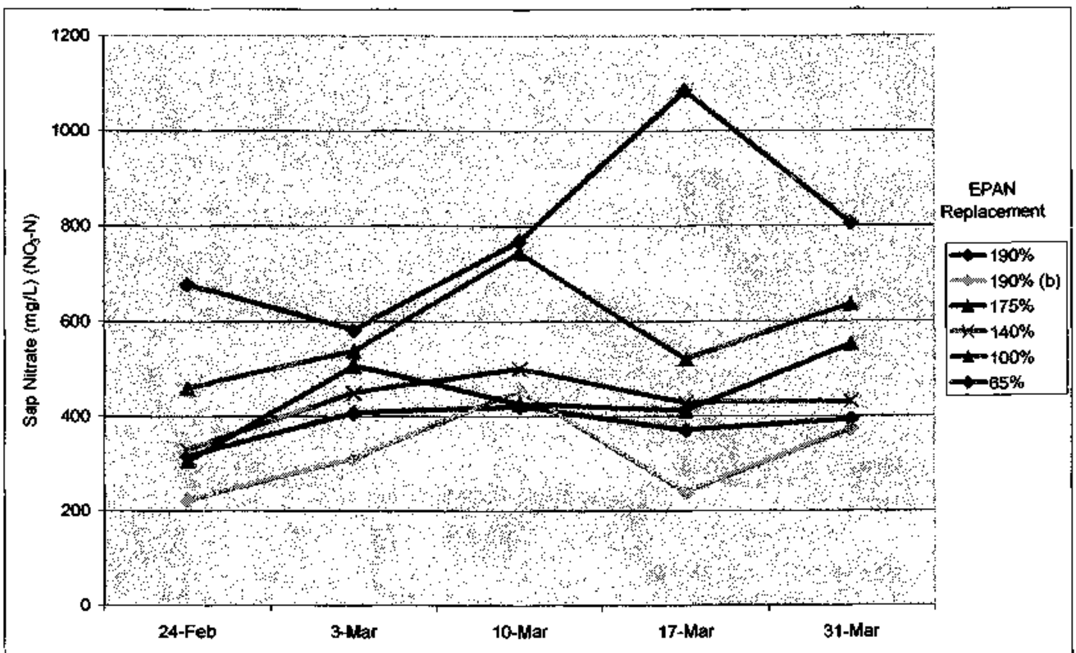

Figure 9: Sap (NO_3 – N) levels over the life of the crop for treatment 60 kg/ha/wk N at all rates of irrigation.

Sap nitrate-N proved to be correlated with yield at most dates of harvest, as shown in Figure 10, where most high yielding treatments recorded 200-400 mg/L (NO_3 – N) and those recording above 400 mg/L had reduced yields. The sap nitrate test proved to be a useful tool for identifying water stress in plants when levels rose above 500 mg/L (NO_3 – N) and this was associated with reduced yield.

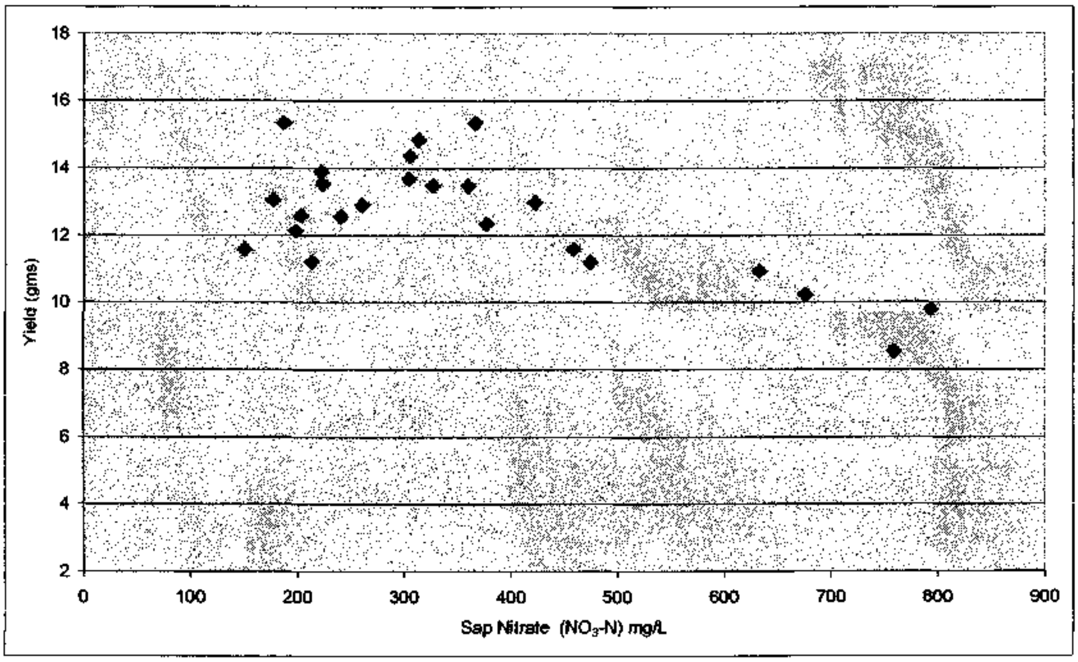

Figure 10: Relationship between sap nitrate-N and fresh weight yield of tops 14 days after transplanting.

Sap phosphate and potassium

Petiole sap analysis for phosphate (PO_4^{3-}) and potassium (K) was also conducted during the trial as a check that these elements were not limiting to yield. These tests were conducted fortnightly.

At 21 days after transplanting, there was little difference between treatments, with the exception being 65% I, which produced lower yields and recorded lower sap phosphate levels (<150 mg/L). The majority of the plots recorded levels between 250 - 350 mg/L PO_4^{3-}. (see Figure 11). This result suggests that phosphorus was not a limiting nutrient for most treatments but low uptake was associated with water stress in the low irrigation rate treatment.

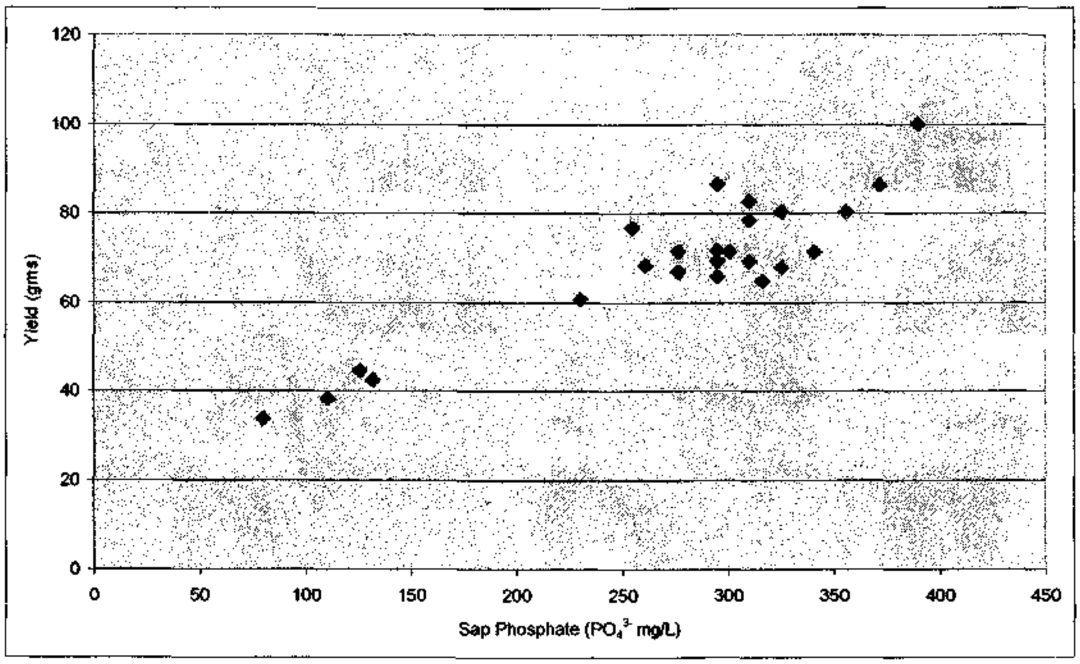

Figure 11: Relationship between sap phosphate (PO_4^{3-}) and fresh weight yield of tops 21 days after transplanting.

The data recorded 35 days after transplanting showed slightly more variability than 21 days after transplanting. Treatment 65% I again had low sap phosphate results compared to the rest of the treatments. The majority of sap phosphate levels were in the range of 250 - 400 mg/L, which was similar to the previous fortnight.

At the final harvest (49 days after transplanting), the same trend between sap phosphate and yield was seen as in the previous two fortnights. The results of 65% I again deviated from the rest of the data recording lower sap phosphate levels when the sampling data for all dates of testing was pooled (Fig. 12). The majority of treatments recorded sap phosphate in the range 300 - 450 mg/L.

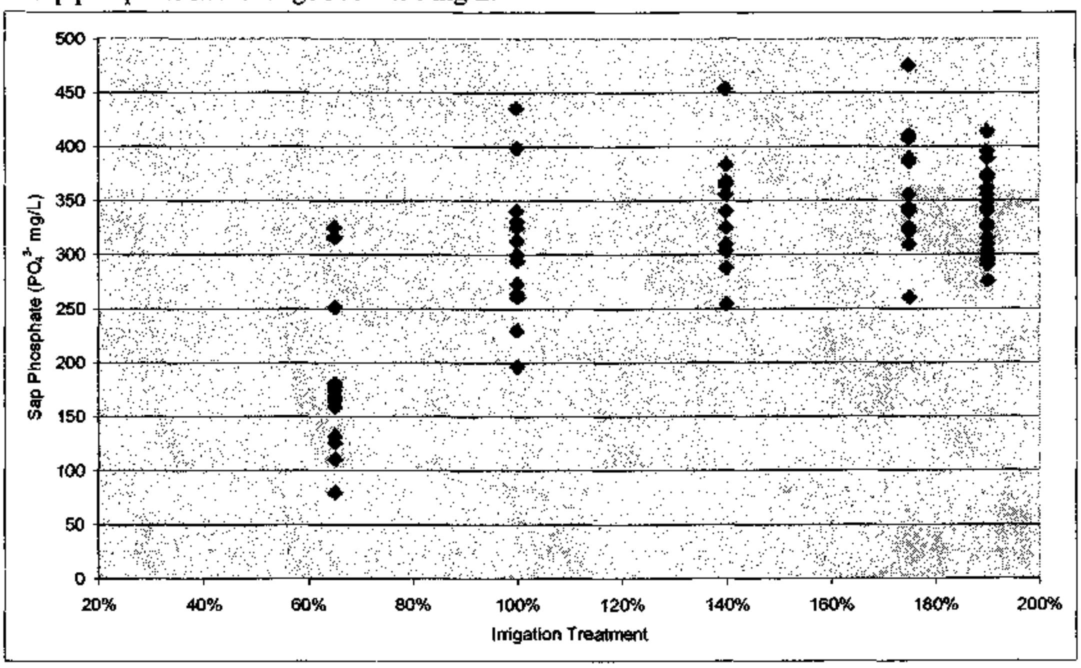

Figure 12: Effect of irrigation rate on sap phosphate levels over all sampling dates.

Figure 13 shows the relationship between sap phosphate and nitrogen rate applied over all dates of testing. Clearly the two were not correlated. The data points below 200mg/L represent the low irrigation treatments, 100% I and 65% I, and these occur at all rates of nitrogen. This indicates that nitrogen rates had little or no effect on phosphorus uptake by the plants but reinforces the effects of low irrigation on phosphorus. The levels of phosphorus recorded were very variable over the range of treatments applied. The fowl manure treatment recorded slightly higher phosphate levels than the other treatments, probably because the fowl manure contributed extra phosphorus to the fertiliser program over and above that supplied by superphosphate.

Phosphorus was not thought to be a limiting factor in this experiment, but levels did decline where irrigation was inadequate. Hence, sap phosphate levels throughout the life to the crop in the range 300 - 400 mg/L were considered sufficient for maximum yield.

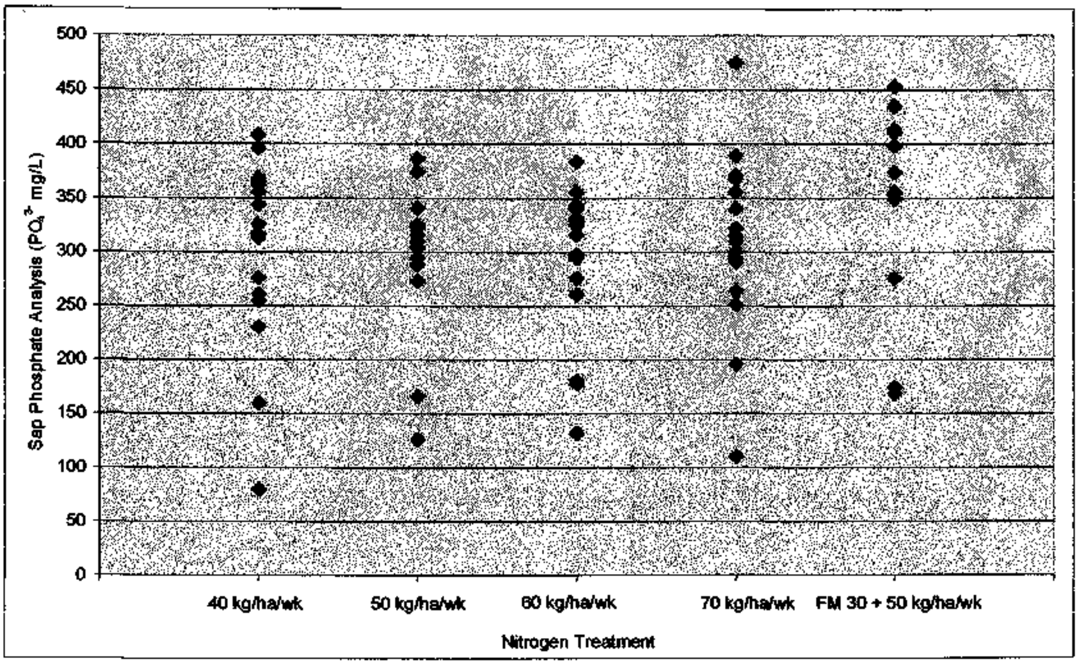

Figure 13: Effect of nitrogen rate on sap phosphate levels over all sampling dates.

Potassium levels in lettuce petiole sap were also measured to monitor trends during crop growth. At 21 days after transplanting, there was a weak negative trend between yield and potassium sap level. The results suggest that potassium was not limiting to growth of any treatments and levels in excess of 2000 mg/L (K) are sufficient for good crop growth.

By 35 days after transplanting, the same negative trend between yields and potassium sap analysis was evident. The majority of the data fell within the range of 2000 - 4000 mg/L K^+. The lowest yields were recorded from treatments which received the 65% I treatment. Unlike phosphate, potassium levels fluctuated more widely within the 65% I treatment, indicating that the nitrogen treatments also had an effect on the K levels in sap. Again at final harvest (49 days after transplanting), the weak negative trend still existed with lower yielding treatments tending to record higher sap potassium levels. (Figure 14).

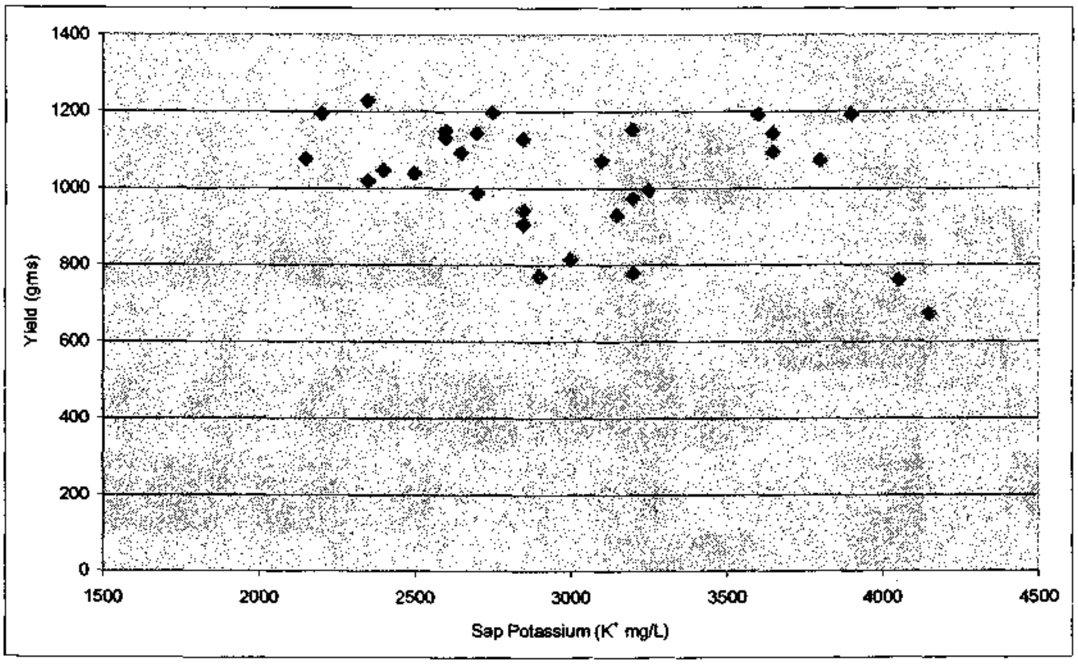

Figure 14: Relationship between sap potassium levels and marketable yield at final harvest (49 days).

Figure 15 shows that sap potassium levels over the course of the crop's life were variable at all rates of irrigation but there was a weak trend towards higher sap levels at lower irrigation rates.

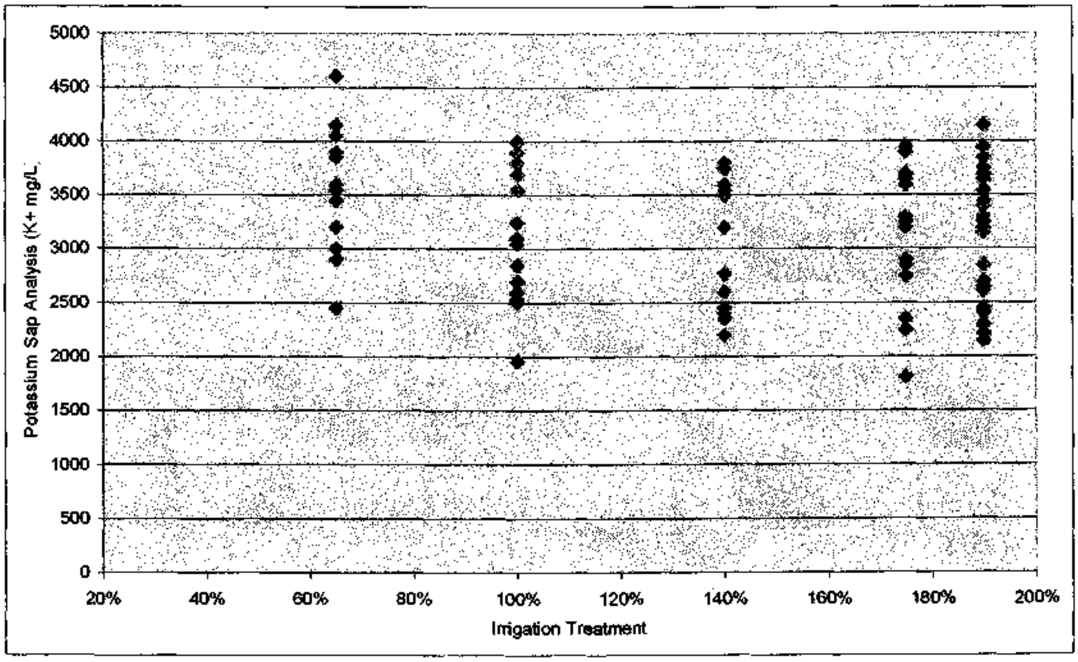

Figure 15: Effect of irrigation rate on sap potassium levels over all sampling dates.

Figure 16 demonstrates the relationship between nitrogen rate and sap potassium level. There was no obvious correlation between the two, suggesting that nitrogen did not influence potassium uptake and that potassium was probably not limiting to growth. The sap levels were highly variable, partly as a result of the effect of irrigation rate on potassium sap levels.

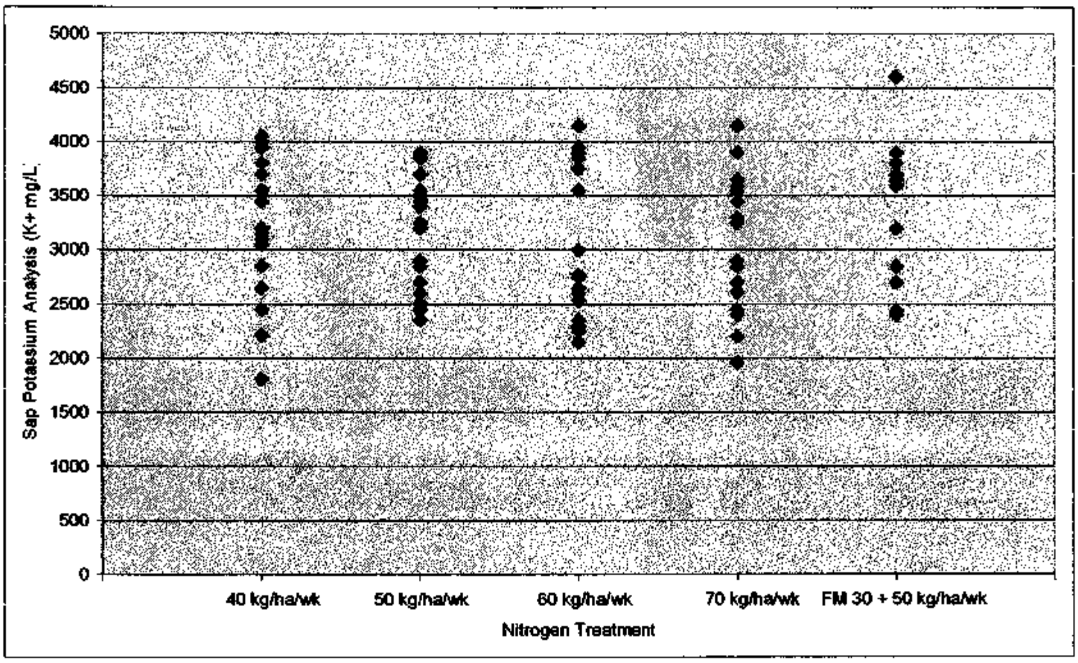

Figure 16: Effect of nitrogen rate on sap potassium levels over all sampling dates and rates of irrigation.

Potassium was not considered to be limiting to yield and the nitrogen and irrigation treatments did not have a significant effect on the sap potassium levels in the crop. Sap levels of K were highly variable at all rates of irrigation and nitrogen. All that can be inferred from the data is that sap levels in excess of 2000 mg/L are adequate for lettuce growth. An upper limit of 4000 mg/L K is possible without significant water stress.

Leachate measurement

Leachate volumes were measured on a weekly basis beginning 14 days after transplanting. Figure 17 compares the amount of water applied in each of the six irrigation treatments with the volume leaching past the root zone and collected in a lysimeter under treatment 60 kg N/ha/wk.

The results shown in Figure 17 demonstrate that all irrigation treatments leached some water past the root zone. On these free draining sandy soils, through-drainage is rapid and inevitable. As shown earlier, 65 % I was insufficient to grow a healthy and marketable crop. Not surprisingly, the 65% I treatment recorded the lowest amount of leaching with 27% of total water applied. At the other end of the spectrum, the 190% I treatments leached between 60% - 90% of the water applied. The difference in collection level between the two 190% I treatments was caused by the lysimeter recording the lower level being installed in the field for less time than all the others as described earlier in the methods section.

At irrigation rates below 190%, leaching percentages declined in direct proportion to rate of irrigation applied. In the optimum irrigation range from 100% to 140%, loss rates were of the order of 60%. The results suggest that losses of this order through leaching are unavoidable on these Karrakatta sands to ensure that a marketable crop is produced with the sprinkler irrigation techniques employed.

These results were obtained with a fixed watering schedule of two applications per day of variable duration depending on the previous day's evaporation. Leaching losses could be reduced further by better timing of irrigation, both in frequency and duration. This would need to be the focus of future work on improving efficiency of water utilisation.

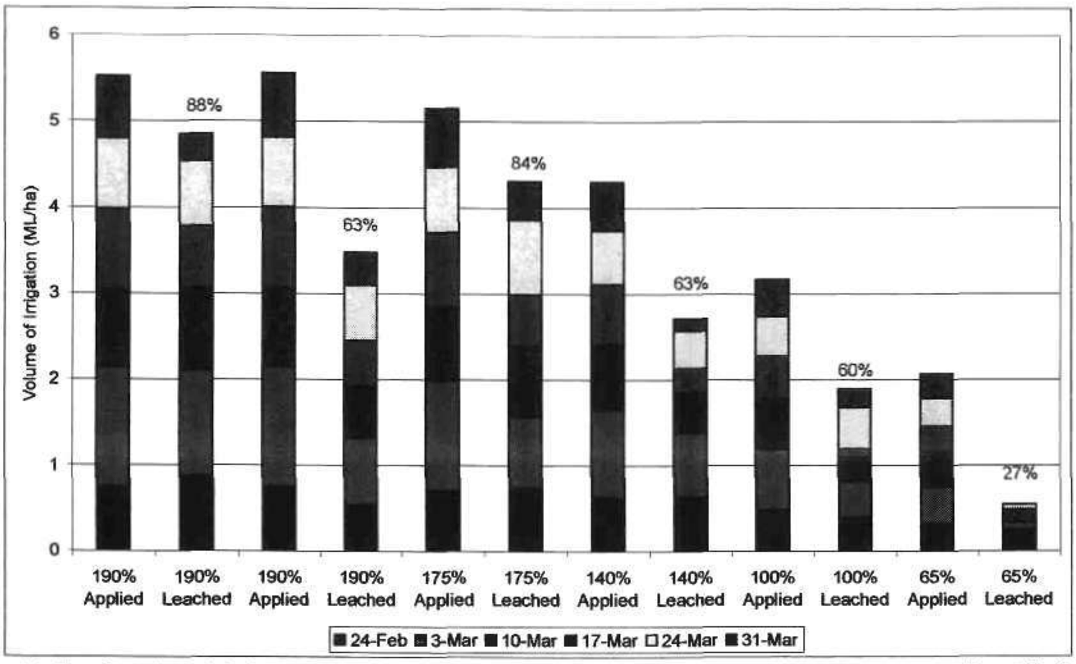

Figure 17: Total and weekly irrigation volumes applied and collected in drainage lysimeters. (60kg N/ha/wk).

An expected result of through-drainage is the leaching of fertiliser and in particular highly soluble nitrate. From Figure 18 it can be seen that the nitrogen treatment of FM30 + 50 kg/ha/wk leached the most nitrate past the crop root zone with a total of 230 kg/ha N recovered in the lysimeters at the 140% irrigation rate. Although this treatment resulted in the largest total quantity of nitrate leached past the root zone, it was not the highest in percentage terms of the total applied. The 50 kg/ha/wk N treatment, recorded the highest percentage leaching with 55% of the total applied leaching past the root zone, but this was only 165kg/ha N because a lower total rate was applied than FM30 + 50 kg/ha/wk.

At optimum irrigation and nitrogen rates for crop yield, losses of nitrogen were substantial as demonstrated by the 60 kg/ha/wk N treatment at 140% Epan. However, the other four lysimeters represented here had only been placed in the field immediately before the crop. They may therefore underestimate the true nitrogen loss rate from the treatments. It is also likely that even more nitrogen moved though the soil profile after harvest was completed but measurements of leachate ceased at harvest.

At the 3 March 1999 sampling, there was a large amount of nitrogen collected in the lysimeters under the FM30 + 50 kg/ha/wk treatment. This was 28 days after the fowl manure was applied to the plots. This indicates that a large amount of the nitrogen content of the manure had been nitrified by this time and was able to be leached past the root zone. This quantity constituted 59% of the total amount of N leached from that treatment over the course of its life.

Nitrogen leaching was not directly proportional to rate of nitrogen applied. This was partly the result of the lysimeter under the 60 kg/ha/wk rate being in place longer than the others, but it is likely that it was also the result of uneven water distribution along the plant rows. Rain gauges placed in the nitrogen treatments at a fixed distance from the sprinklers showed that irrigation rate was uneven along the rows of plants. This was an inherent weakness of the line source technique, which was unavoidable.

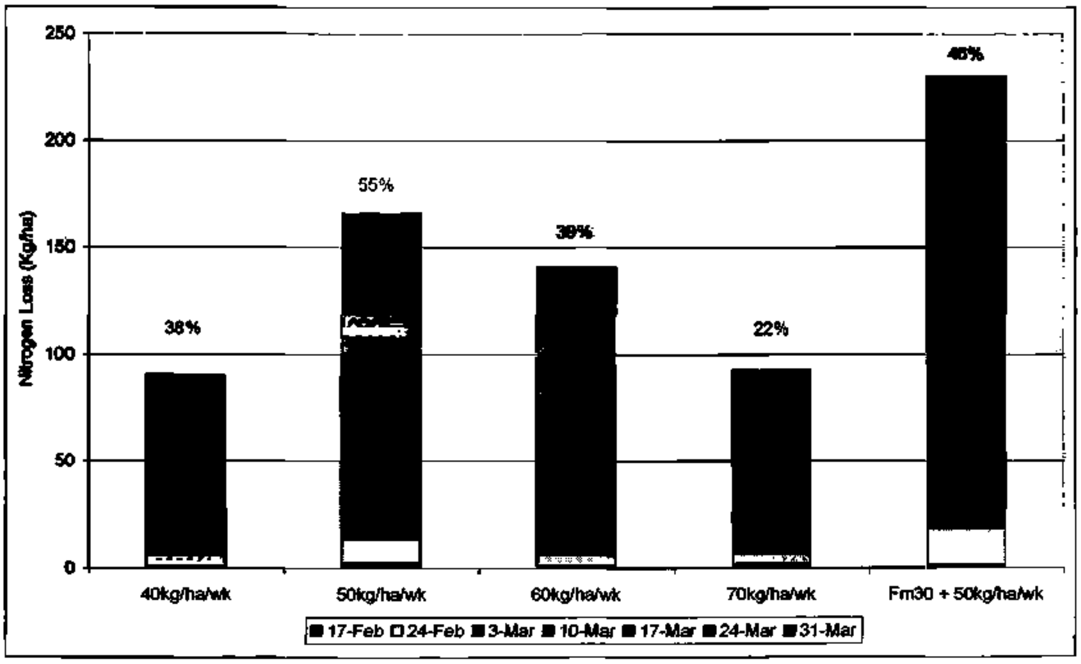

Figure 18: Total and weekly nitrogen level applied and collected (nitrate fraction) in drainage lysimeters - 140% Epan treatment.

Figure 19 shows that for all irrigation rates some nitrogen leaches past the root zone. Treatment 65% I only leached 2% of the nitrogen that was applied, but as indicated by the yield results this treatment is sub-optimal.

Both 175% and 190% recorded levels of around 50% of the total amount of nitrogen applied leaching past the root zone. This indicates that the plants were only able to access 50% or less of that applied. These treatments also produced sub-optimal yields due to excessive leaching.

Yield maximising treatments in the range 100% to 140% Epan only leached around 30% - 40% of the total nitrogen applied. These treatments are the best compromise between high yield and minimised water and nitrogen loss through leaching under the irrigation frequencies and duration's imposed.

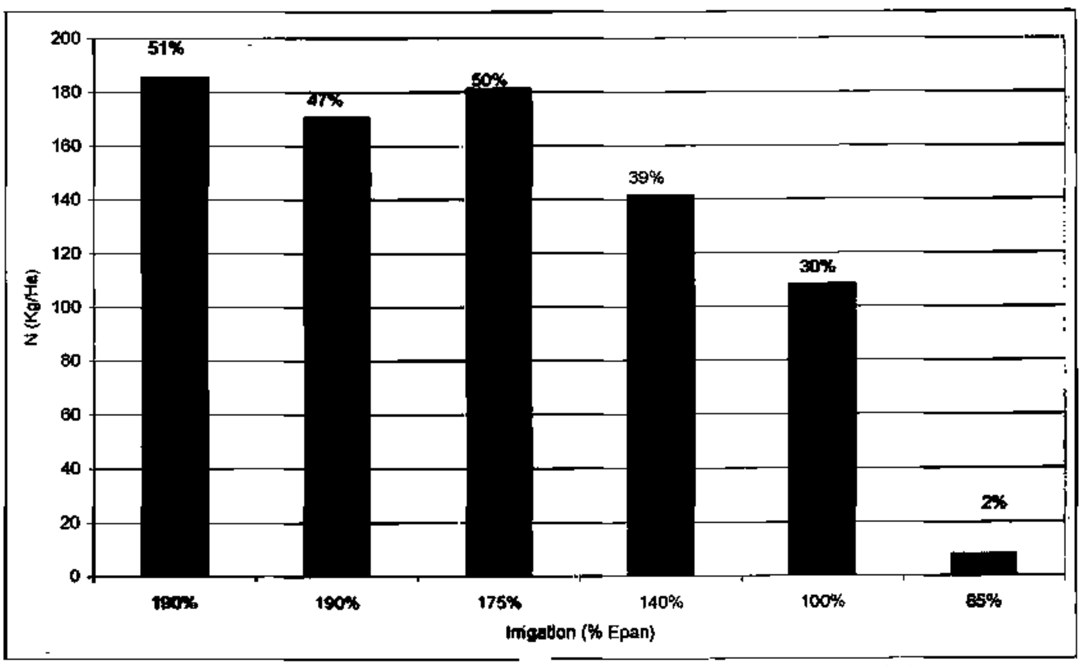

Figure 19: Amount of nitrogen leached over time vs irrigation treatment in the 60 kg/ha/wk treatment.

Soil moisture monitoring

Tensiometers were read on a weekly basis to monitor the soil moisture levels at 4 of the 6 Irrigation treatments over the life of the crop.

Figure 20 represents tensiometer readings from the week of the 24 February 1999 to the 3 March 1999. This figure shows a typical wetting and drying cycle for a 7 day period at a depth of 15 cm. The soil is saturated at zero kPa and approaching early water stress at around -8 kPa. Irrigation events each day are shown by vertical spikes on the graph. This soil monitoring technique would allow a grower to see whether there is sufficient water in and around the root zone of the crop and whether there is a need to irrigate.

Tensiometer monitoring showed that at 3 of the sites, the soil remained sufficiently wet to suggest that the lettuce were not under any water stress. The data from the 65% I treatment deviated from the other data indicating that in the first part of the week there was some plant water stress occurring.

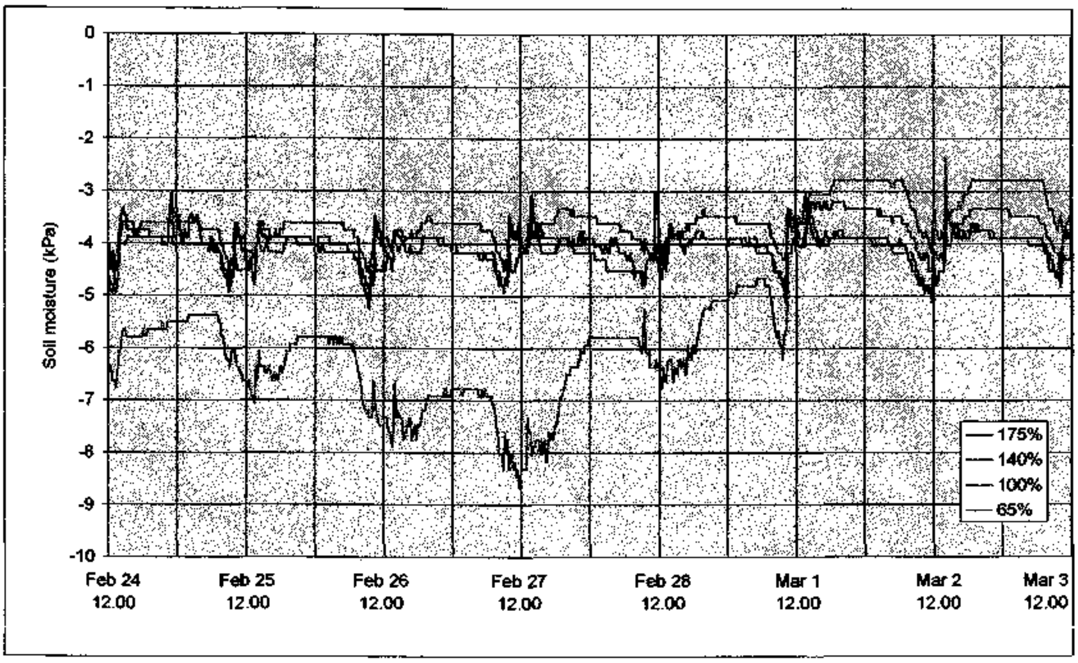

Figure 20: Tensiometer readings for four irrigation rates from 24 February 1999 to 3 March 1999 (15cm depth).

Figure 21 shows similar results to that of Figure 20 but at a depth of 30 cm. At this depth there was even more divergence between the 65% I treatment and the other three treatments. The 65% I treatment at this depth still showed plant water stress, but over a longer period. Once the soil had dried out at this depth, it took longer to recover after a period of cooler weather or increased irrigation rate. The other three treatments recorded sufficient soil moisture to indicate that the plants in these plots were not under any water stress.

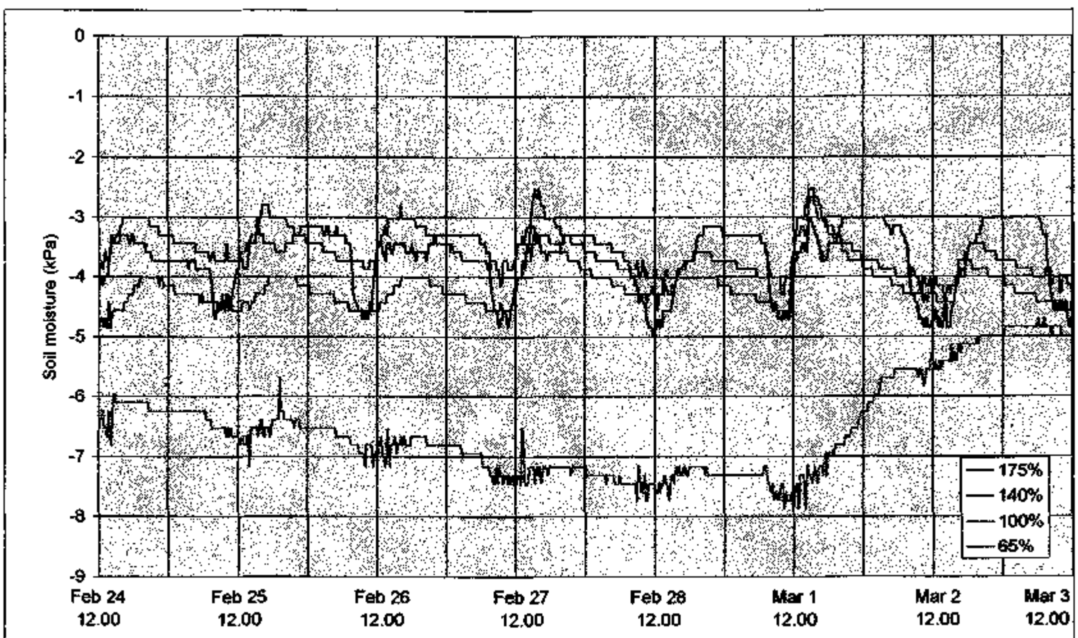

Figure 21: Tensiometer readings for four irrigation rates from 24 February 1999 to 3 March 1999 (30 cm depth).

Conclusion

The 'line source' irrigation technique used in this experiment provided the opportunity to predict the optimum combinations of irrigation and nitrogen fertiliser to maximise lettuce crop yield. The system and the method assumed overhead irrigation with sprinklers on a twice daily basis and nitrogen applications on a weekly cycle applied as a liquid solution of nitrogen, potassium and magnesium. The results are applicable to a summer transplanted 'iceberg' lettuce crop.

Taking into account these constraints, the yield maximising combinations of nitrogen and irrigation were consistently in the range 50-60 kg/ha/wk N with an irrigation rate commencing at 110% Epan for 14 days after transplanting and rising to 140% for the rest of the crop's life. The law of diminishing returns applied strongly to the nitrogen response with up to 25% of the total nitrogen applied being required to gain the last 5% of yield increase in the weeks soon after planting. Closer to harvest, this effect was less pronounced with a 15% increase in rate required to gain the last 5% of yield. This effect allowed for significant reductions in fertiliser rates if small reductions in yield could be tolerated by the grower.

Yield was far more sensitive to irrigation rate with small reductions in irrigation rate resulting in disproportionately large reductions in yield throughout the life of the crop. There was little opportunity for water savings below 140% Epan at most stages of growth.

Final harvest yield differences between treatments which had fowl manure applied before planting and treatments with the same rates of chemical fertiliser only could not be demonstrated. This suggests that fowl manure is not essential to produce maximum yield of lettuce on these soils despite their high nutrient leaching characteristics. Yield data from the 14 day sequential harvest suggested an advantage from fowl manure at that stage but the advantage could not be shown to be maintained to maturity despite an apparent positive effect on yields at slightly sub-optimal irrigation rates at day 35. This effect needs to be more thoroughly investigated in a future study.

Petiole sap analysis, conducted weekly, was used in conjunction with the yield data to determine an optimum sap nitrate range which would ensure maximum yield throughout the crop's life. This optimum range was determined to be 390 - 600 mg/L NO_3-N, over the life of the crop. Sap nitrate levels proved to rise in direct proportion to nitrogen rate applied but they were also highly sensitive to water stress, rising markedly above the optimum range when irrigation rates were sub-optimal. Sap nitrate was probably a better indicator of water stress than sub optimal nitrogen rates.

The rapid sap testing device, the RQFlex® meter proved to be accurate and reliable and a useful tool to monitor crop performance rapidly when used in conjunction with the standards derived in this study. For this technique to be meaningful strict adherence to optimum irrigation practice, timing of sampling, sampling method and testing procedure is required. It would be best done in commercial practice by a specialist but could be used by a grower with attention to detail.

Potassium and phosphate levels in petiole sap were also measured as a check that they were not limiting to yield. The results suggested that neither of these elements was limiting and sap levels of both were not affected by nitrogen rate. Low levels of irrigation were associated with slightly elevated sap potassium levels and reduced sap phosphate levels.

The adequate range for sap K was 2000 - 3700 mg/L and 300 - 400 mg/L for PO_4^{3-}. Levels of both elements were highly variable at the same rate of irrigation or nitrogen and the 'adequate range' concept is appropriate for interpreting sap levels of these elements. Duplicate tests with the RQFlex® meter showed that the variation was not a result of analytical technique but real differences in sap levels between plots over time.

Leachate measurements were taken on a weekly basis to determine the efficiency of the nitrogen and irrigation treatments. Irrigation rates in the optimum range of 110 - 140% were shown to have leached around 60% of the water applied on these free draining sandy soils. Sub-optimal irrigation rates still leached a large amount of applied irrigation and these plots did not produce marketable standard plants. The conclusion was reached that some leaching is unavoidable on these free draining sandy soils with overhead sprinkler irrigation even for sub-optimal treatments.

Nitrate nitrogen was also shown to be readily leached below the root zone for the optimal and higher irrigation rates. The optimum treatment of 50 -60 kg/ha/wk N resulted in 40 -50% of the total nitrogen applied leaching into the catchment lysimeter. Any treatments less than this optimum were unable to produce marketable yields and still showed evidence of leaching. The rate of loss of Nitrogen was in direct proportion to the amount of irrigation applied.

Tensiometers (Irrometer® LT) modified to continuously record soil moisture with a digital readout proved highly sensitive to changes in soil moisture status. They demonstrated that soil moisture levels in the range –3 to –7 kPa at 15 cm depth below the soil surface and in the root zone were associated with yield maximising treatments. These levels could be considered desirable targets for growers to use to ensure optimal irrigation rates were being applied. Tensiometers were considered to be suitable as a monitoring tool to ensure that irrigation schedules based on evaporation were doing what they should. They were considered to be of limited value as a scheduling tool in their own right due to the rapid fluctuation of soil moisture content during the course of a day and the narrow operating range between adequate soil moisture and water stress. They were also subject to variation due to siting within the root zone and were sensitive to associated equipment failure such as damage to cabling or battery discharge.

References

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2. Graham M, 1994. *Growing lettuce.* Department of Agriculture Western Australia Bulletin 4282.

Lettuce Cropwatch

4. Irrigation and Nutrition Case Studies

4.1. Adoption of Nutrient Management Practices - Case Study 1 - Nitrogen programmes for winter lettuce.

L. K Teasdale, D.R Phillips and D. G Gatter

Summary

A demonstration of fertiliser schedules derived from previous Medina lettuce research (Chapter 3) was established to compare against a typical grower program on a commercial lettuce crop. Other treatments examined included irrigation water polluted with different levels on nitrate nitrogen from past cropping and a liquid extract from fowl manure (5th Element®). From this demonstration it was determined that:

- Fertigation strategies developed for summer and autumn crops were equally valid for winter lettuce, but total fertiliser rates were greater because the crop grew for longer in winter.
- Fowl manure side dressings were not essential to maximise crop yield and could be substituted by regular applications of chemical fertiliser.
- Sap nitrate levels for maximum yield of winter lettuce (cv Oxley) were similar to those for other times of the year.
- Nitrate polluted groundwater can make a contribution to plant growth and needs to be taken into account when planning fertiliser programmes, but was insufficient to produce marketable crops at the levels in the range 9-16 mg/l NO_3-N.
- The 5th Element® device was able to extract nutrients from deep litter fowl manure but not essential nitrate nitrogen. This deficiency in performance would severely limit its commercial potential.
- Grower fertiliser programmes may underestimate crop nitrogen requirements close to harvest, compromising weight yield at harvest.
- As an extension technique, in-crop demonstration was successful in attracting grower interest in the results of research with more than 30 attending a field walk on site. However, the technique alone did not result in significant adoption of the new practices. For this to occur, a more personalised approach was considered necessary.

Introduction

During the commercial crop monitoring and research phases of this project, a number of issues arose which demanded further evaluation and demonstration to growers. These included:

- Uncertainty that fertiliser recommendations derived from research plots in irrigated autumn and summer crops would hold true in winter crops, with a different cultivar, high rainfall and leaching.
- A number of aquifers used for irrigating lettuce had been found during the course of crop monitoring to be polluted to varying degrees with nitrate nitrogen. The contribution these nutrients could make to crop growth, needed to be demonstrated to growers and taken account of in future fertiliser programmes.
- Government regulatory authorities were threatening to ban the use of untreated fowl manure for vegetable growing by the end of 1999 due to its contribution to fly breeding. Viable alternative nutrition strategies needed to be found and demonstrated.
- A commercial device called 5th Element® which the manufacturers claimed could extract the nutrients from fowl manure into a water solution suitable for fertigation came available for testing. The device offered an alternative way of using the nutrient content of fowl manure without the fly breeding side effect.

The main aims of this experiment were:

1. To test and demonstrate optimal nutritional research findings on a commercial crop.
2. To evaluate optimum fertiliser treatments derived in autumn trials for their suitability to winter lettuce.
3. To compare lettuce crop nutrition programmes, using only chemical fertilisers, with a typical grower programme including fowl manure.
4. To demonstrate the effects of nitrate polluted irrigation water from 2 sources on lettuce crop growth.
5. To evaluate the effects of the nutrient solution produced from the 5th Element® machine used according to manufacturers instructions on lettuce crop growth.
6. To assess the value of in-crop demonstrations as an extension technique for changing grower nutrient management practices.

Materials and Methods

A Wanneroo grower provided part of his commercial crop of lettuce (cultivar Oxley) approximately 54 m^2 in area as a trial crop to test the practicality of the new fertiliser schedules derived from Medina research. The trial was designed to compare different frequencies of chemical fertiliser over the life of a crop.

Six treatments were compared, 3 chemical fertilisers and 3 from other sources of nitrogen. The three chemical treatments were based upon optimal nutrition schedules derived from Medina research. These were given the treatment codes F1(1), F1(3) and F2.

The F1(1) treatment was applied once a week, F1(3) was the same total rate as F1(1) but was applied to the crop three days a week in split applications. Treatment F2 was based upon the optimum from Medina research but with higher rates to account for expected higher leaching rates in winter. This treatment was also applied three times per week.

Two treatments were polluted water samples (most likely contaminated by chemical fertilisers), one with moderate (W1) and one with high levels of nitrate pollution (W2). The third treatment was a liquid extract from fowl manure produced in the 5th Element® machine (5E).

The 5E extract was produced by placing fresh deep litter chicken manure which had been stockpiled under cover for at least three weeks into a metal box and lowering it into a water filled tank. The box was made of galvanised steel plate containing many small holes of about 1mm diameter for aeration. A small electric compressor attached to the box forced air through the contained fowl manure and out into the water solution as a stream of bubbles for 4 hours. A proprietary solution of micro-organisms was also added to the water at the commencement of aeration according to the manufacturers instructions.

The water source used for this test was later found to be polluted with nitrate. This water before the aeration treatment is hereafter designated as W2 and after it is denoted as 5E. Table 1 shows the results of the Fifth Element extraction process compared to polluted aquifer samples W1 and W2.

Table 1: Water Test Results from Fifth Element Treatment and other nitrate polluted water samples.

Sample	*NO_3-N mg/L*	*P mg/L*	*K mg/L*
W1	9	9.2	0.02
W2	16	0.04	6
(5E)	3	12	58
Fifth Element (5E) (after 6 weeks) in W2	< 0.6*	15*	

Tests conducted by Chemistry Centre (WA). * Results determined by handheld RQFlex® in AgWest laboratory.

The water solution before aeration (W2) contained higher levels of nitrate than after the aeration treatment (5E). The results suggest that the manure actually stripped nitrate from the polluted water over the period of aeration. It was postulated that the decline in nitrate level may be a result of aerobic decomposition of the manure in the 5E box. The 5E device was shown to extract phosphorus and potassium into the water solution over time with levels after 4 hours aeration rising to 12 mg/L and 58 mg/L respectively.

After the solution was prepared it was stored in drums for easy access at the trial site. A sample from the storage drum was taken after 6 weeks into the trial and tested for the nitrogen concentration. The result showed a decline in the concentration again and an increase in the phosphorous concentration. Thus the results obtained from this process did not result in the Fifth Element Fertigation system producing the product that it claimed.

This process was tested several times to determine the correctness of this outcome. All other tests recorded the same result with a decline in the nitrate concentration in the solution after the four hour aeration period and also when aerated for longer periods. Refer to table 2.

Table 2: Fifth Element results.

Sample	*Test 1 NO_3-N mg/L*	*Test 2 NO_3-N mg/L*	*Test 3 NO_3-N mg/L*
Before Aeration	20	24	13
After 4 hours aeration	<1	18	10
After 2 days aeration	<1		
2 weeks sitting covered	<1	<1	

The trial plot was situated at the end of a bed of the commercial crop of lettuce. This allowed the weekly comparison of the Grower's own practice (GO) on the remainder of the bed against the 6 different treatments. The trial plots were unreplicated. Chemical fertiliser plots were 9m in length and 4 rows of lettuce wide (1.5m) and the 3 other treatments were 3m long and 4 rows wide.

The seedlings were transplanted on the 24 June 1999. The soil type at the site was grey phase Karrakatta sand. Karrakatta sands have low volumetric water holding capacity typically around 10% v/v and little capacity for sustainable organic matter enrichment. They readily leach nitrogen and potassium but are capable of retaining adequate levels of phosphorus for crop growth.

Weekly leaf samples (20 recently matured or head wrapper leaves) from each trial plot and the surrounding commercial crop were taken from 28 July 1999 until the end of the crop to monitor sap levels of nitrogen, potassium and phosphorous. All sap samples were tested using the RQFlex® meter and Merckoquant test strips. Results from these tests were compared to standards derived from the Medina research.

A new type of mini-lysimeter was tested on site to get an estimate of nutrient leaching in the field plots. These were buried underneath the trial plot and the grower's commercial crop at planting. No leachate was recorded throughout the life of the crop, and it was concluded that the catchment area of these smaller models was not sufficient for this type of trial and some modifications to design were required for future work.

Site

The site was typical of lettuce production areas on the Swan Coastal Plain and readily accessible for a future field day. A soil composite sample was taken of the area prior to transplanting. The results are shown in Table 2.

Table 3: Soil test results from site before transplanting (29 June 1999).

Nitrate Nitrogen (+)	5 mg/kg
Phosphorous (*)	97 mg/kg
Potassium (*)	18 mg/kg
pH (by $CaCl_2$)	6.70
pH (by H_20)	7.60

* Modified Colwell (1963) method, by Rayment and Higginson (1992).
\+ Method by Rayment and Higginson (1992), with exception of 1M KCL rather than 2M KCL as the extracting agent.

From first principles, these results suggested that soil phosphorus levels were adequate for at least one crop of lettuce and no supplementary phosphorus was applied to the trial site before planting. Nitrogen and potassium were both considered to be insufficient without supplementation.

Irrigation

All six trial plots were irrigated using the same methods as the surrounding commercial crop, using an overhead sprinkler system with risers at 6m x 6m spacing. Trial plots received additional watering of between 2 - 6mm of irrigation per week during fertigation. The surrounding commercial crop also received additional water when fertigation was used in the grower's schedule.

Nutrition

The method of application of fertiliser used was to simulate fertigation with a water solution of nutrients at the appropriate frequency of application for the particular treatment. At each application, the nutrient solution was watered over the top of the growing crop with the equivalent of 2mm of irrigation through watering cans. The solution was not washed off the leaves with nutrient free water after application. Treatments which received 3 applications per week got 6mm extra irrigation after week 6 as a result of the treatment and the 'once per week' application received 2mm more than the grower's own treatment throughout. The weekly fertiliser applications are shown in Table 4.

Table 4: Weekly Nitrogen fertiliser treatments (treatments F1 and F2).

Week	*Treatment F1(1) N kg/ha/wk*	*Treatment F1(3) N kg/ha/wk*	*Irrigation (mm)*+*	*Treatment F2 N kg/ha/wk*	*Irrigation (mm)**
1	15	15	2	15	2
2	15	15	2	15	2
3	15	15	2	35	2
4	35	35	2	35	2
5	35	35	2	35	2
6	35	35	2	55	6
7	35	35	2	55	6
8	35	35	2	55	6
9	35	35	2	55	6
10	35	35	2	55	6
11	35	35	2	55	6

* Volume of irrigation applied to distribute fertiliser via fertigation.
+ This volume of irrigation was used for both F1 (1) and F1 (3).
Fertiliser that was applied to the plots consisted of Ammonium Nitrate, Potassium Nitrate and Magnesium Sulphate (Espom Salts).

Temperature

The maximum and minimum air temperatures, daily Epan and rainfall during the season of the crop (24/6/99 - 8/9/99), were recorded by the Bureau of Meteorology. (See Figures 1 and 2).

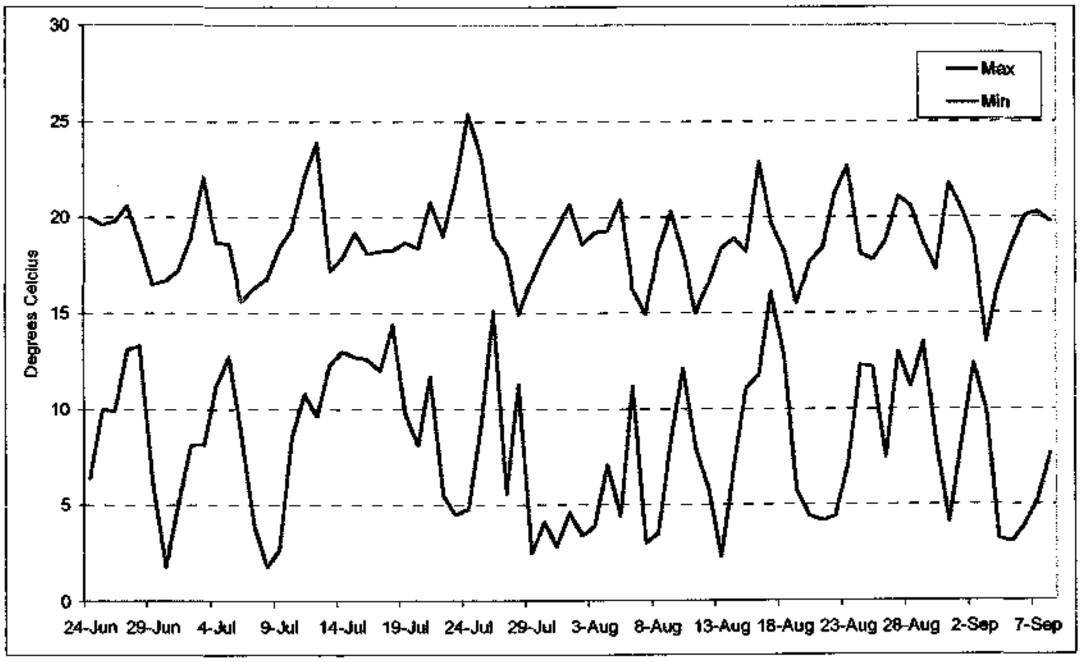


Figure 1: Maximum and Minimum Temperatures during the life of the crop (24/6/99 - 8/9/99).

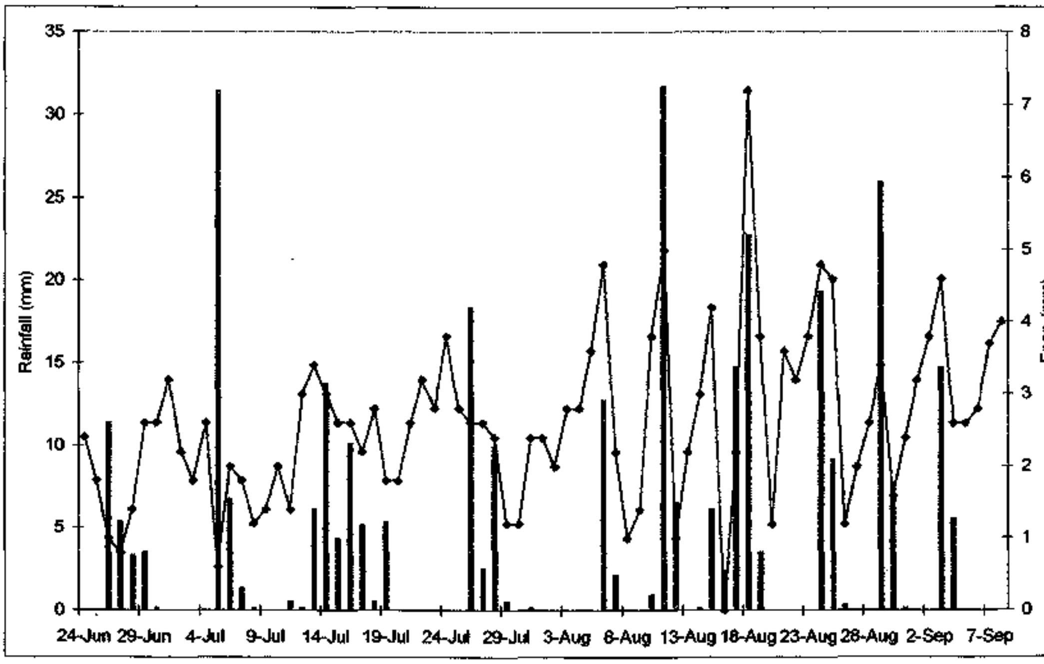


Figure 2: Daily "A Class" pan Evaporation and Rainfall during the cropping period (24/6/99 - 8/9/99).

Data Recording

For each week during the life of the crop (24/6/99 - 8/9/99) sap levels of nitrogen, phosphate and potassium were recorded from the RQFlex® test. At harvest, a random sample of 12 representative lettuce heads was harvested and weighed from each treatment.

Results

Petiole Sap Nitrate Analysis

The recommended nitrate sap standard for the life of the crop (Medina research) was compared to levels recorded for the 3 chemical treatments, the moderately polluted water treatment and the grower's crop treatment. These results are shown in Figure 3 below.

The grey shaded area of the graph was derived from Medina research in 1999 and represents the optimum sap nitrate range for a healthy summer lettuce crop. The graph shows that the three chemical fertiliser treatments, F1(1), F1(3) and F2 were above or near the top end of the desirable range for most of the crop's life. The Grower's Own (GO) schedule also followed this pattern until around Week 8 (18 Aug.) after which the nitrate levels dropped well below the optimum level for a healthy crop. It was notable that Fowl Manure was banded between the crop rows of the Grower's Own treatment on 14th July 1999.

W1 was the treatment which received moderately polluted water, daily throughout the life of the crop. During Week 6 (4 Aug) one application of the GO treatment was inadvertently applied to all plots as a banded application of 250 kg/ha Nitraphoska®. This resulted in a rise in sap nitrate levels during Weeks 7 and 8 (11 Aug to 18 Aug) for the W1 treatment, followed by a steep decline to sub-optimal levels thereafter for W1 and GO treatments.

All other treatments were also affected by the additional fertiliser application but did not show as large an increase in sap nitrate levels as the W1 treatment. The other treatments were receiving 35kg/ha/wk of nitrogen and therefore the extra 30 kg/ha N contributed by the Nitraphoska® had a lesser relative effect on sap levels than that recorded for the W1 treatment. Statistical analysis showed that there was no real significant difference between the sap levels for the 3 chemical fertiliser treatments and GO at these dates ($p \leq 0.23$).

During week 8 (18 Aug) sap levels for the F treatments started to diverge because F2 had been receiving a higher rate of nitrogen (55/kg/ha/wk N) for the preceding three weeks. These levels could not be shown to be significantly different however.

The GO schedule dropped to the lower half of the optimum range by week 9 (25 Aug) whereas the 3 chemical treatments remained at the top and just above the range. Week ten showed a rise in the 3 chemical treatments significantly higher than the optimum range while the GO schedule fell below the optimum. At harvest, the GO schedule recorded levels similar to the previous week and the chemical treatments dropped slightly again but were still recording levels within the optimum range.

The sap nitrate results were also statistically analysed to determine whether there were any significant differences between them. The comparison of F1, F1(1) and F2, throughout the life of the crop showed that there was no significant difference between the sap nitrate levels of these three treatments over the trial period. ($p \leq 0.23$).
It was also found that there was no significant difference ($p \leq 0.36$) between the GO and the three chemical treatments throughout the life of the crop.

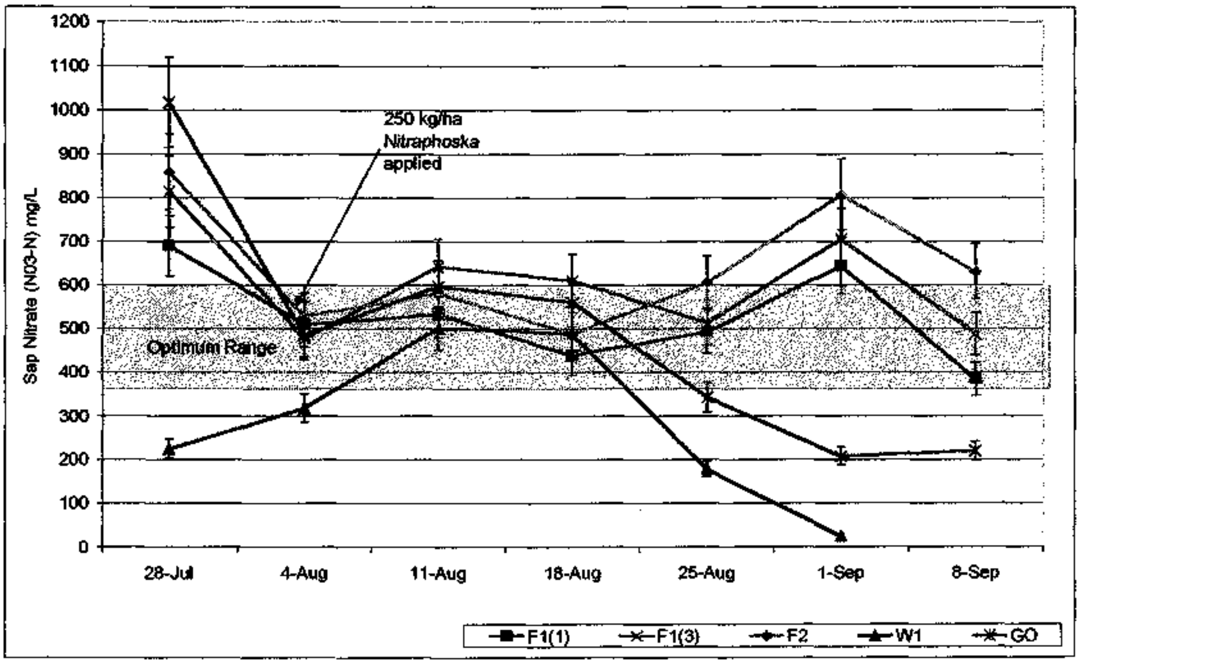


Figure 3: Sap nitrate profiles over the life of the crop for the chemical fertiliser treatments (F) compared to the growers own treatment (GO), water control (W1) and the Medina optimum range.

Sap nitrate levels for the two other treatments within this trial, The Fifth Element (5E) and highly polluted water (W2) were also monitored over the crop's life. These levels are compared to W1 in Figure 4.

The two nutrient enriched water samples gave similar results throughout the life of the crop, remaining sub optimal for most of the period except for 2 weeks around 11 Aug-18 Aug, following the Nitrophoska® application in week 6. The Fifth Element Treatment followed a similar trend but did not drop off as dramatically as W2 and W1. After week 9, the extra fertiliser that was applied had been used by the crop or had leached past the root zone, and this is shown in the falling sap nitrate levels.

Although this sap analysis showed that the recommended fertiliser schedules exceeded the optimum range, this is not the only way to measure crop health. Other factors such as water stress were also shown to affect sap nitrate level in the Medina research. With this in mind a visual interpretation of crop growth was made to assess crop performance.

The 3 chemical fertiliser treatments were all of a healthy green colour and a good size throughout the life of the crop. The 5E and W treatments were visually inferior to the other treatments and the GO despite recording optimal sap levels for a short period in the middle of the crop's life. By Week 8 these treatments had fallen behind in size and also in colour, which was matched by the decline in the sap nitrate levels.

The sap nitrate results of the nutrient enriched water samples and the Fifth Element treatments were also statistically analysed to determine whether there were any significant differences between them. There were no significant differences between the three non-chemical fertiliser treatments for sap nitrate levels throughout the life of the crop ($p \leq 0.54$). Comparing the two polluted water treatments, it was found that there was no significant difference ($p \leq 0.52$) between W1 and W2 throughout the life of the crop. It was also found that during the life of the crop there was no significant difference between the W1 sample (used in this trial as the control) and the Fifth Element treatment ($p \leq 0.81$).

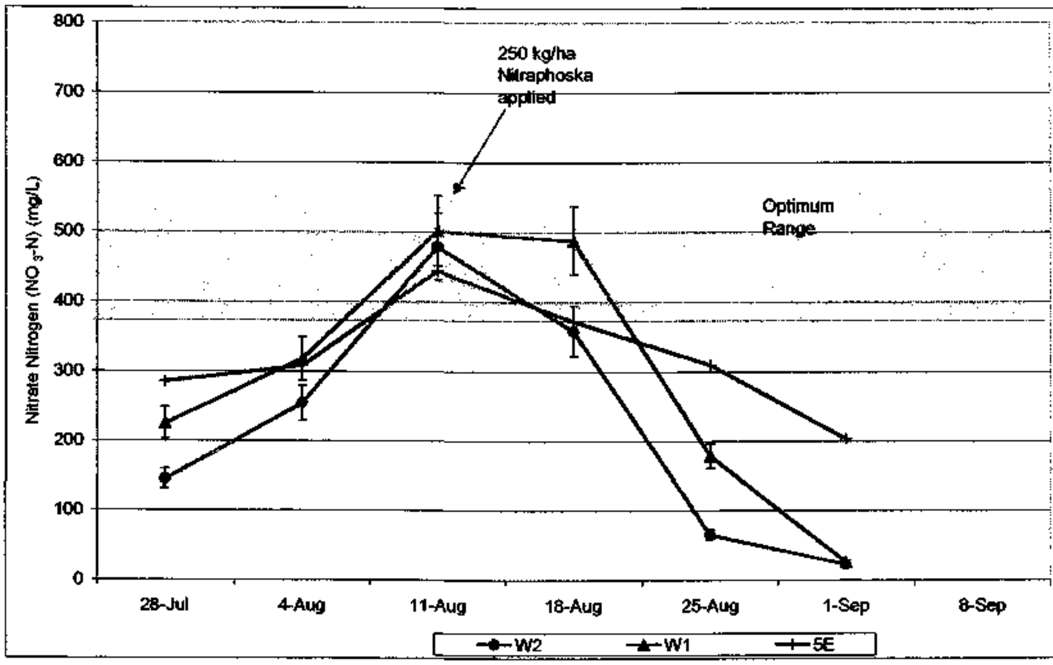


Figure 4: Sap nitrate profiles over the life of the crop for the two nitrate enriched water samples and the Fifth Element Treatment.

Phosphorous Sap Analysis

Sap Petioles were also analysed for phosphate levels during the life of the crop using the RQFlex® equipment. During the 7 week monitoring period, all treatments fluctuated in the range of 250 - 500 mg/l phosphate which conforms with results from Medina research. There was no significant difference between the chemical fertilisers and Grower's Own ($p \leq 0.49$) sap levels despite the grower using phosphorus containing fertilisers on his crop on more than one other occasion. The additional Nitraphoska® that was applied to all plots equated to 6kg/ha of elemental phosphorous, but this did not visually affect any of the F treatments which were planted without applying phosphorus to the soil, and more was sidedressed while the crop was growing (Figure 5).

Phosphate sap levels were also statistically analysed to determine any differences between treatments. No significant difference ($p \leq 0.48$) was determined between all seven treatments throughout the life of the crop. This result indicates that there was a sufficient amount of soil phosphorous present at planting that was available to the lettuce crop. Therefore it is fair to assume that the phosphorous was not a limiting factor in the growth of the lettuce crop in each treatment.

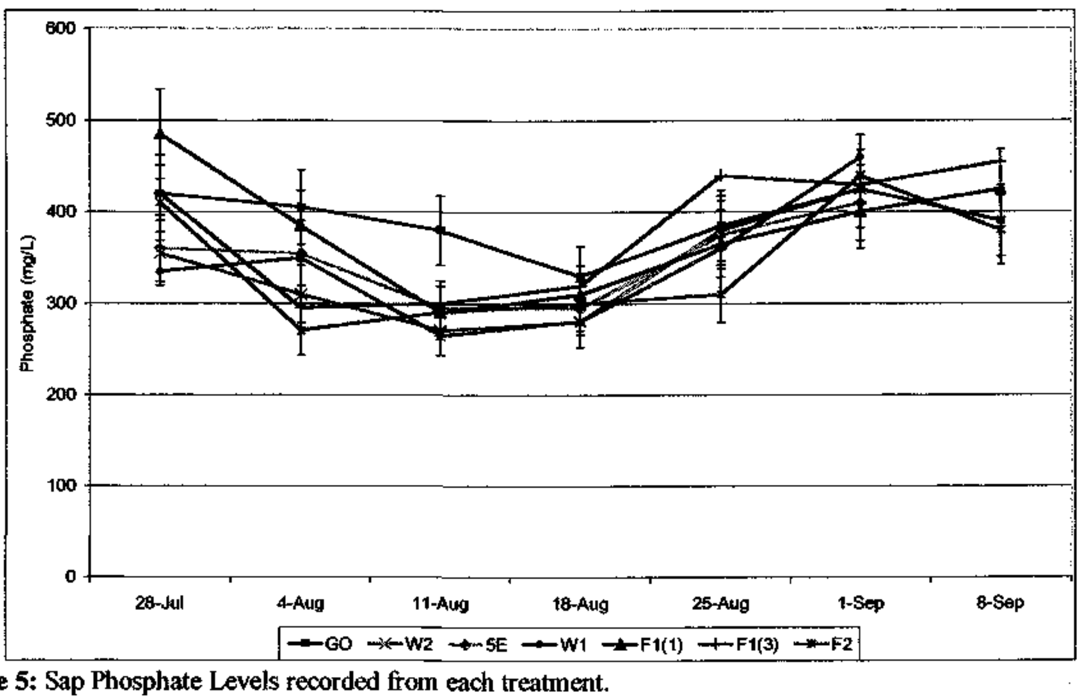


Figure 5: Sap Phosphate Levels recorded from each treatment.

Potassium Sap Analysis

Potassium sap levels were also monitored throughout the crop and these are depicted in Figure 6. The potassium that was added to the F treatments equates to 30kg/ha/wk of elemental potassium throughout out the life of the crop. This rate was applied to the 3 chemical fertiliser treatments to ensure that this nutrient was not limiting and that nitrogen would be the only nutrient effecting the performance of the crop.
The soil test showed 18mg/kg potassium which was considered to be low for a lettuce crop on sandy soils. All sap treatments fell within the range of 3000 - 6000 mg/l potassium which is similar to that of previous Medina research.

Potassium Sap levels were also statistically analysed to determine whether potassium had an effect on the treatment results and outputs. There was little difference between all of the treatments at the start of the monitoring period, however as the crop matured the treatments separated out showing some significant differences ($p \leq 0.04$). This main difference occurred between the F2 treatment and the growers own practices, which recorded a significant difference between them during the second half of the trial ($p \leq 0.04$). However there was no significant difference recorded between the three chemical treatments ($p \leq 0.12$) indicating that the 30kg/ha/wk of elemental potassium was not limiting to the lettuce growth in these three treatments.

The GO treatment by the final two weeks of monitoring registered the lowest potassium level. This was followed closely by the highly polluted water (W2) and then the Fifth Element treatment (5E). W1 recorded higher levels than all these three treatments.

The three chemical treatments were a bit more spread out with F2 recording the highest level followed by F1(1) and then F1(3). All three were above the 4000 mg/l level which is considered to be non-limiting.

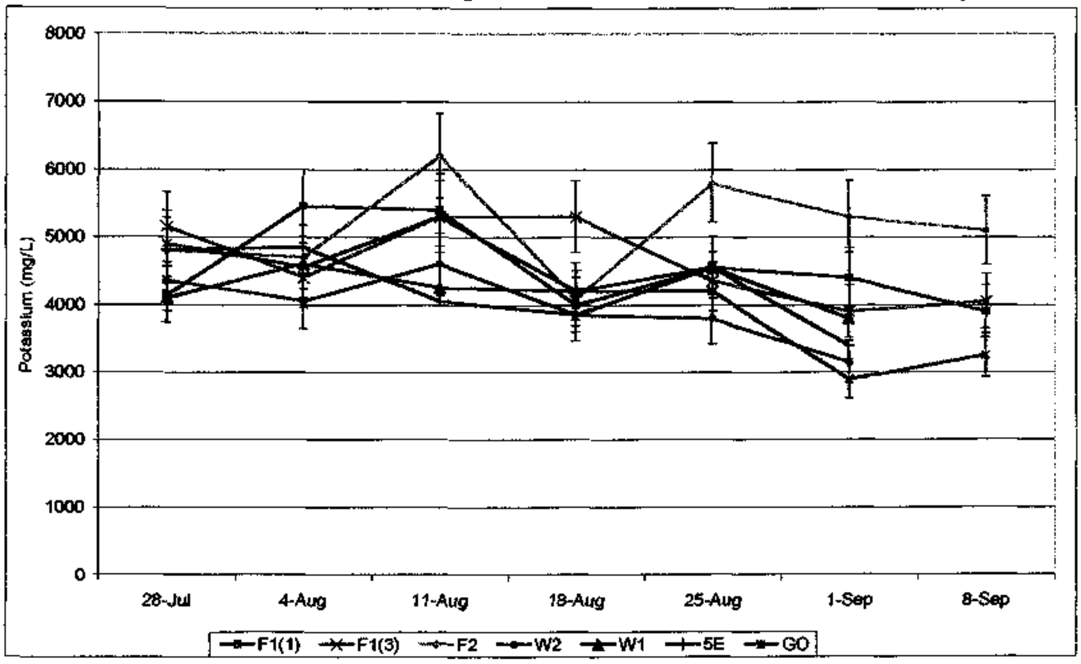


Figure 6: Sap Potassium levels recorded from each treatment.

Yields

The final yields at harvest were also recorded to determine the most beneficial treatment for the life of the crop. The three chemical fertiliser treatments, F1(1), F1(3) and F2 gave yield increases of 19%, 16% and 18% compared to the grower's practice (GO) but there was little visual difference between them. There were minimal visual differences between the 3 chemical treatments and only small percentage differences in weight. There was no apparent advantage in the increased nitrogen rates between the F1 and F2 rate, nor could any significant advantage be found between applying fertiliser 3 times per week and only once. The only note of caution from the work was a higher level of *Sclerotinia minor* in the F1(1) treatment than others. This may have been a chance occurrence as the disease was present throughout the crop or it may have been a consequence of plant stress from the high osmotic strength of the fertiliser solution applied to the plants without a 'washoff'. This would not occur in commercial scale fertigation because the dilution factor in irrigation water would be greater.

The three other chemical treatments, 5E,W1 and W2 did not yield well which was expected from their visual appearance. These three plots fell behind the rest in both colour and size from an early stage. Also the sap nitrate analysis (Figure 1) gave levels that suggested that these plots would not produce a marketable lettuce crop. Yields of the two nitrate enriched water treatments were in direct proportion to nitrate level, with W2 yielding more than W1. The 5E treatment yielded better than could be explained by its nitrate content alone, suggesting that it may have also contained some nitrogen in other forms.

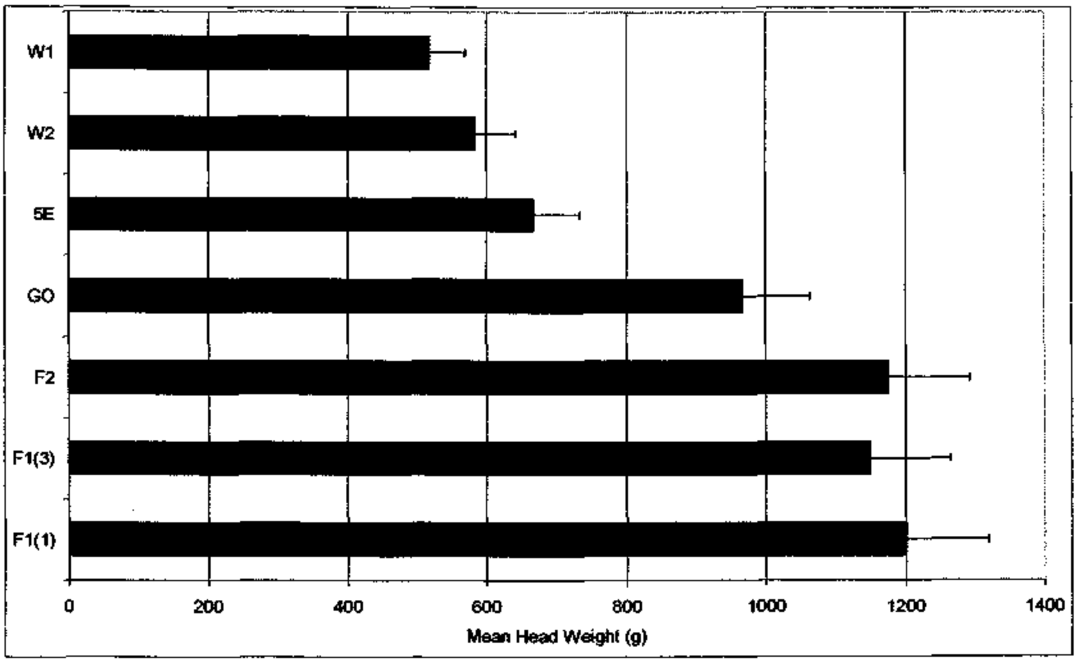


Figure 7: Mean head weights of treatments (12 heads) at Harvest (11 weeks after transplanting).

Conclusions

As the yield results show there was no significant difference between all three chemical treatments, with only 130gms separating the heaviest from the lightest harvest weights. This illustrates that the F1(1) treatment was a sufficient fertiliser recommendation to grow a marketable lettuce crop. This treatment had a total of 325kg/ha of elemental nitrogen applied over the life of the crop (11 weeks) with applications once per week only.

This conclusion that F1(1) was the most suitable recommendation was confirmed by the results of the Petiole sap analysis tests. There was no significant difference between the Grower's own schedule and the three chemical treatments ($p \leq 0.36$) and as there was also no significant difference between the three chemical treatments ($p \leq 0.23$). Treatment F1(1) is preferred because it is the lowest cost option of the three. It was not possible to assess the cost effectiveness of the grower's schedule because an accurate programme could not be obtained.

The results demonstrate that at least equivalent yields can be obtained from fertiliser programmes that do not include applications of fowl manure, which was the case for the GO treatment. In fact, visual observations suggested that late applications of chemical nitrogen may be more important than previously realised in ensuring high yield. The GO treatment suffered from sub optimal petiole sap levels after week 9, because fertiliser applications ceased at row closure. This effect was visually evident at harvest by a loss of green colour and a trend to lower yield than the F treatments.

Results from the nitrate enriched water samples (W1 and W2) showed that the nitrate content of these made a contribution to crop growth in proportion to the nitrate concentration and this effect needs to be taken into account in planning optimal fertiliser programmes.

There was also no significant difference in yield between W1 and the Fifth Element treatment ($p \leq 0.81$) and both produced unmarketable lettuce. The conclusion reached was that the potential of this product as a source of inexpensive nutrients is too low to justify the time and expense of producing the liquid extract. This is also confirmed by the petiole sap analysis where the results were always below the optimum range.

The observation that there was no significant difference between the treatments in the levels of phosphorus in petiole sap confirms that there were sufficient amounts of phosphorous already present in the soil (97 mg/kg) to grow the crop and therefore was not a limiting factor.

The potassium results also showed no significant difference between all 7 treatments which indicates that the weekly application of 30 kg/ha was sufficient for sustaining the plant's growth throughout the trial and was not limiting to yield.

4.2. Adoption of Nutrient Management Practices - Case Study 2 - Nitrogen programmes for winter lettuce.

L. K Teasdale, D.R Phillips and D. G Gatter.

Summary

This demonstration tested 'Best Bet' fertiliser programmes adapted from Medina research results alongside the grower's own nutritional practices to determine the practicality of these standards in the commercial environment.

The results showed that the grower's own programme which included both fowl manure application and mineral fertiliser produced a healthy marketable crop which met or exceeded the sap nitrate guidelines throughout its life. The 'Best Bet' programme using mineral fertilisers only, applied on a 7 day cycle by a simulated fertigation method produced a crop which was virtually indistinguishable in yield or appearance from the growers own practice.

The same programme applied to the crop by mechanised means on a weekly but less regular schedule produced a market standard crop with mean head weights approximately 10% less than the grower's own schedule. The difference between the mineral fertiliser treatments was thought to be the result of less even application of granular fertilisers with mechanised equipment and less precise timing of applications than that achieved by the simulated fertigation method. Heavy rain occurred throughout the trial period and this was also thought to have disadvantaged the granular fertiliser treatment through leaching.

The results showed that the sap nitrate guidelines developed through research were a reliable indicator of crop yield and that winter lettuce could be grown successfully with mineral fertilisers only, as long as applications were regular and adequate rates were applied.

Phosphorus and potassium fertilisers were shown to be non limiting to yield and the sap testing procedure was shown to be a quick and reliable method to confirm this.

Introduction

The nutritional practices employed by growers for commercial vegetable production on the sandy soils of the Swan Coastal Plain are largely based on their experience. From previous Medina research, an optimum schedule for fertiliser application (Best Bet) has been developed under experimental conditions. These nutritional guidelines needed to be tested further on commercial crops as a first step in the commercial adoption process.

The main aims of this experiment were:

1. To implement nutritional research outcomes on a commercial crop.
2. To evaluate optimum fertiliser treatments for winter lettuce.
3. To grow a marketable lettuce crop with only chemical fertilisers.

Materials and Methods

A commercial crop of lettuce (cultivar Assassin) approximately 2400m^2 in area, was provided by a Wanneroo grower as a test site for nutrition practices derived from Medina research. The site was divided into three sub blocks, two of 1200 m^2 and one of 27m^2 area. The grower applied his own fertiliser program on a weekly basis to one of the 1200m^2 areas, for the life of the crop (Growers Own - GO). This included a pre planting application of fowl manure at 10m^3/ha. To the other 1200m^2, the grower applied the recommended optimum schedule to the crop using methods of application that were convenient to him but excluding any fowl manure application (Recommended Grower - RG). On the 27 m^2 site, the recommended schedule was applied weekly by project staff using simulated fertigation as the sole application method (Trial - T).

Lettuce seedlings were planted on the 28th June (GO) and 9th July 1999 (RG and T). The soil type for the trial was Grey Karrakatta Sand, which characteristically has a low nutrient and water holding retention ability.

Leaf samples (20 leaves) from all three sites were collected on a weekly basis after the 12th August 1999 to monitor petiole sap nitrate, phosphate and potassium. These were recorded and compared to the standards determined from previous Medina research.
A new type of mini lysimeter was tested on this site to estimate nutrient leaching in all treatment plots. These were buried beneath the all treatments at planting. No leachate was recorded throughout the life of the crop, and

it was concluded that the catchment area of these smaller models was not sufficient for this type of trial and some modifications need to be made.

Soil

The soil type for the site was Karrakatta sand, which have a low water volumetric capacity of 10% v/v and little potential for sustainable organic matter enrichment. The site was typical of lettuce production areas on the Swan Coastal Plain.

Irrigation

All trial plots were irrigated using the same method as the surrounding commercial crop, using an overhead irrigation sprinkler system with 12m x 12m riser spacings. The trial plot received an extra 2 - 6mm water per week in the process of applying fertiliser treatments.

Nutrition

The recommended fertiliser schedules for RG and T are shown in Table 2.

Table 2: Weekly Recommended Fertiliser Schedules.

Week	*RG N kg/ha/wk*	*Method of Application*	*Trial N kg/ha/wk*	*Method of Application*	*Extra Irrigation to apply treatments (mm)*
1	15	Broadcast	15	"Simulated Fertigation"	2
2	15	Broadcast	15	"Simulated Fertigation"	2
3	35	Band	35	"Simulated Fertigation"	2
4	35	Band	35	"Simulated Fertigation"	2
5	35	Band	35	"Simulated Fertigation"	2
6	55	Fertigation	55	"Simulated Fertigation"	6
7	55	Fertigation	55	"Simulated Fertigation"	6
8	55	Fertigation	55	"Simulated Fertigation"	6
9	55	Fertigation	55	"Simulated Fertigation"	6
10	55	Fertigation	55	"Simulated Fertigation"	6
11	55	Fertigation	55	"Simulated Fertigation"	6

The fertilisers used in this trial consisted of ammonium nitrate as the nitrate source, Potassium sulphate 30kg/ha/week (K) and Magnesium sulphate 50kg/ha/wk.

Yield

The Growers Own treatments was harvested on the 17/9/99 and the Recommended Grower (RG) and the Trial (T) were harvested on the 21/9/99. Four replicates of 6 heads were harvested in the Growers Own treatment and 3 replicates of 8 heads were harvested in the RG and T treatments and their average head weight were recorded.

Temperature

The maximum and minimum temperatures, daily EPan and rainfall during the life of the crop (9 July 1999 - 21 Sept 1999), were recorded by the Bureau of Meteorology (see Figures 1 and 2).

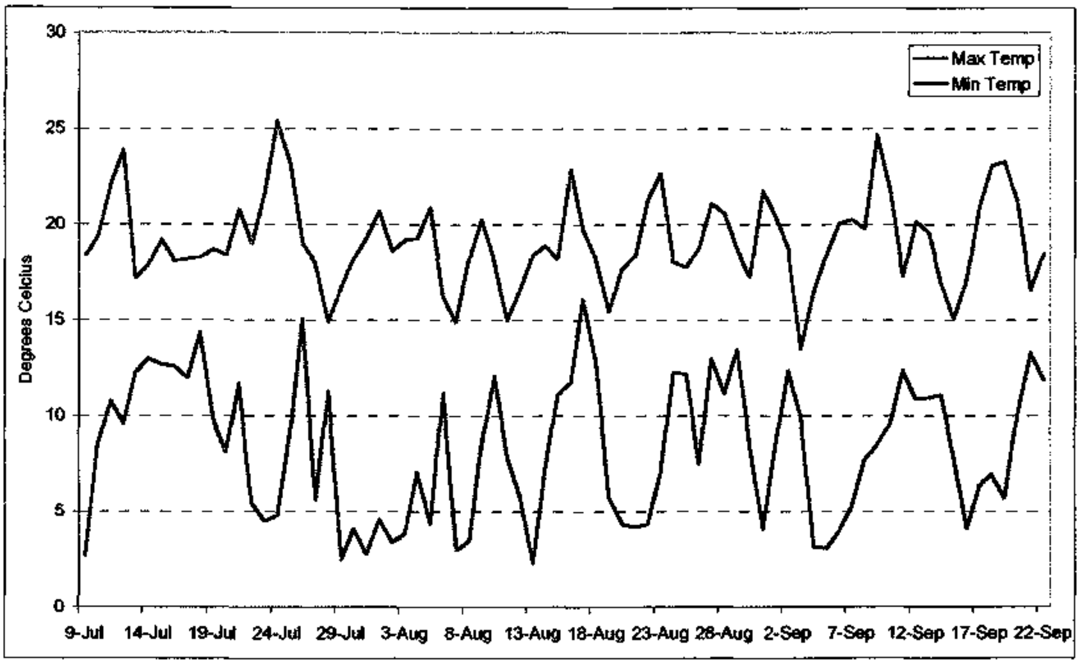


Figure 1: Maximum and minimum temperatures during life of the crop (Source: Bureau of Meteorology).

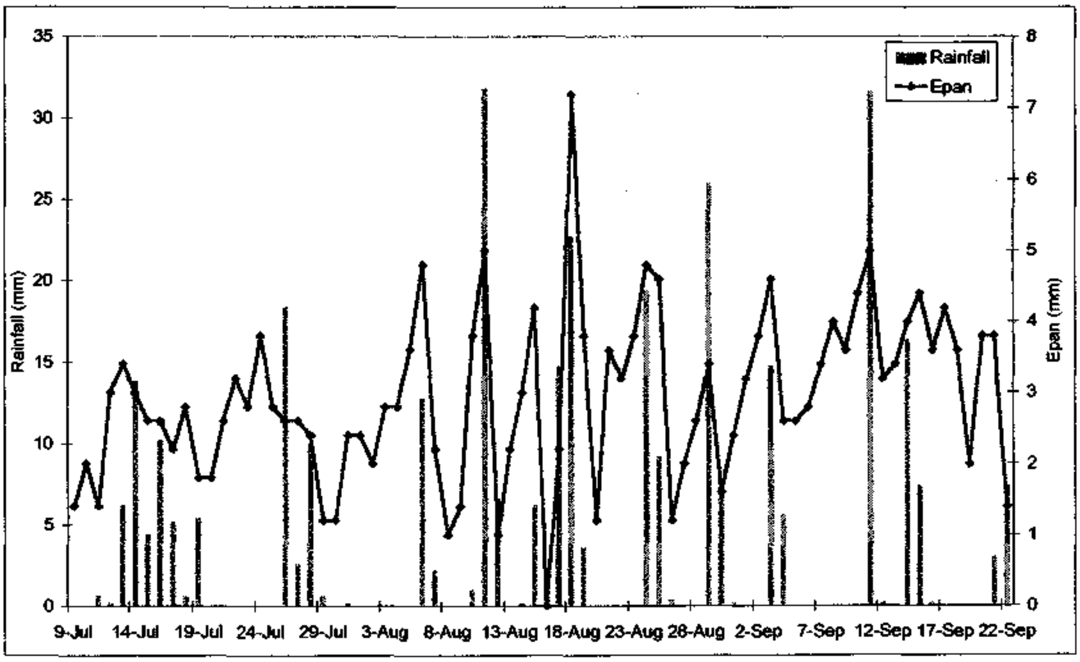


Figure 2: Daily Rainfall and Evaporation Pan Replacement (Epan) during the life of the crop (Source: Bureau of Meteorology).

Data Recording

For each week during the life of the crop (28/6/99 - 21/9/99), the following were recorded:

1. Petiole sap levels of nitrogen, phosphate and potassium.
2. Mean Head Weight at harvest.

Results

Petiole Sap Nitrate

Results of sap monitoring are shown in Figure 3 below. The GO treatment was 11 days older than the other treatments because it was planted on the 28th June and the other two treatments were planted on the 9th July. Therefore at the start of the petiole sap monitoring period, the GO treatment was seven weeks old and probably receiving higher rates of the Growers Own fertiliser program, while the T and RG plots were five weeks old and were still receiving the medium 35 kg/ha/wk N rate.

At the start of the monitoring period, all three treatments were recording similar sap nitrate levels of around 500 – 700 mg/L NO_3-N, which is slightly higher than the recommended level.
During the period 12th - 18th August, sap nitrate levels in the three treatments diverged, with GO recording levels in the upper part of the optimum range. The T and RG treatments started their first week of 55kg/ha/wk N at this time, and the fertigated T treatment recorded levels higher than the optimum range. Conversely the RG treatment which was receiving the same amount of nitrogen but in a granular broadcast form, recorded a value in the lower end of the optimum range. Heavy rainfall fell during this period, and this may have been the cause of the decline in sap nitrate in the RG. The fertiliser for this treatments was applied on 16th August and in the next two days there was heavy rainfall, probably causing the fertiliser to leach past the root zone.

During the next week (19th - 25th August), RG sap levels dropped below the optimum range, whereas the GO and the T treatments rose above the optimum level. Both the T and RG plots received the same amount of fertiliser during this period. During this period, 55mm of rainfall fell. Fertiliser was applied to the RG plot on the 23rd August 1999, when approx 20mm rainfall fell. This probably would have caused some of the fertiliser to leach past the root zone.

The T treatment was not as badly affected by the rainfall because the fertiliser was applied on the 19th August 1999, the week before heavy rainfall was recorded. The GO plot was also not as severely affected even though the fertiliser was applied on the same day as RG. This may have been due to the amount of slower release nitrogen from fowl manure which was present in the soil.
During the next week (26th August – 1st September), the RG sap levels climbed again to sit within the optimum range. The GO and T levels dropped slightly with T levels declining into the optimum range and GO remaining slightly above.
The sudden rise by RG may have been due to the quick uptake of fertiliser by the plants as soon as it was applied.

During the next week (2nd September – 8th September) 20mm of rainfall fell. The RG treatment stayed within the optimum range. The T treatment recorded levels just above the upper end of the range, and GO continued to decline and was recording levels within the optimum range.

The next week (9th September – 15th September) saw all the treatments rise but diverge. Treatment RG remained within the optimum range and T rose above the optimum range. The GO treatment was harvested this week and, recorded sap nitrate levels just above the optimum range. Fifty five millimetres of rain was recorded during this period, but it did not have the same effects on sap nitrate that had been noted before, possibly because the plants were extracting nutrients from a greater depth of soil by this time.

During the final week of monitoring the RG treatment recorded a level within the optimum range. The T treatment however recorded levels higher than the optimum range.

From these petiole sap nitrate results it was concluded that there was a significant difference between all three treatments ($p \leq 0.05$) over the life of the crop. There was a significant difference between the GO practices and the recommended schedule applied by the grower ($p \leq 0.03$). There was no significant difference between the T and the GO schedule ($p \leq 0.53$), which indicates that the determined optimum schedule for fertiliser application is adequate for a commercial crop. There was a significant difference between the T and the RG ($p \leq 0.01$) indicating that the method of fertiliser application is also a significant factor in the outcome of marketable winter lettuce.

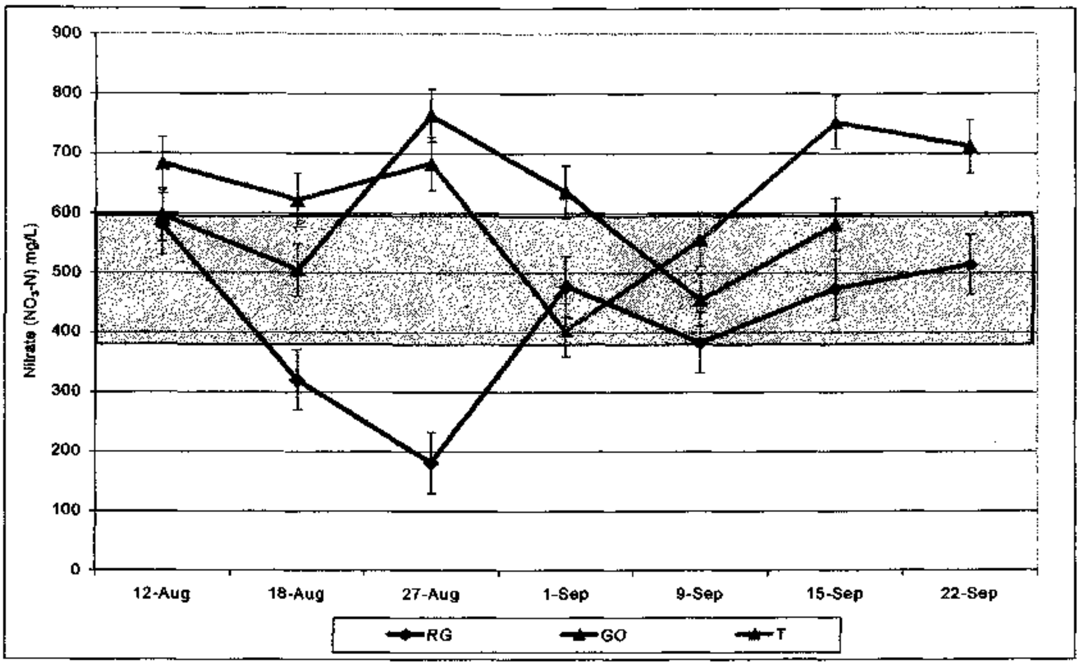


Figure 3: Sap nitrate profiles over the life of the crop for the Recommended Grower treatment (RG), Growers Own treatment (GO), and trial treatment (T) compared to the Medina recommended range.

Phosphorous

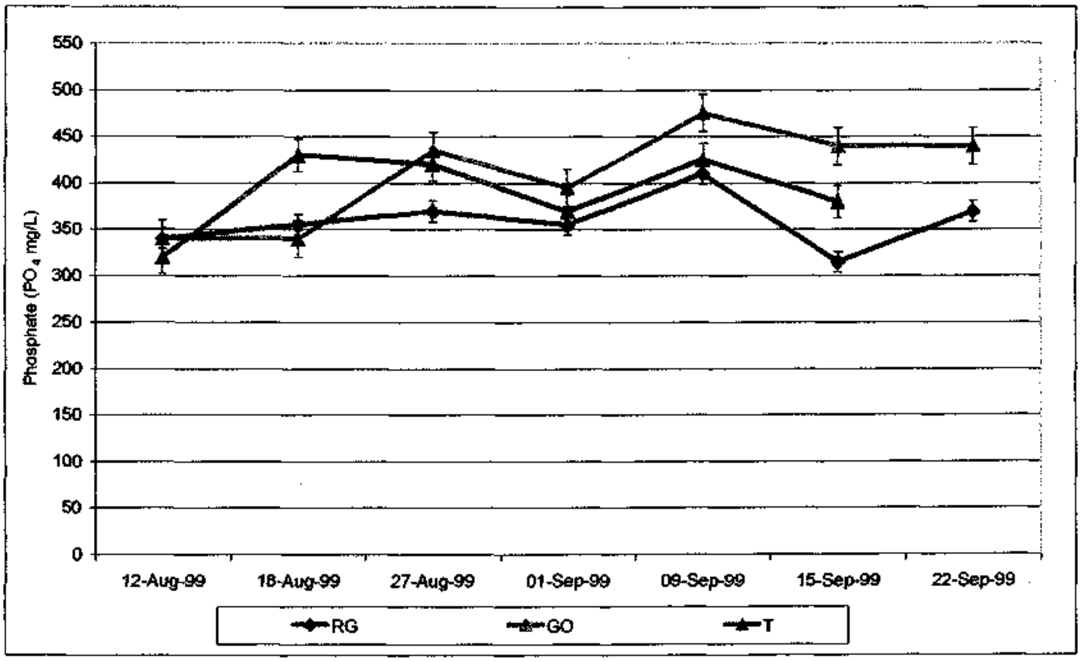


Figure 4: Sap phosphate levels recorded from each treatment.

Phosphate levels in sap were monitored during the life of the crop using Merckoquant® test strips and the RQFlex® meter. The levels recorded for all three treatments were within the range of 300 - 450 mg/L, which corresponds to previous lettuce research results. There was no significant difference between all three treatments over the life of the crop ($p \leq 0.12$), which was expected as the amount of phosphorous applied to all three treatments was not limiting.

Potassium

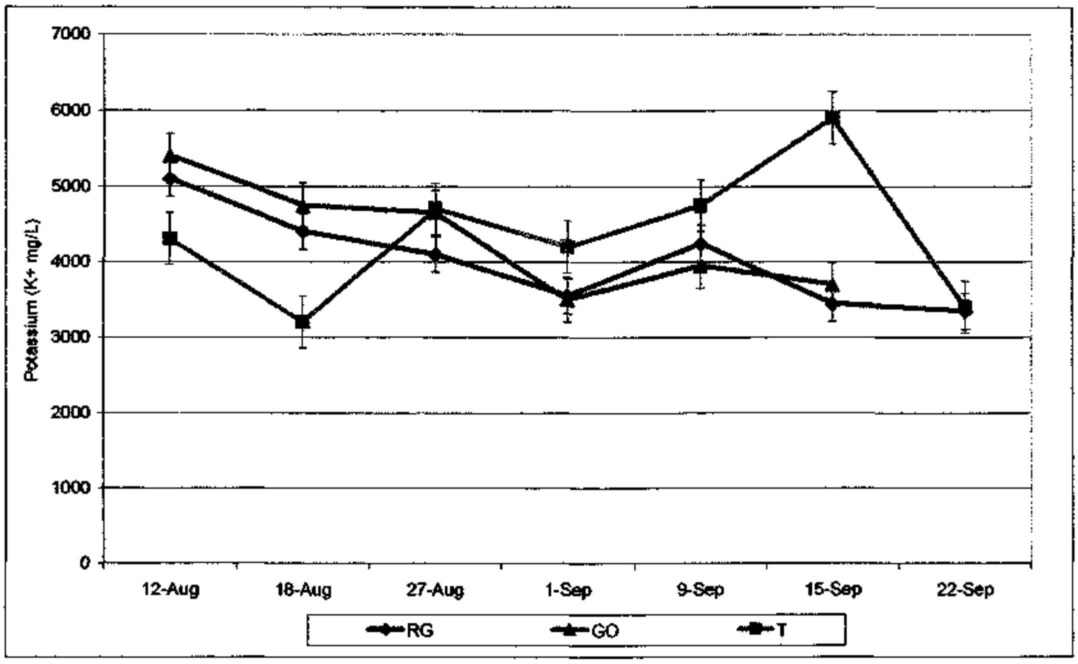


Figure 5: Sap Potassium levels recorded from each treatment.

Potassium was also monitored for the seven week period. The results for all three treatments were within the range of 3000 - 6000mg/L which is comparable to that of previous research. There was no obvious difference between all three treatments in their potassium sap levels ($p \leq 0.69$). The results suggest that potassium was not limiting to growth in any of the treatments.

Yields

The three treatments were harvested at the end of the crop's life to determine marketability and mean head weight.

There was no significant difference between the weight of the three treatments with the GO methods having slightly heavier head weights than the T treatment. The RG treatment recorded the lowest mean head weights, but was still only 130g per head lighter than the GO schedule. Although there was a slight difference in the weight of the lettuce at harvest, there was virtually no visual difference in the colour and size of heads.

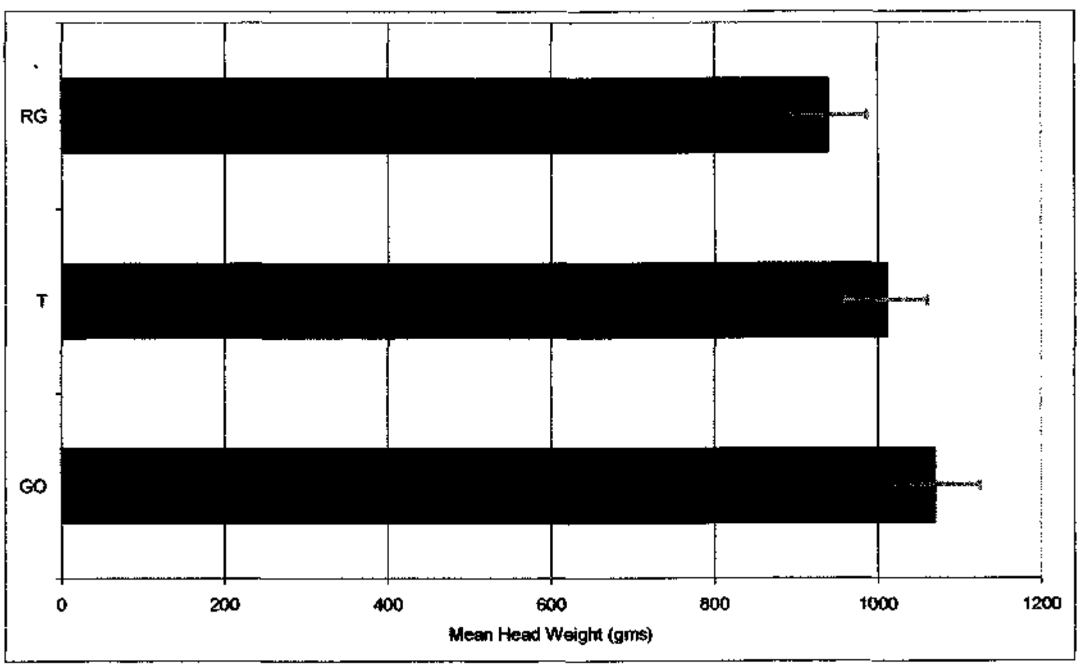


Figure 6: Mean head weight of 24 lettuces at harvest for each of the 3 treatments.

Conclusion

There was no visual difference in the size of the lettuce or colour at harvest indicating little difference between the three treatments. Lettuce at present is sold by the crate at the Perth fresh market and not by weight. The small difference in weight between treatments would not be likely to result in a price difference between lettuce from each of the treatments. Lettuce for processing and export are paid for by weight and if these differences were real, the treatments could result in a difference in gross return.

Petiole sap testing showed that there were differences between the sap nitrate levels in all three treatments at times during the course of the crop's life. Despite the differences, the Growers Own treatment and the simulated fertigation Trial treatment had sap nitrate profiles that fell within or above the optimum range throughout the life of the crop. Notably the mean head weights from these two treatments were little different at harvest.

The Recommended treatment (RG) applied by the grower using granular fertilisers, banded and broadcast gave a sap nitrate profile which on two occasions fell below the optimum range. Notably, mean head weights from these treatments were the lowest of the three treatments tested. Assuming that the same total nitrogen was applied by this treatment as the T treatment, the results suggest that this method of application of fertilisers may be inferior to the fertigation technique.

In interpreting this result, it needs to be taken into account that the timing of application of the RG treatment was not as precise as that for the T treatment because of commercial demands on the grower's time and at times throughout the life of the crop unfavourable weather conditions for spreading granular fertilisers were encountered. The combination of both observations suggests that timing of fertiliser application or method or both are critical to maximise marketable yield.

There was minimal difference in both the petiole sap profiles and the final yield between the Trial and the Growers Own treatments. The trial showed that fowl manure can be substituted by chemical nitrogen, and still produce a comparable marketable lettuce crop.

Sap phosphate and potassium levels were within a similar range to those recorded in previous research and at other demonstration sites and were considered to be non limiting to yield. Phosphate levels exceeding 300mg/l and potassium exceeding 3000mg/l in plant sap could be considered adequate throughout the life of the crop.

4.3. Adoption of Irrigation Management Practices - Case Study - 1 Irrigation Scheduling for autumn Lettuce.

L. K Teasdale, D.R Phillips, and D. G Gatter.

Summary

This study explored the practical aspects associated with adoption of irrigation scheduling using evaporation replacement principles in a commercial crop. The crops also doubled as an extra monitoring site for commercial crop nutrition and the application of petiole sap testing.

In this case, the crop factor technique proved difficult to adopt because the sprinkler lines on the property were aligned in the direction of the common prevailing winds, leading to a regular requirement to irrigate to prevent sand movement in the crop. The need to use sprinklers as a wind control measure tended to over-ride the crop's water demand, leading to over-irrigation. This was particularly so before the crop achieved full ground cover. After that time, crop factor scheduling was effective. Effective irrigation system design which takes account of wind speed and direction is a pre requisite to adoption of irrigation scheduling techniques based on evaporation replacement.

High rates of irrigation associated with wind control were associated with increased leaching of water, nitrogen and phosphorus below the root zone into drainage lysimeters. Levels of nutrients leached were closely related in magnitude and time to organic and inorganic fertiliser applications. Water and nutrient loss was greatest at the windier site tested, where more irrigation was applied to manage wind blown sand.

Sap nutrient monitoring showed that the test crops fell below the recommended standards for nitrate for most of their life and phosphate levels were well below those encountered in Medina research and other grower case studies, suggesting that yields may have been limited by one or both nutrients.

Introduction

Irrigation practices for commercial vegetable production on the sandy soils of the Swan Coastal Plain are largely based on grower experience. Guidelines for irrigating iceberg lettuce based on evaporation replacement (Crop Factor) principles have been published by Agriculture Western Australia, but there has been little adoption in commercial practice.

New research conducted at Medina as part of this project derived a "Crop Factor Function" for the life of the crop when grown in summer and autumn. The new function also better defined the relationship between crop factor and fertigated nitrogen throughout the growing cycle. The end point of this work is a proposed optimum irrigation and nitrogen schedule for the crop grown from transplants.

The main aims of this experiment were:

1. To test the 'Crop Factor Function' for irrigation scheduling in a commercial scale crop for its practicality of use and relevance to commercial practice.
2. To test intensive 'one to one' support and feedback as an extension technique to facilitate adoption of this new technology.
3. To identify barriers to adoption of this technology and propose strategies to overcome them.

Materials and Methods

A commercial crop of iceberg lettuce (cultivar Napean) approximately 3000m^2 in area was provided by a willing grower as a test crop to evaluate the new 'crop factor' function derived from Medina research.

The crop was direct sown on March 15, 1999 and will be referred to as 'Site A'. Another site, on the same farm, also 3000m^2 in area, was sown to the same cultivar on March 19, 1999 (Site B). The plan was to compare the grower's own irrigation scheduling technique based on experience (Site B) with a schedule based on the crop factor model (Site A) using long term average evaporation figures from a nearby weather station (Perth Meteorological recording station).

Both plantings were made on Bassendean sand with a long history of continuous vegetable growing. Bassendean sand has a low volumetric water holding capacity of < 10 % v/v and little capacity for sustainable organic matter enrichment. Consequently, daily irrigation with overhead sprinklers was required to avoid crop water stress for most of the study period.

Irrigation applications were made by the grower who was given recommendations for the length of time sprinklers would need to be run each day during the study period. These times were determined by calculating sprinkler output rates and applying the crop factor model for each crop growth stage using long term evaporation figures from each week of the study period. The data these calculations were based on and recommended times is shown in Table 1.

Table 1. Weekly Recommended Scheduling figures for Site A(15 March - 25 May 1999).

Week	*Day*	*Mean Evap. (12 years data) mm*	*Crop Factor*	*Minutes to be applied/day*	*Rounded minutes*	*Total Applied / week (minutes)*
1	0 – 7	7.75	**80%**	41.3	**40**	280
2	8 – 14	6.80	**80%**	36.3	**35**	245
3	15 – 21	6.59	**80%**	35.2	**35**	275
4	22 – 28	5.92	**80%**	31.6	**30**	180
5	29 – 35	5.53	**65%**	24.0	**25**	175
6	36 – 42	4.51	**65%**	19.5	**20**	205
7	43 – 49	4.16	**100%**	27.8	**30**	215
8	50 – 56	3.68	**130%**	31.9	**30**	240
9	57 – 63	3.10	**130%**	26.8	**30**	205
10	64 – 70	2.90	**130%**	25.2	**25**	175
11	71 – 77	2.68	**130%**	23.2	**25**	50

The crop factor for the first 4 weeks of the study was arbitrarily set at 80%, because the crop was direct sown and the crop factor model had been derived from a transplanted crop. After 4 weeks, the crop factor model was applied as if the crop had been transplanted at that date. The crop factors are different from those shown in Chapter 3 because detailed statistical analysis of the Medina Research was not complete when this study commenced.

The grower used his own discretion to decide if daily irrigation rates needed to exceed these recommended levels and the results of each week's irrigation times were reviewed at the end of the week to determine reasons for deviation from the schedule.

A water balance for the crop was conducted by measuring precipitation inputs across the planted bed with rain gauges and through-drainage below the root zone with drainage lysimeters buried 40cm below the soil surface under the crop.

Seven PVC rain gauges were measured once per week to determine if the recommended watering times were complied with, and to monitor the distribution of precipitation across the planted area. The precipitation levels for the week (mm) were compared to irrigation times recorded by the grower and those recommended for Site A. Reasons for deviations from the recommended times were recorded by the grower. The Grower also recorded daily watering times for his control plot Site B, which enabled a comparison between the grower's own scheduling methods and the recommended schedule. Rain gauges on the grower's control plot were also measured for comparison between recommended rates and the grower's own schedule.

Lysimeters buried under both sites were read each week to measure the volume of leachate and the amount of nitrogen and phosphorous leaching past the root zone. Leaf samples (20 leaves) from both sites A and B were collected each week commencing on the 21st April 1999 for sap testing.

Soil moisture levels were monitored continuously throughout the life of the crop at Site A using continuously recording LT® tensiometers coupled to a data logger. Four pairs of tensiometers were sited at 15cm and 30cm depths below the soil surface at intervals across the sprinkler bed to reflect the range of variation in precipitation from sprinklers over the course of the study period. Data was downloaded onto a notebook computer at weekly intervals.

Site

The soil type at the site was Bassendean Sand which has a low water and nutrient holding capacity. The site was typical of the lettuce production areas on the Swan Coastal Plain. A soil composite sample was taken from Site A, prior to planting. Results of that test are shown in Table 2. Phosphorous and Nitrogen were both low due to the low nutrient retention capacity of this soil type.

Table 2. Soil Test Results from Site A before planting (10/3/99)

Element tested	*Recorded level*
Nitrate Nitrogen *	18 mg/kg
Phosphorous ^	19 mg/kg
Potassium ^	80 mg/kg
pH ($CaCl_2$)	7.50
pH (water)	8.40

^ Method by Colwell (1963).
* Method by Rayment and Higginson (1992).

Irrigation

Sites A and B were irrigated using the same methods as the surrounding commercial crops, using an overhead sprinkler irrigation system with risers spaced at 12m x 12m. Site A was irrigated based on a recommended schedule and the Site B was irrigated using grower's own methods.

Nutrition

Fertiliser was applied to both plots based on the grower's own schedule. A dressing of $13m^3$/ha of fowl manure was applied to both beds before seeding. Urea and Superphosphate were applied to the crops on a weekly basis. After four weeks of growth (10th April 1999) the crops were thinned out and a second application of fowl manure was broadcast over the whole crop area at an approximate rate of $9m^3$/ha. Chemical fertilisers were then applied regularly until harvest.

Temperature

The maximum and minimum temperatures, daily Epan and rainfall during the season of the crop (15/3/99 – 1/6/99), were recorded by the Bureau of Meteorology. (Refer to Figures 1 & 2).

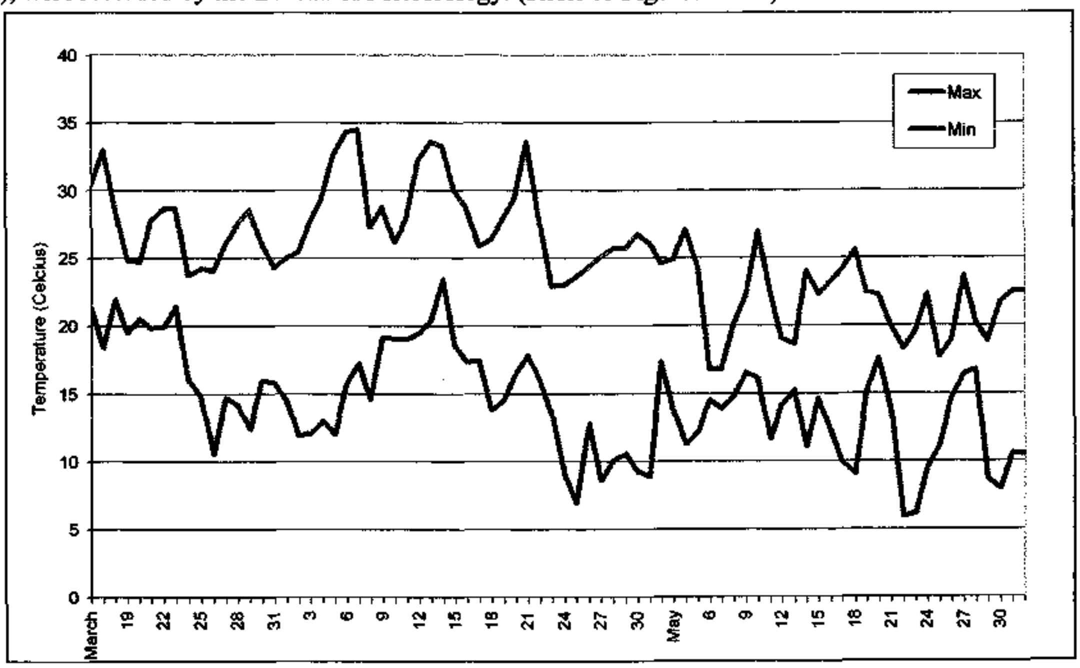


Figure 1: Daily Maximum and Minimum Temperatures during the study period (15/3/99 - 1/6/99).

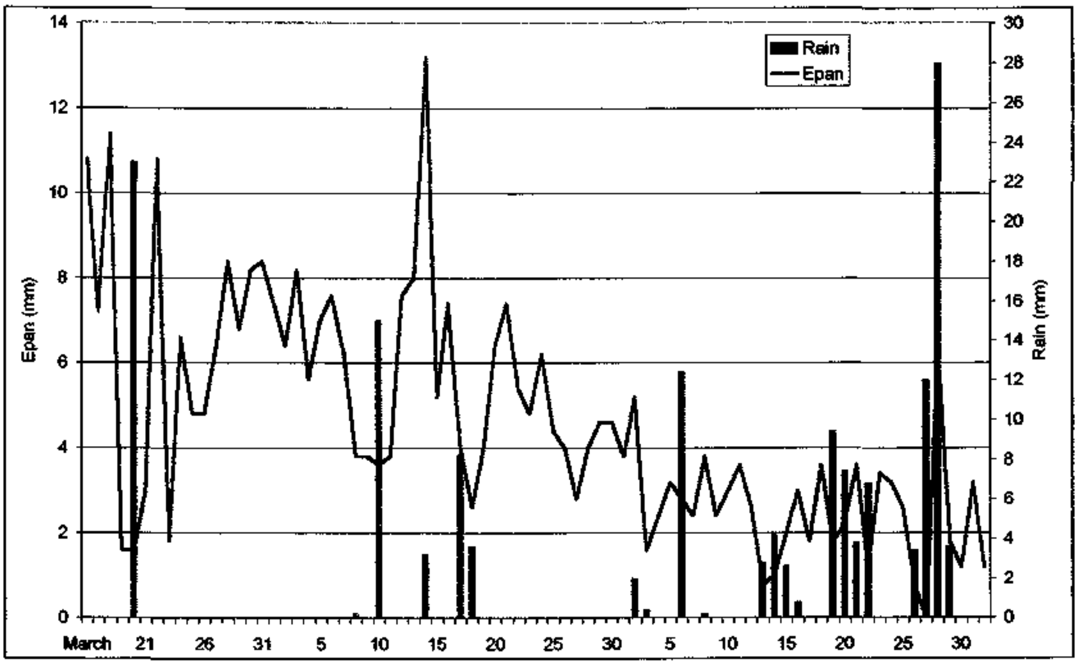


Figure 2: Daily "A Class" pan Evaporation and Rainfall during the study period (15/3/99 - 1/6/99).

Data Recording

For each week during the life of the crop (15/3/99 – 1/6/99) the following were recorded:

1. Volume of water applied.
2. Leachate volume.
3. Amount of nitrogen leached.
4. Amount of phosphorous leached.
5. Levels of nitrogen, phosphorous and potassium.

Results

The recommended irrigation schedule for the life of the crop is compared to actual rates applied by the grower (excluding rainfall) at Sites A and B in Figure 3.

Figure 3 shows significant deviations from recommended irrigation rates at both sites. Strong winds (which blew dry sand if not irrigated), and hot days were reasons given by the grower for deviation from the recommended levels. From week 6 onwards (19 April 1999) the grower seemed to settle for levels around or below the recommended levels, probably because by that time, plants had achieved full ground cover and the effect of sand movement caused by the strong winds was not as significant.

The Grower's control crop (Site B) had a similar pattern, with slightly lower irrigation levels. The reason for this was that the area where the Site B crop was grown had more protection from the wind.
Figure 4 shows a similar pattern but includes the rainfall during the trial.

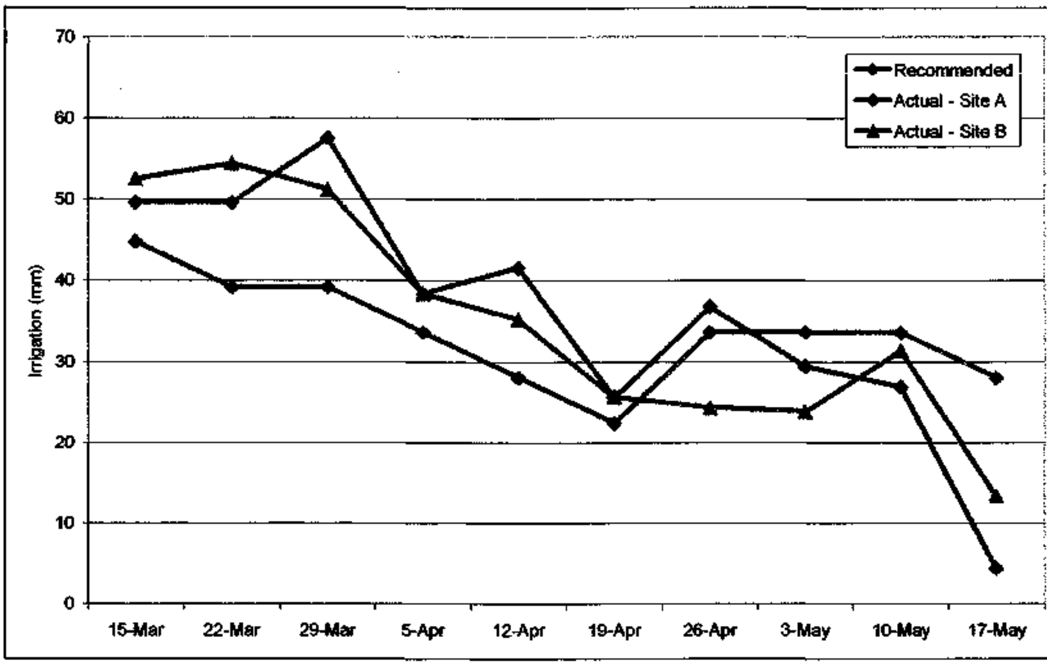


Figure 3: Weekly irrigation levels (mm) applied to crops at Site A and Site B during the study period.

Comparing Figures 3 and 4 demonstrates that more water was applied to the crop than the optimum level for plant growth for most of the study period and that rainfall which fell during the trial did not substitute for irrigation applications except towards the end of the period.

During Weeks 1 to 5, Site A exceeded the recommended irrigation levels by up to 102% when rainfall was included. Without rainfall, actual weekly applications exceeded recommended levels by 11% - 49%.

By week 6, recommended and actual rates were similar, for both Sites A and B and rainfall made little contribution. However, one week before harvest rainfall again significantly distorted crop factors.

The amount of water (including rainfall) that was recorded in rain gauges during the trial caused the actual crop factor to exceed the recommended level by 33% at Site A and 22% at Site B (refer to Figure 5). Rainfall was not efficiently used by the crop because on many days prior to "row closure", irrigation was applied 2 - 3 times a day to prevent dry sand at the surface from moving in the strong winds. The low water holding capacity of the soil contributed to rapid drying at the soil surface.

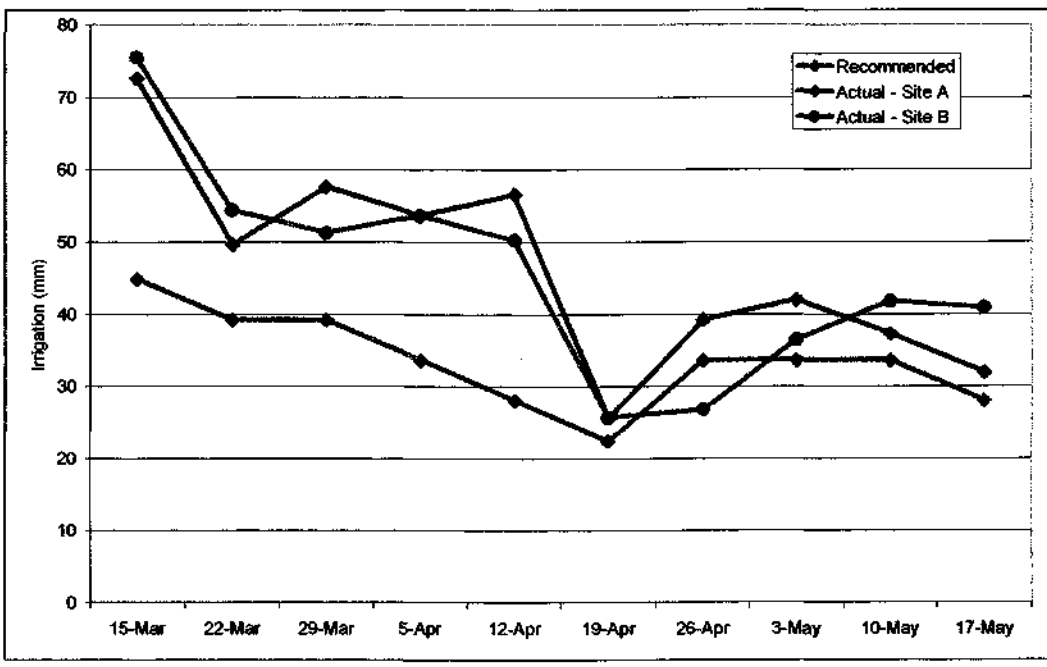


Figure 4: Weekly precipitation including irrigation and rainfall at both sites during the study period.

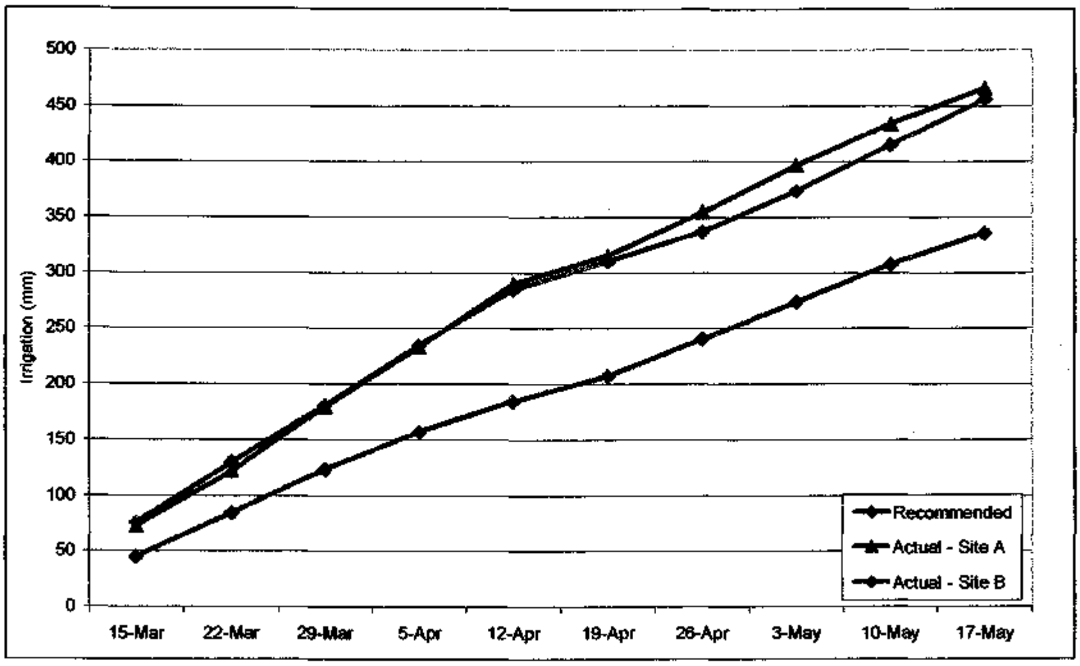


Figure 5: Cumulative water applied to both crops including rainfall.

Soil Moisture Monitoring

Tensiometer monitoring showed that at all four sites the soil remained sufficiently wet to suggest that plant water stress did not occur at any of the monitoring sites.

Figure 6 shows a typical wetting and drying cycle for a 7 day period at a depth of 15cm. The soil is saturated at 0 kPa and approaching early water stress at around - 7 kPa. Irrigation events around midday each day (except 10 May 99) are shown by vertical spikes on the graph. This soil monitoring method allows the grower to see whether there is sufficient water in and around the root zone of the crop and hence whether there is a need to irrigate.

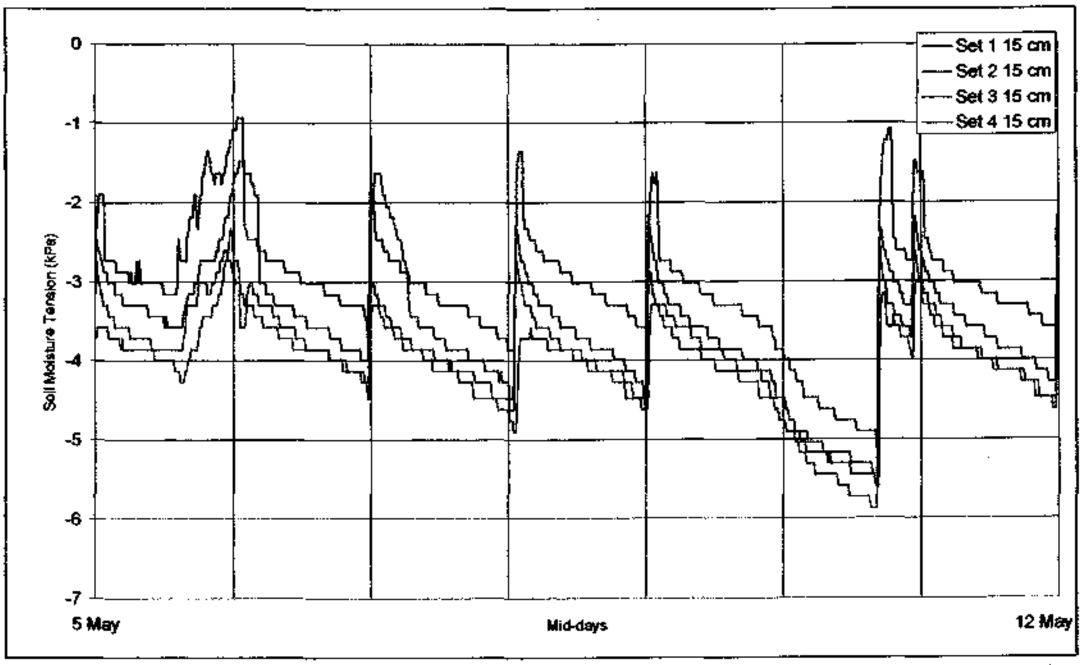


Figure 6: Soil Moisture tension (kPa) recorded by a tensiometer sited at the root zone at 15cm depth (Site A).

Water and Nutrient Leaching

Water

The lysimeters under each crop were pumped weekly to determine the volume of leachate and the amount of Nitrogen and Phosphorous leaching past the root zone.

The volume of water leached below the root zone of the crop and into the lysimeters rose steadily from planting until April 19 at both sites. Levels fell after this due to cooler weather following rain and "row closure" by the crop. Volumes leached at Site A were generally greater than Site B, as Site B was better protected from the wind and had a longer history of cropping with higher organic matter levels in the soil.

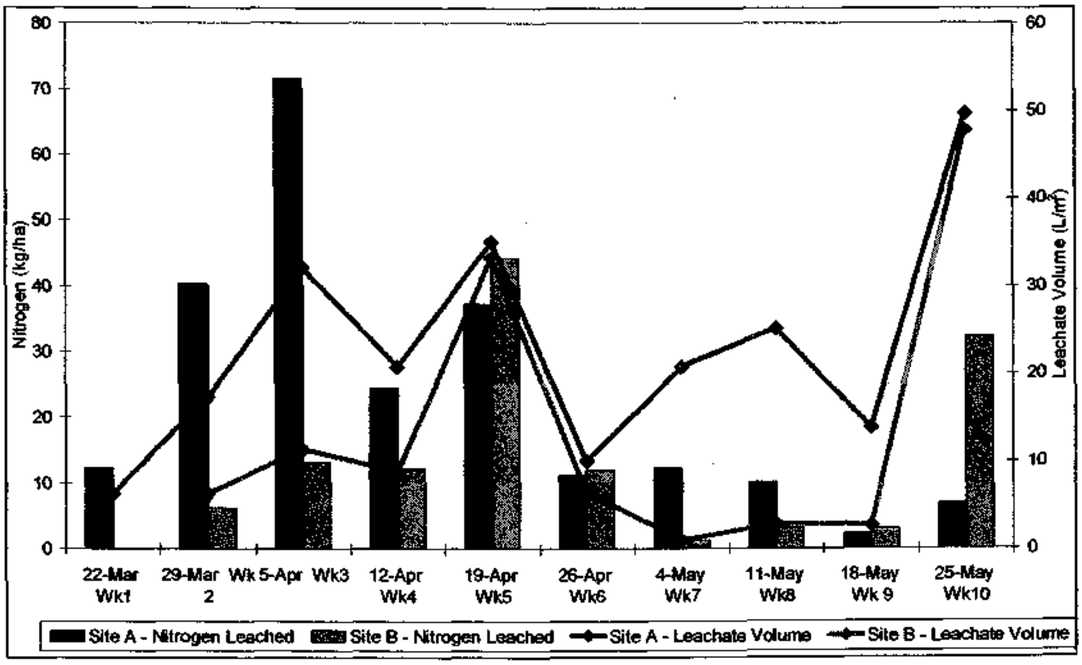


Figure 7: Nitrogen and water volumes leached over the study period.

Nitrogen

Nitrogen was present in the leachate at Site A, one week after planting and 10 days after planting at Site B. This was most likely coming from the pre planting dressing of fowl manure. During the next two weeks there was a dramatic increase in the amount of Nitrogen. Since the chemical fertiliser program began at this time this is probably the combined effect of fowl manure and chemical fertilisers.

In the Grower's control crop (Site B) there were parallel increases in Nitrogen at this time, but not to the same degree. This part of the garden is older and the soil had more organic matter. It is likely that under these conditions, the Nitrogen is able to be trapped for longer periods before leaching past the crop's root zone.

On 12 April 1999 the plants were thinned out and fowl manure was again applied. No chemical fertiliser was applied. Figure 7 shows that there was no increase in leaching during this week, but by the next week (April 19) levels rose again at both sites. Part of this rise would be due to nitrification of ammonia in the fowl manure applied the previous week as well as a contribution from freshly applied chemical fertiliser.

Leaching dropped off considerably for both sites in the following week (26 April 1999) even though the fertiliser program was slightly heavier. This may have been because the plants were becoming larger and therefore taking up more of the nutrients before they passed the root zone. Nitrogen from the April 12 application of fowl manure may also have been in decline by this time.

The leaching that occurred at both sites declined steadily after this period, as the crop was able to use more nitrogen, with the exception of the final week, which showed an increase.
Heavy rainfall (27.4mm) was recorded during this week, which would have caused this increase in leaching.

Phosphorous

The phosphorous recorded in the leachate water fluctuated more widely than the nitrogen. As with the nitrogen, Site A had a larger volume of phosphorous leaching than the grower's control (Site B).

Phosphorous was found in the leachate the first time the lysimeters were pumped out at both sites, probably reflecting pre planting applications of superphosphate at both sites.

Chemical fertilisers commenced in Week 3 and hence an increase in leaching was recorded during Week 4. This chemical fertiliser application continued until the end of the crop. During the 5th week, the quantity of phosphorous peaked. This closely followed fowl manure being applied for a second time after the crop was thinned out. This, along with chemical fertiliser being applied in Week 5, probably contributed to the increase in phosphorous leaching.

During Week 6 the levels dropped. This was probably the result of the plants beginning to use more of the P in the soil and therefore less was available for leaching past the root zone. The levels began to rise again in the next two weeks, which could also be due to the heavy rain that fell during these weeks. During the final week of the crop, the phosphorous levels in the lysimeters increased again, as 27.4mm of rain fell in this week, contributing to the leaching process.

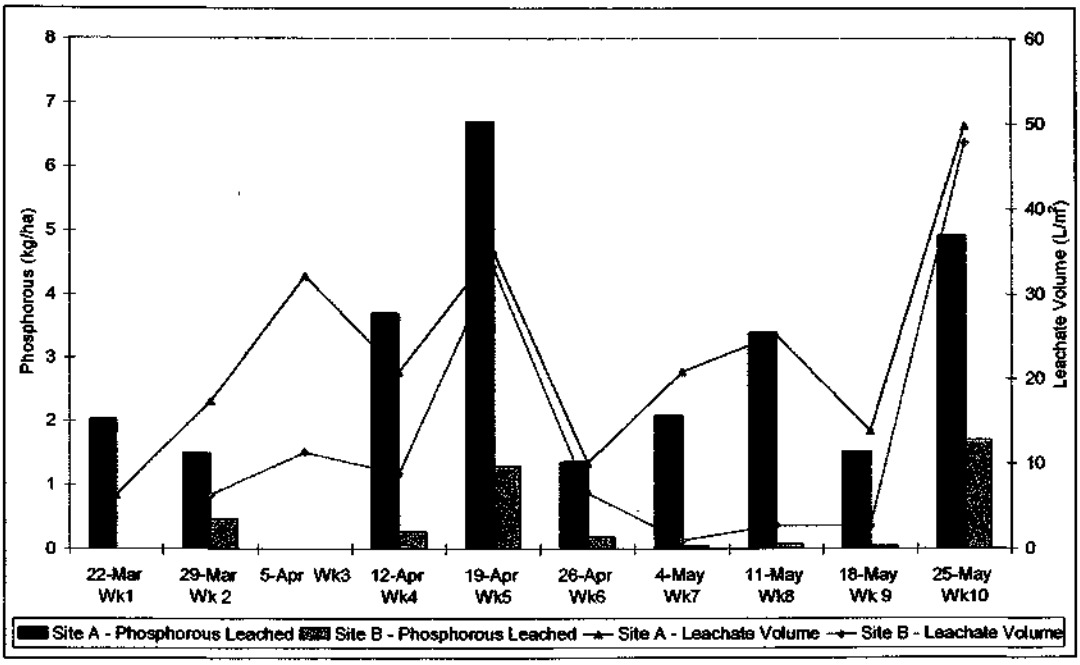


Figure 8: Phosphorous and water volumes leached during the study period.

Petiole sap nitrate

Previous research conducted as part of this overall project showed that healthy, marketable lettuce have sap nitrate levels within the range of 390 – 600 mg/L NO_3-N.

From Figure 9 it can be seen that this lettuce crop did not fall within this range for most of the monitoring period.
During the first and second week of sampling the crop was on the very lower end of the range, indicating that the crop would not reach its full yield potential. Visually the crops in Site A and Site B looked healthy, sound and of marketable standard despite the low sap nitrate levels.

During the third week, sap levels dropped dramatically in both crops. Site A dropped substantially below the optimum lower critical limit but still looked healthy. Site B also dropped dramatically from the upper limit to below the lower limit, but also appeared healthy.

During the next three weeks the Site A sap nitrate levels plateaued at around 135mg/L NO_3-N, while the Site B levels fluctuated between 160mg/L and 250mg/L NO_3-N. These were considered to be well below optimum levels, although the crop remained healthy and marketable. Despite being marketable, the sap levels suggested a likely yield loss compared to optimal performance.
During the final two weeks of the Site B crop, *Sclerotinia minor* became an evident problem in the bed causing many plants to die.

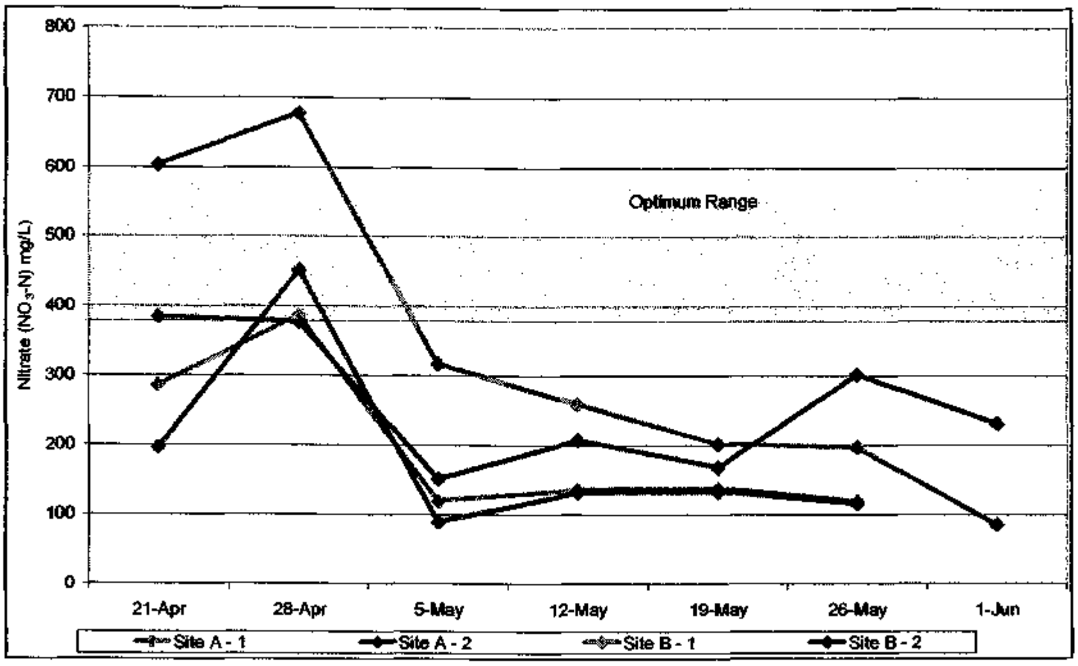


Figure 9: Sap nitrate profiles for the treatments compared to the optimum range.

Phosphorous and Potassium

As with nitrate, the phosphate sap levels fluctuated. Levels recorded from both Sites A and B were below levels recorded in previous research plots (250mg/l -350mg/L). The critical levels for this nutrient throughout the life of the crop are not known, but it is possible that for some or most of their lives, crops at Site A and Site B may have been sub optimal.

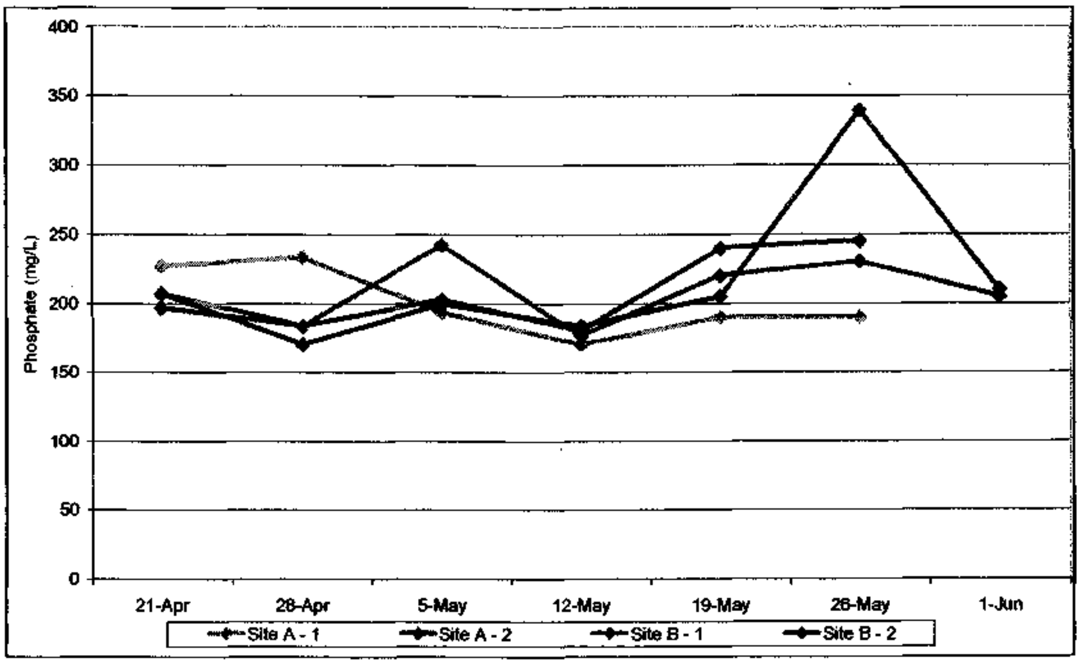


Figure 10: Sap Phosphate levels during the monitoring period.

Potassium levels in the sap samples from both Site A and Site B were within the same range of levels found in previous research. Both began high around 3500 – 5000 mg/L and then decreased to around 3000 mg/L potassium. It can only be assumed that these levels of K were not limiting to crop growth. (see to Figure 11).

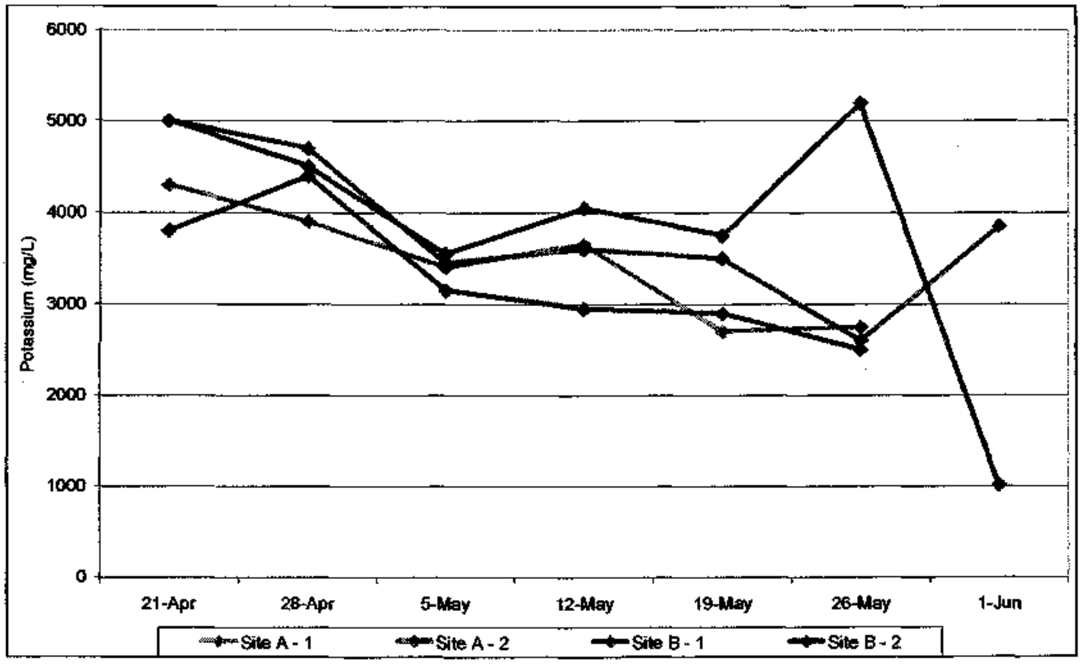


Figure 11: Potassium sap levels during the monitoring period.

Conclusion

The 'Crop Factor Function' for irrigation scheduling could not be followed closely by the grower at this site because the site was too windy for the crop to be protected from sand movement without regular daily irrigation. The soil surface of this light sandy soil dried out quickly during the course of most days before the crop had achieved full ground cover. If this was allowed to happen, sand grains would blow into leaf axils or at worst cause plant damage through sand blasting.

The grower believed that the minimum irrigation duration to stop this happening was 20 minutes or nearly 3mm of irrigation. Early in the life of the crop, only 2 applications of this duration were sufficient to reach the recommended irrigation rate. On many occasions, the soil dried out so fast that a third irrigation was required each day to stop sand movement. Each time this happened, the scheduled figure was exceeded by 34%. Late in the life of the crop when sand movement was no longer a major problem, the crop factor recommendation was effective and achievable by the grower.

At all times during the life of the crop, tensiometer monitoring showed that the crop was not water stressed under the regimes imposed.

The Bassendean Sand at the site readily leached water and nutrients, including phosphorus. The strategy of using irrigation to control wind blown sand led to excessive water and nutrient loss through leaching. These losses were in turn related to sub optimal sap nitrate levels for much of the life of the crops at both sites. Sap phosphorus levels were also lower than encountered in other studies in this project, suggesting that they too may have been sub optimal. The net effect of these practices may have been that crop yield was limited by both nitrogen and phosphorus and maximum yield potential was not achieved. Sap potassium levels appeared to be adequate.

For irrigation scheduling techniques based on evaporation replacement to be adopted in a situation like this one, the sprinkler irrigation system would need to be redesigned with laterals running north-south rather than east-west. In addition, other sand control measures would need to be employed for crop establishment such as inter-row mulching with a material stable in the wind. Cellulose based spray-on products similar to those used to establish direct sown turf could be investigated as possible alternatives.

4.4 Irrigation uniformity and irrigation scheduling - Case Study 1

N.C. Lantzke and R.A. Deyl

Summary

The uniformity of irrigation applied to a lettuce crop was measured by placing 25 raingauges within the sprinkler wetting pattern on a grower's property in a crop of lettuce. The uniformity of the irrigation was below the accepted uniformity in some weeks of the crop's life.

The amount of irrigation applied to the crop was in each week greater then Agriculture Western Australia's recommendation. Low tension tensiometers (Irrometer®) were installed into the wetter and drier areas of the irrigation pattern to monitor soil moisture. The soil remained moist and the crop did not experience moisture stress.

Measurements of lettuce yield were taken at harvest from areas immediately adjacent to the 25 rain gauges. There was no relationship between irrigation applied within the wetting pattern and yield.

Introduction

Assessment of sprinkler irrigation systems used by vegetable growers on the Swan Coastal Plain has shown that many apply water with a poor uniformity (Milani, 1992, Lantzke and Calder, 1997). Growers generally over irrigate to ensure drier areas of the wetting pattern receive sufficient water. The level of uniformity at which increased pumping costs outweigh a cheaper, less uniform initial design has not been determined on coastal plain sands in Western Australia. Internationally accepted standards recommend a Co-efficient of Uniformity of 85% or greater. Placing low tension tensiometers (Irrometer LT®) within wetter and drier areas of the irrigation pattern will allow variations in soil moisture content to be measured. This soil moisture data combined with rain gauge and yield data from different areas of the wetting pattern will allow examination of the extent of overwatering or underwatering and any yield loss due to poor uniformity.

Most vegetable growers on the Swan Coastal Plain use their experience only to determine when and for how long they should irrigate. It is likely that the use of low tension tensiometers will increase the accuracy of their irrigation scheduling. Recent trial work with carrots (McKay and Gibbard, private correspondance) on a Karrakatta sand has defined a critical soil moisture tension of about 7 centibars, above which carrots become stressed and photosynthesis declines. The critical soil moisture content for lettuce on Bassendean sands is likely to be similar to carrots grown on Karrakatta sands.

Materials and methods

A section of irrigation on a vegetable property at Bullsbrook was assessed for its uniformity. The section contained Rainspray Rainmaster model AR2 impact sprinklers with a 3/16 inch jet and spaced at 12m by 13 m.

Twenty five rain gauges constructed from 50 mm diameter PVC pipe were placed on a 2.5 x 2 m grid between two sprinkler lines. The volume of water in the rain gauges was measured weekly and a Co-efficient of Uniformity (C.U.) calculated both weekly and for the life of the crop.

In February 15 cm and 30 cm long tensiometers were placed in wet and dry areas of the irrigation pattern. The soil suction on each tensiometers was logged every 15 minutes by a data logger (Starlogger Model No. 6004-11) which was downloaded weekly.

The irrigation uniformity and soil moisture data was presented to the farmer each week.

At maturity, 5 lettuce were harvested next to each rain gauge. The variability in yield between different parts of the wetting pattern was examined.

Results and Discussion

Uniformity of Irrigation

Figure 1 shows the depth of irrigation and rainfall that fell over the trial for the week ending March 4, 1999. This figure shows that the wettest areas, which occur to the south of each sprinkler, receive about 80% more water then the driest area.

The coefficient of uniformity (CU) of the irrigation for this week was 84 %, which is just below the acceptable standard of 85%. The CU measured over a weekly period is almost always higher then that measured over a single irrigation. Variations in wind speed and direction that occur within and from day to day even out the wetting pattern. Previous monitoring of the irrigation on this property showed a CU of only 78% over a half hour irrigation.

The poor uniformity of the irrigation system is due to excessive pressure loss down the laterals and because sprinklers are spaced too far apart for the wind speed in the district.

The pressure on a lateral adjacent to the trial site varied from 280 kPa near the main to 190 Kpa at the end of the lateral. Design guidelines recommend only a +/- 10 % variation in pressure down a lateral. The minimum recommended operating pressure of the sprinkler used is 300 kPa. This pressure loss resulted in a 25% reduction in the amount of irrigation applied to the crop at the end of the lateral. The excessive pressure loss is due to incorrect pipe size. Increasing the pressure at the beginning of the lateral will have little effect on increasing the pressure at the end of the lateral because of this head loss. To improve the uniformity the lateral needs to be replaced with another with a greater diameter.

The Rainspray Rainmaster model AR2 impact sprinkler with a 3/16 jet will throw 15 metres with 300 Kpa pressure. The low pressure will result in the sprinkler not throwing to the adjacent sprinkler. This combined with the windy conditions experienced on the property will result in a poor uniformity. Windbreaks should be installed on the property to reduce wind speed. This will improve irrigation uniformity.

The sprinkler laterals run in an east - west direction. On the Swan Coastal Plain the laterals should be run north – south to counter tunnelling of the spray pattern down the sprinkler line by the dominant easterly wind.

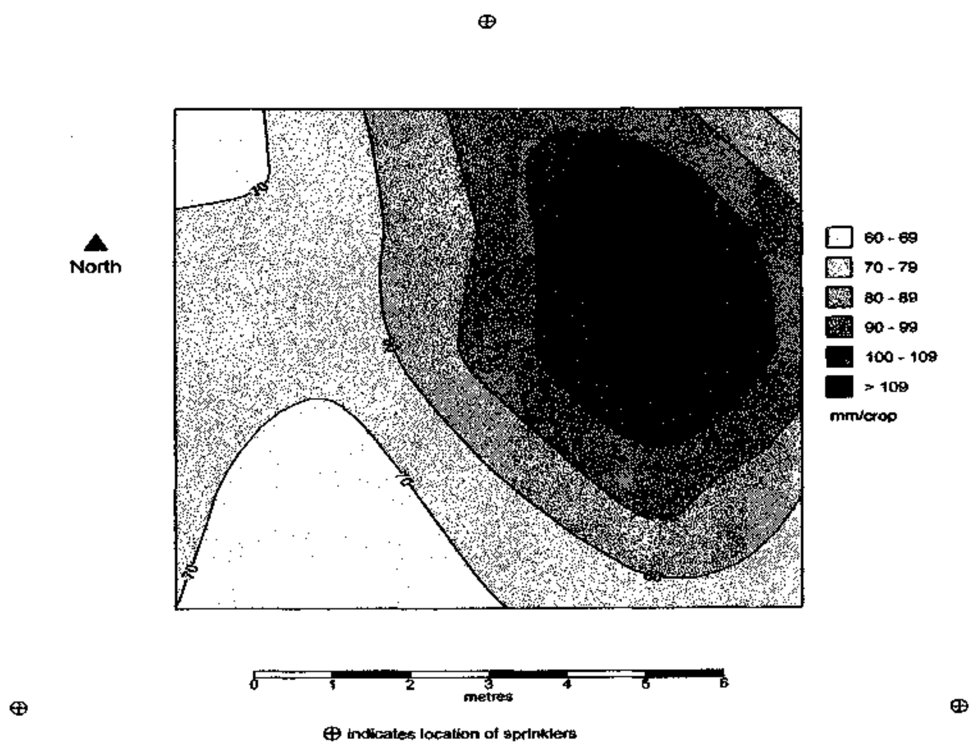


Figure 1: Irrigation applied and rainfall (mm) for the week ending March 4, 1999.

Amount of irrigation applied

Figure 2 shows the average amount of irrigation applied to the trial area each week expressed as a percentage of pan evaporation. The irrigation was applied at a rate of between 120 % and 250 % of pan evaporation throughout the crops life. The Agriculture Western Australia recommendation of 100 % of evaporation in the first 2 weeks and thereafter 150 % is given as a guide. It is likely the crop was over watered in the last two weeks of its life.

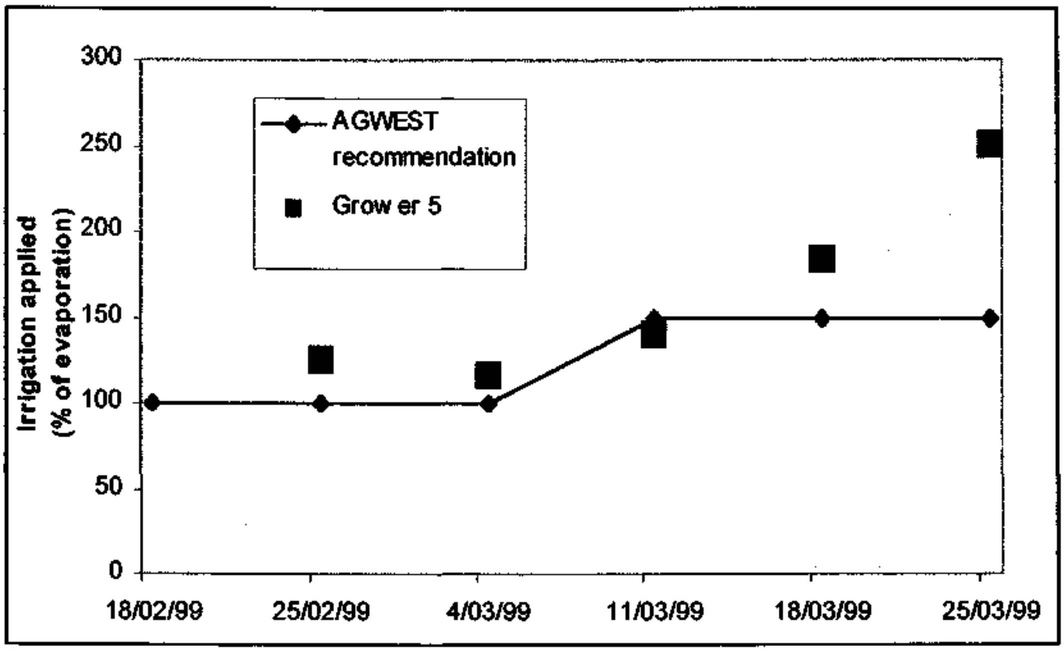


Figure 2: Irrigation applied by the grower expressed as a percentage of evaporation and Agriculture Western Australia recommendation

Soil moisture content

Figures 3 and 4 show the soil moisture tensions measured by the tensiometers in the wet and dry areas of the wetting pattern respectively. The soil was kept close to saturation in both areas for the life of the investigation. Additional water was applied to ensure that drier areas of the wetting pattern received sufficient water.

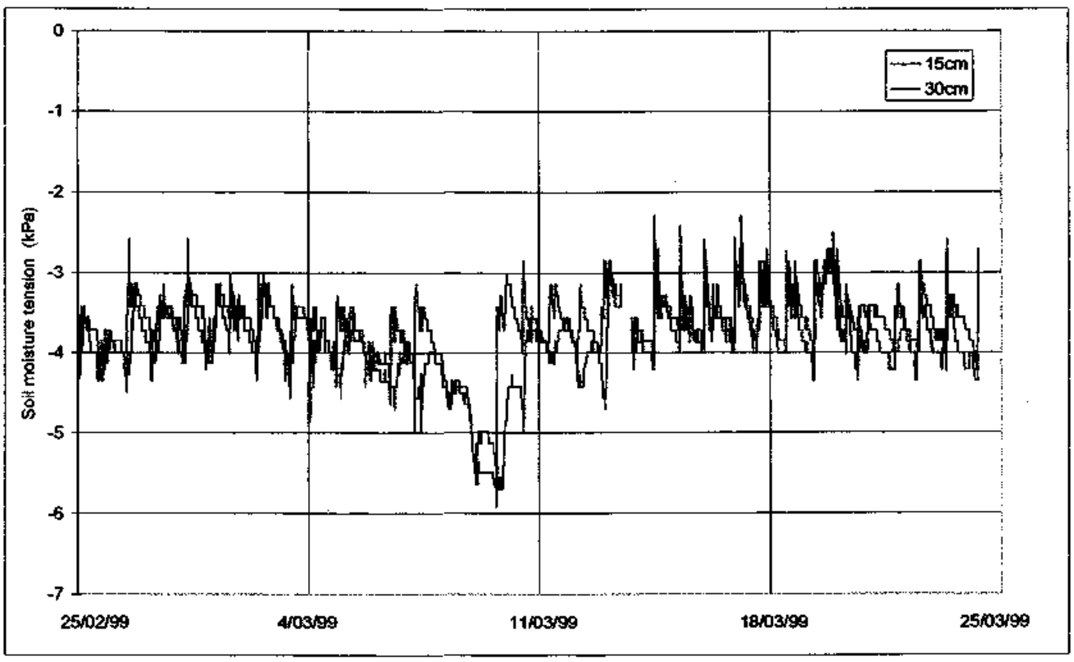


Figure 3: Soil moisture tension in a wet area of sprinkler pattern (Grower 5).

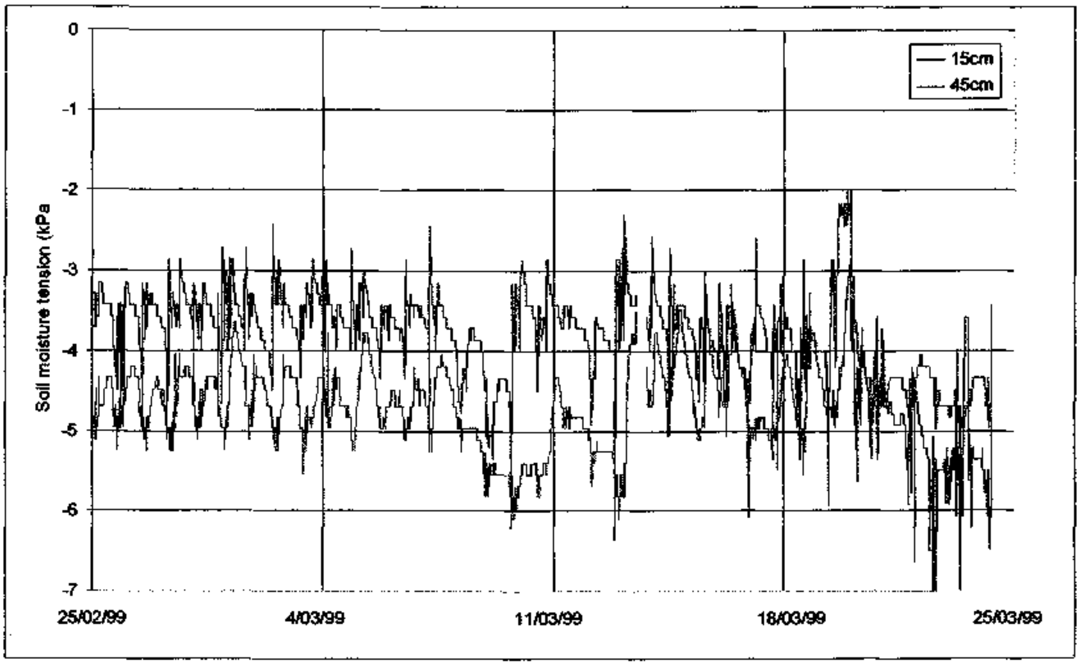


Figure 4: Soil moisture tension in a dry area of sprinkler pattern (Grower 5).

The soil type on the property can hold about 30 mm of readily available water per metre of soil. Assuming a root zone of 15 cm, then the soil profile can hold about 5 mm of water within the root zone (less when the crop is younger). An extra 20 % should be applied to supply sufficient water to the dry areas of the wetting pattern. Apply about 6 mm in each application to a crop that is over a third grown. Applying greater amounts of irrigation than this is wasteful and will result in water moving past the root zone.

Yield

Lettuce were harvested adjacent to each rain gauge. Figure 5 plots lettuce yield recorded next to each rain gauge against the total volume of irrigation and rainfall in that gauge. There was no statistical difference in yield within the wetting pattern. As mentioned above additional water was applied to ensure that drier areas of the wetting pattern received sufficient water.

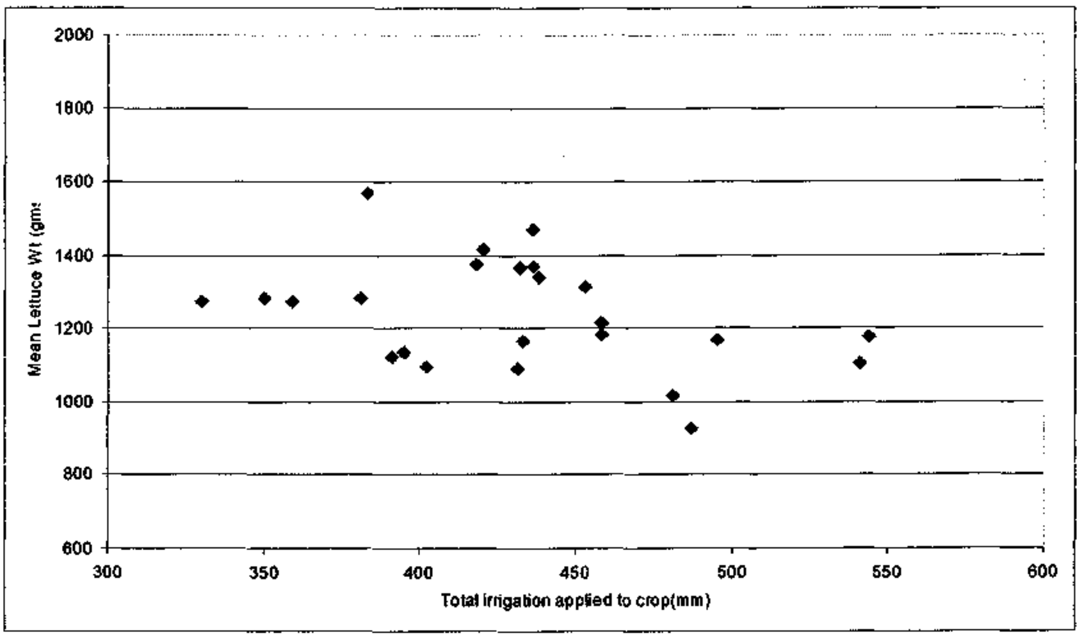


Figure 5: Marketable yield adjacent to each rain gauge verses total irrigation and rainfall.

Recommendations

1. To make significant improvements in the uniformity of the irrigation system the lateral pipe sizes need to be increased to reduce excessive head loss down the lateral.
2. Windbreaks will improve the uniformity of irrigation.
3. Use a soil moisture sensor or pan evaporation to allow more accurate scheduling of irrigation.
4. Apply no more irrigation then what the soil can hold plus 20 % to account for dry areas of the wetting pattern. For a lettuce crop that is older then a third grown apply no more then 6 mm of irrigation in one application.

References

1. Milani, S. (1992). *Survey of irrigation efficiencies on horticultural properties in the Peel - Harvey Catchment.* Division of Resource Management Technical Report 119. Agriculture Western Australia.
2. Calder, T and Lantzke, N. (1997). *Irrigation efficiency testing. Carrot growing properties - Swan Coastal Plain.* Agriculture Western Australia. Internal Report.

4.5 Irrigation uniformity and irrigation scheduling - Case Study 2

N.C. Lantzke and T.R. Shimmin.

Summary

The uniformity of irrigation on a vegetable property was measured by placing 16 raingauges within the sprinkler wetting pattern. The rain gauges were emptied weekly from November until December 1998 during which time a lettuce crop was grown on the area. The irrigation in the section of garden monitored had a good uniformity.

The amount of irrigation applied was generally greater then Agriculture Western Australia's recommendation. Low tension tensiometers (Irrometer®) were installed to monitor soil moisture. The crop was over watered and did not experience moisture stress.

Measurements of lettuce yield were taken at harvest from areas immediately adjacent to the 16 rain gauges. No variation in yield was recorded within the sprinkler wetting pattern.

Introduction

Assessment of sprinkler irrigation systems used by vegetable growers on the Swan Coastal Plain has shown that many apply water with a poor uniformity (Milani 1992, Lantzke and Calder, 1997). Growers generally over irrigate to ensure drier areas of the wetting pattern receive sufficient water. The level of uniformity at which increased pumping costs outweigh a cheaper, less uniform initial design have not been determined on coastal plain sands in Western Australia. Internationally accepted standards recommend a Co-efficient of Uniformity of 85% or greater.

Soil moisture data combined with rain gauge and yield data from different areas of the wetting pattern will allow examination of the extent of overwatering or underwatering and will determine if yield loss due to poor uniformity occurs.

Most vegetable growers on the Swan Coastal Plain use their experience only to determine when and for how long they should irrigate. It is likely that the use of low tension tensiometers will increase the accuracy of their irrigation scheduling. Recent trial work on carrots (McKay and Gibbard, private correspondance) on a Karrakatta sand has defined a critical soil moisture tension of about 7 kPa, above which carrots become stressed and photosynthesis declines. This critical soil moisture content on Bassendean sands is likely to be similar to that on Karrakatta sands.

Materials and methods

A section of irrigation on a vegetable property at Wanneroo was assessed for its uniformity. The section contained standard butterfly sprinklers spaced at 6m by 6m. The pressure at the sprinklers was adequate.

Sixteen rain gauges constructed from 50 mm diameter PVC pipe were placed approximately on a 1.5 x 1.5 m grid within 3 sprinklers. The volume of water in the rain gauges was measured weekly and a Co-efficient of Uniformity (C.U.) calculated both weekly and for the life of the crop.

Tensiometers were placed in the crop. The tensiometers were 15 cm and 45 cm long. The soil suction on each of the tensiometers was logged every 15 minutes by a data logger (Starlogger Model No. 6004-11) which was downloaded weekly. The irrigation uniformity and soil moisture data was presented to the farmer each week.

At maturity, five lettuce plants were harvested next to each rain gauge. The variability in yield between different parts of the wetting pattern was examined.

Results and discussion

Uniformity of Irrigation

Figure 1 shows the depth of irrigation and rainfall that fell over the trial area from 19/11/98 to 24/12/98. The irrigation system on the property contained butterfly sprinklers. Butterfly sprinklers spaced at 6m by 6m produce good irrigation uniformity. This figure shows that there was very little variation in the amount of irrigation applied. The coefficient of uniformity of the irrigation measured each week was always greater then 90%. A uniformity of 85% is considered acceptable.

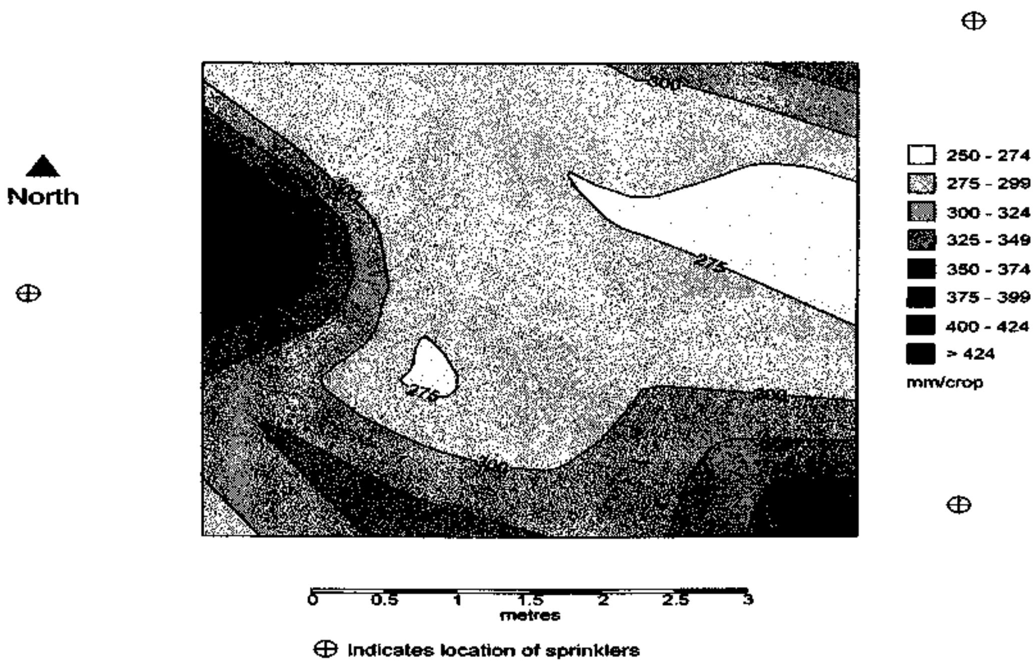


Figure 1: Irrigation applied and rainfall (mm) (November to December 1998)

Amount of irrigation applied

Figure 2 shows that irrigation was applied at a rate of between 145 % and 195 % of pan evaporation throughout the crop's life. The Agriculture Western Australia recommendation of 100 % of evaporation in the first 2 weeks and thereafter 150 % is given as a guide. It is likely the crop was over watered in some weeks.

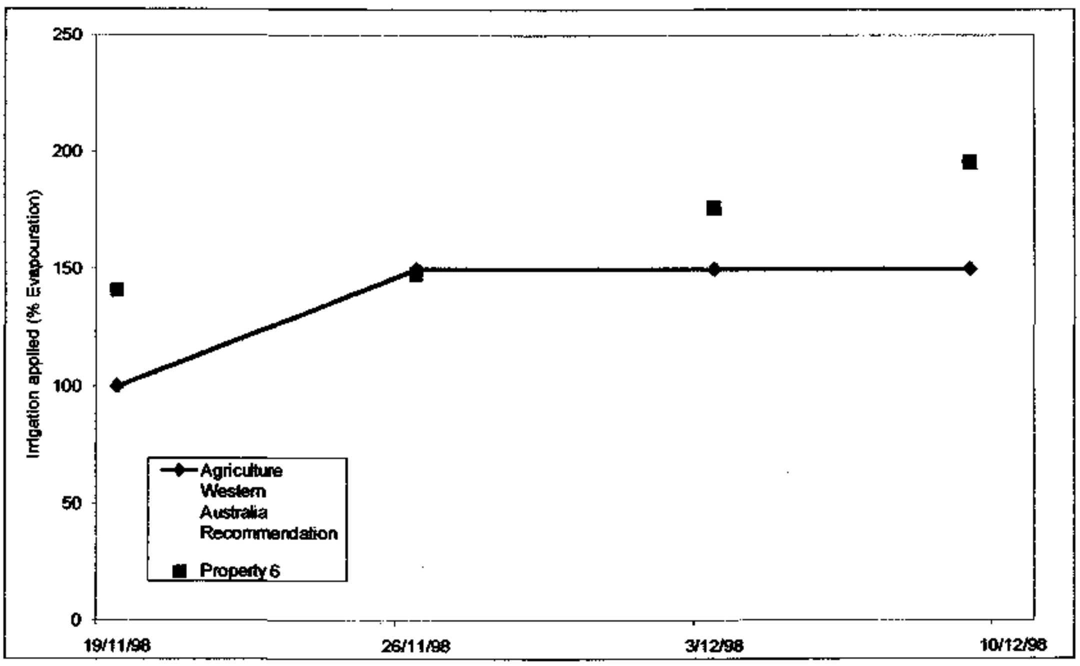


Figure 2: Irrigation applied by the grower expressed as a percentage of evaporation and Agriculture Western Australia recommendation.

Soil moisture content

Figure 3 shows the soil moisture tensions measured over a 3 week period. The critical soil moisture content at which lettuce yield declines is approximately –7 kPa. It can be seen that the soil moisture content was keep above this level. The excessive irrigation applied keep the soil moisture content generally below 5 kPa.

The soil type on the property can hold about 25 mm of readily available water per metre of soil. Assuming an effective root zone of 15 cm, then the soil profile can hold 4.5 mm of water within the root zone (less when the crop is younger). An extra 20 % should be applied to supply sufficient water to the dry areas of the wetting pattern. Apply no more then about 6 mm in each application to a crop that is over a third grown. Applying greater amounts of irrigation then this is wasteful and will result in water moving past the root zone.

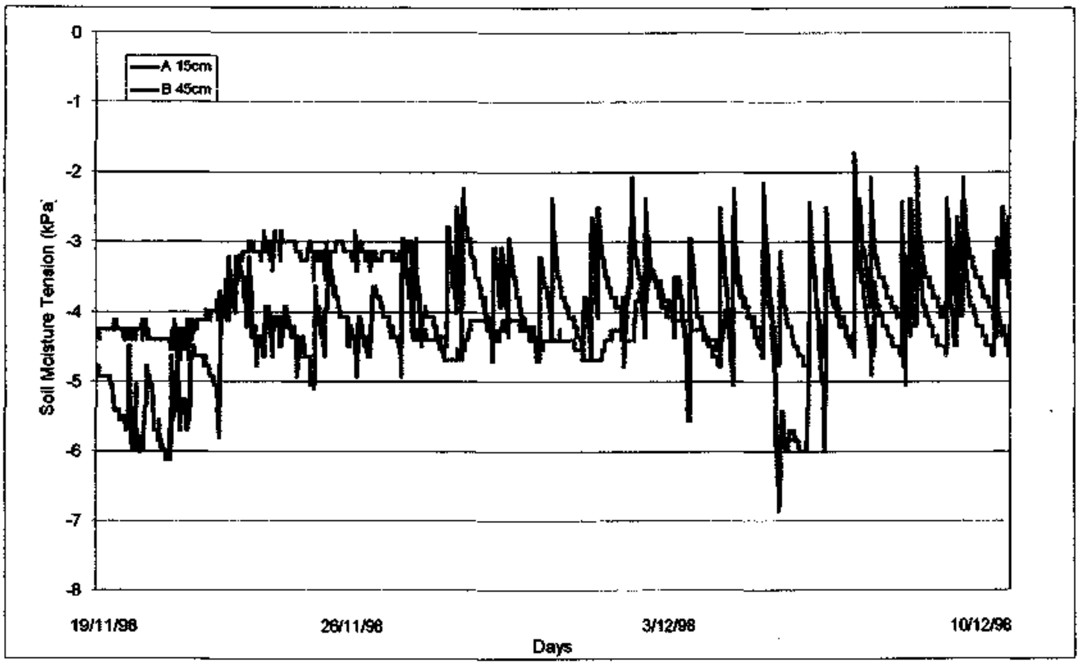


Figure 3: Soil moisture tension in trial area (Property 6).

Yield

Lettuce was harvested adjacent to each rain gauge. Figure 4 plots marketable lettuce yield recorded next to each rain gauge against the total volume of irrigation and rainfall in that gauge. There was no statistical difference in yield within the wetting pattern. On properties with a poor irrigation uniformity variations in yield may occur within the wetting pattern and are related to under or over irrigation.

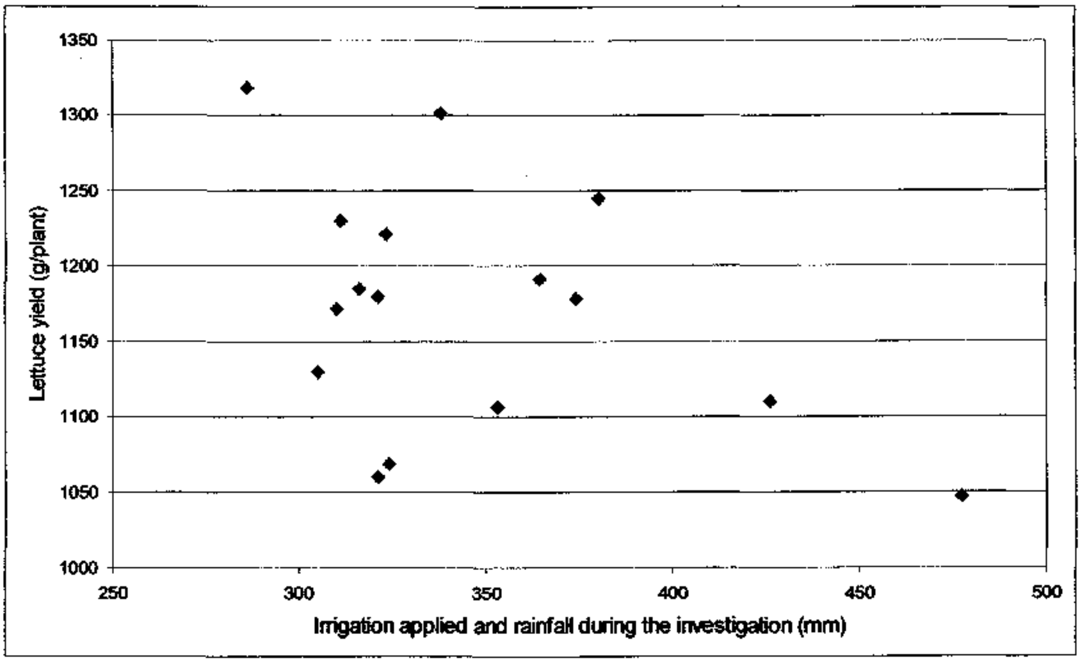


Figure 4: Marketable yield adjacent to each rain gauge verses total irrigation and rainfall

Recommendations

1. Use a soil moisture sensor or pan evaporation to allow more accurate scheduling of irrigation.
2. Apply no more irrigation then what the soil can hold plus 20 % to account for dry areas of the wetting pattern. For a lettuce crop that is older then a third grown apply no more then about 6 mm of irrigation in one application.

References

1. Milani, S. (1992). *Survey of irrigation efficiencies on horticultural properties in the Peel - Harvey Catchment.* Division of Resource Management Technical Report 119. Agriculture Western Australia.
2. Calder, T and Lantzke, N. (1997). *Irrigation efficiency testing. Carrot growing properties - Swan Coastal Plain.* Agriculture Western Australia. Internal Report

Lettuce Cropwatch

5. Commercial Crop Monitoring and Surveys

5.1 - Lettuce Disease Monitoring

S. Kumar, L. K Teasdale, D. G Gatter.

Summary

A survey of lettuce disease incidence and severity in commercial crops was undertaken in the winters of 1998 and 1999 in the Wanneroo, Bullsbrook and Gingin districts of Western Australia. The survey attempted to quantify the occurrence of common plant diseases in typical commercial crops with different cropping histories and to identify any unknown disorders so that future research and development projects to control them could be planned. An attempt was made in one case to also quantify the magnitude of yield loss associated with a common disease.

The most widespread diseases encountered in the survey were Sclerotinia drop (mostly *Sclerotinia minor*) and lettuce big vein virus, causing the greatest yield loss in commercial production despite regular spraying by growers and soil fumigation with metham sodium. Spasmodic occurrences of Dry leaf spot (*Xanthomonas campestris pv. vitians*) and Downy mildew (*Bremia lactucae*) were also noted.

Sclerotinia regularly exceeded 60% incidence on one property from mid June to late July 1999 and was regularly noted at levels above 20% on other properties surveyed. This was despite widespread use of metham sodium as a soil fumigant before planting.

Lettuce big vein virus also infected every crop surveyed at levels of incidence often exceeding 80%. This was most notable in the widely grown cultivar Oxley. The number of infected plants usually increased exponentially from about 4 weeks after transplanting when night minium fell to around 10° C. Infected plants mostly remained marketable but were associated with reductions in head weight of up to 20%.

Dry leaf spot was serious on some farms in the cultivar Assassin, with total losses being recorded in some plantings. Downy mildew was present at low levels in most crops later in the winter. Some as yet undiagnosed virus-like symptoms were noted in a number of crops.

Future research work will investigate better control measures for these diseases through variety resistance (big vein) and fungicide and biological control methods for sclerotinia. The effectiveness of metham sodium as a fumigant for controlling this disease also needs closer attention.

Introduction

Production and export of lettuce in Western Australia had been in steady decline throughout the 1990's with yields remaining static despite advances in technology. There may have been many reasons for this but one possible cause may have been increased losses from pests and disease. Possible contributory factors included increased intensity of cropping, a slow down in registration of new chemicals and possibly pest/disease resistance to existing control measures.

There had been no systematic attempt to quantify the occurrence or impact of diseases in lettuce crops in Western Australia in the past. This information was considered to be an essential pre-requisite to development of a plan to increase industry productivity in the future through targeted research and development.

Diseases like sclerotinia rot, lettuce big vein and dry leaf spot were known to be widespread before commencement of this study and part of this project was thus devoted towards getting better information on the impact of these diseases on the industry as a whole. Grower disease control practices vary from crop to crop and season to season but there are many common practices between growers, some of which may be unique to lettuce growers in WA cropping on free draining sandy soils.

Materials and Methods

1998 Monitoring

Autumn and winter crops

At the commencement of the project in 1998, all known commercial growers of iceberg lettuce in WA were invited to participate in a crop survey to identify the impact of diseases and pests on the crop. Three vegetable producers growing "iceberg" lettuce were chosen from a list of volunteers to participate in the survey in autumn and winter crops. The 3 properties were selected to allow monitoring of a range of crop histories from a newly established to an older property that had been cropped for more than 15 years. These are referred to as Property A, B and C.

Property A was established on newly cleared land. The lettuce crop that was monitored was the second consecutive crop at that site.
Property B had been in operation for more than 15 years and grew a wide range of vegetables. The monitored plot was established 4 years before and had an average of 2 crops of lettuce per year since.
Property C had been cropped for more than 15 years and for the last 4 years the monitoring plot has a crop of lettuce and Chinese cabbage grown each year.

Two plots of transplanted lettuce on each property were selected for monitoring, one in autumn (transplanted 19/05/98) and the second in winter (22/07/98). At each site, 4 blocks of 80 plants (20 plants per row x 4 rows per bed) were pegged out randomly within the crop soon after transplanting. All plots were visited once per week from transplanting, and disease development was recorded. General observations on other plantings on these properties and neighbouring properties were also made during these visits. Identification of common diseases was made visually and plants expressing these symptoms were progressively counted on the Tuesday of each week. Those with any unfamiliar symptoms were collected and submitted for diagnosis by the AGWEST disease diagnostics centre.

The diseases that were routinely monitored for were:
Sclerotinia rot – *Sclerotinia minor* Jagger and *S. sclerotiorum* (Lib.) de Bary
Dry leaf spot – *Xanthomonas campestris* pv. *vitians* (Pammel) Dowson
Downy mildew – *Bremia lactucae* Regel
Rhizoctonia base rot – *Rhizoctonia solani* Kühn
Lettuce big vein virus (LBV)

Other viral diseases

To confirm the symptoms of these diseases, specimens were collected and submitted to the AGWEST Diagnostics unit prior to commencement of the monitoring programme. Confirmation was made using pathogen isolations and other diagnostics tools. To investigate whether LBV affected the harvest weight of lettuce, plants from one of the four blocks of the 2nd transplanting (cultivar Oxley) were rated for LBV severity and weighed on properties A and C. Just before harvest, lettuce plants were rated visually as follows; no symptoms (1), slightly affected (2), moderately affected (3) and severely affected (4). The harvested and marketable trimmed heads in each category were weighed individually.

Summer crops

A summer monitoring programme started on the 10th November and was conducted on properties B, C and an additional property, D. Property D had been cropped for over 10 years and other crops grown included cauliflower, celery, cabbage and Chinese cabbage. Only one lettuce crop was monitored from transplanting to harvest. Lettuce was pegged out and monitored as in the winter crop.

1999 Monitoring

The survey was conducted on properties B, C, D and an additional property, E in 1999. The field surveyed on property B was in its 2nd year of cropping on virgin soil. Property E had been cropped for more than 15 years, growing a wide range of vegetables. This grower ceased growing carrots on the property in 1997 due to a high incidence of *S. sclerotiorum*. Weekly surveys were conducted from 18/5/99 to 5/10/99 using methods previously described. Based on previous season's findings the intensity of survey was reduced from 4 blocks of 80 plants to a single block of 100 plants.

As well as surveying disease progress, a weekly snapshot of the incidence of each of the targeted diseases was taken in young, medium and mature crops on each of the 4 properties. This allowed observations of any changes in disease incidence over the 20 week period.

Results

Sclerotinia diseases

After field observations and lab isolations, it was evident that *S. minor* was more prevalent on lettuce than *S. sclerotiorum*. *S. sclerotiorum* was only isolated on lettuce from properties where carrots, broccoli and cauliflower were used as rotation crops. Lettuce were susceptible to *S. minor* at any stage from transplanting to harvest whereas *S. sclerotiorum* appeared to affect mostly mature lettuce.

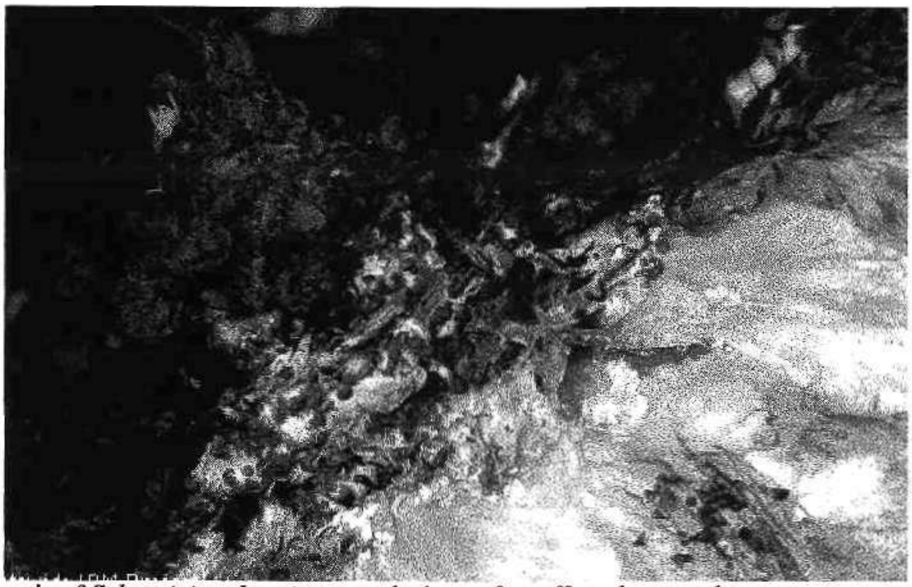


Figure 1: Sclerotia of *Sclerotinia sclerotiorum* at the base of an affected mature lettuce

When comparing the 3 properties (Fig. 2), lettuce on property C was the most severely (14%) affected. This property was a relatively old garden that had vegetable crops including lettuce grown continuously for more than 15 years. Only 2% of the crop on property B was affected. This was the 4th year of cropping on this part of the property. Property A was in its first year of establishment with the 2nd consecutive lettuce crop in the ground at the time of the survey. No sclerotinia disease was recorded on this crop. Similar observations were made on other properties visited, where older gardens were more severely affected by sclerotinia disease than newer properties.

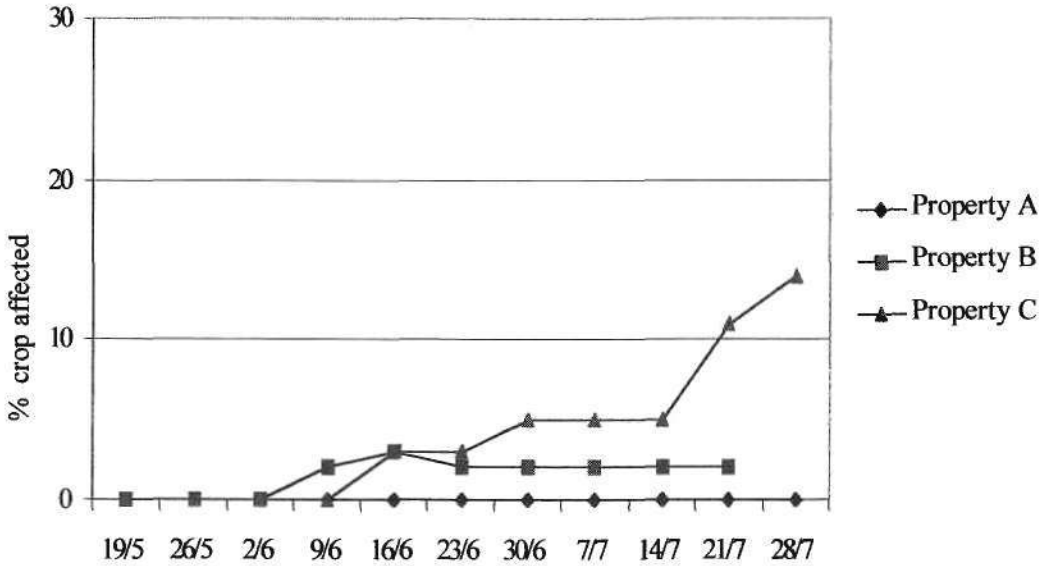


Figure 2: Incidence of sclerotinia disease on lettuce transplanted in May 1998.

The severity of disease caused by *Sclerotinia* spp. was higher in lettuce transplanted in July than May of 1998. The plots surveyed on properties B and C were on older gardens. On these 2 properties 20 and 25% of the lettuce was affected just before harvest (Fig. 3). May and July surveys on Property A were conducted on the same plots. By July, this plot had its 3rd successive lettuce crop transplanted. Although there was no disease caused by *Sclerotinia* spp. in the 2nd crop (Fig 2), the 3rd crop had 5% affected by harvest (Fig. 3). It is likely that the inoculum of *Sclerotinia* spp. was introduced via machinery used on the older property in Wanneroo.

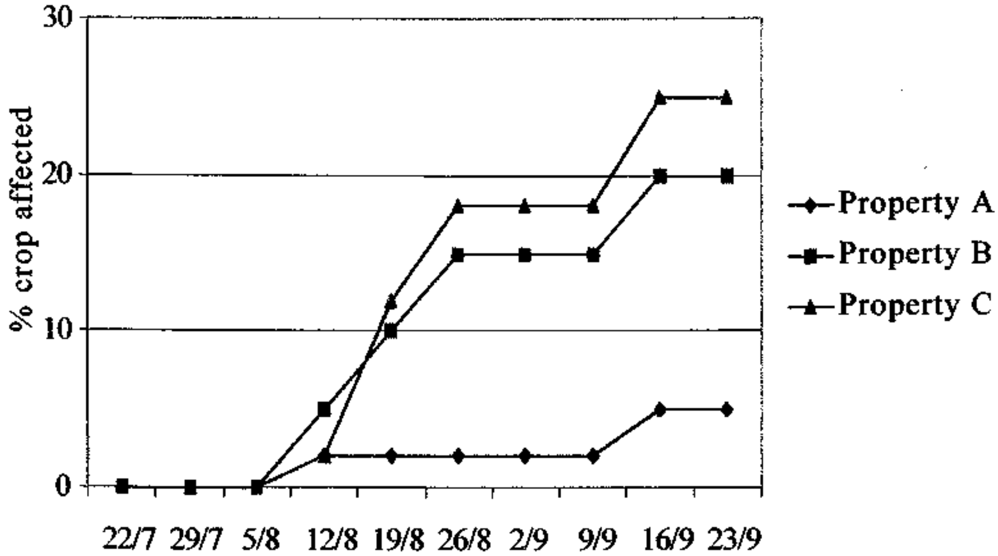


Figure 3: Incidence of Sclerotinia disease on lettuce transplanted in July 1998.

The crop survey in 1999 revealed similar disease patterns to that observed in 1998. The severity of sclerotinia diseases were higher in the colder wet winter months, however there was no consistent pattern in relation to temperatures. Most severe incidence of sclerotinia disease on property C and E was observed between mid to end of June 1999 (Fig. 4). This coincided with abundant apothecia formation observed on the soil surface, leading to release of abundant ascospores for additional inoculum apart from infection due to myceiogenic infection. Relatively high disease levels were recorded, especially on older properties, despite growers using a regular fungicide program that included control measures for *Sclerotinia* spp. All lettuce fields were treated with metham-sodium before transplanting. It appears that this does not have an effect on sclerotia of the 2 *Sclerotinia* spp.

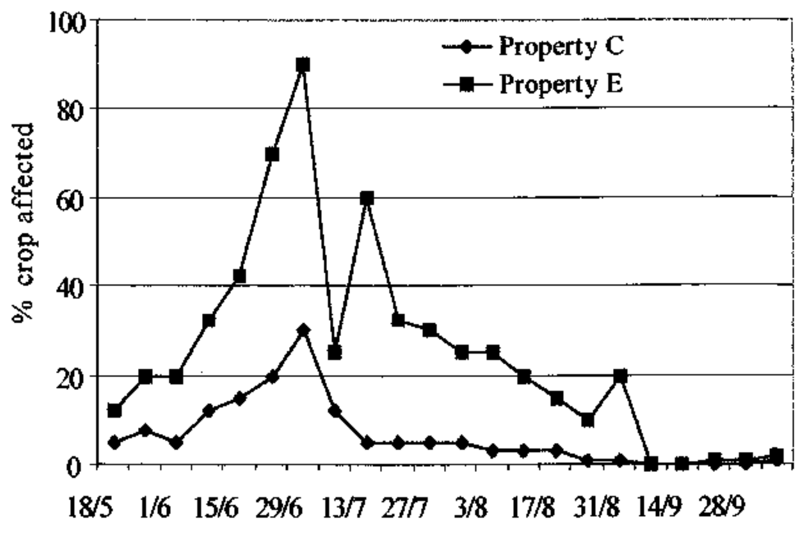


Figure 4: Incidence and severity of sclerotinia disease of lettuce from May to September 1999. The period of high incidence of disease coincided with abundance of fungal apothecia noted in lettuce plots.

Lettuce big vein virus (LBV)

It has been noted that LBV is predominantly a winter disease. In both 1998 and 1999 seasons the first symptoms on lettuce were not seen until 4-5 weeks after transplanting. The symptoms increased rampantly between 6-8 weeks after transplanting. Lettuce plants that did not show symptoms of LBV 8-9 weeks after transplanting remained visually unaffected until harvest.

The first early obvious symptoms of LBV on lettuce in the field was visible by the 1st week of May with severe infestations in July to October. Only a few LBV symptoms were noted in November and none in December. The older gardens appeared to have higher percentages of lettuce crop affected (80% of lettuce on property C - Fig. 6). Unlike sclerotinia disease, LBV was recorded at a higher level on the newer property (42% of lettuce on property A - Fig.6). This was the 2nd consecutively grown lettuce on Property A. As LBV can only be spread in soil by the fungal vector *Olpidium brassicae* (Woronin) P.A. Dang, the inoculum on this new farm may have been introduced on dirty machinery and/or infested seedlings from the nursery.

Figure 5: Symptoms of lettuce big vein virus on cultivar Oxley.

The cultivar Oxley appeared to be much more susceptible to LBV when compared to cultivars like Grande, Napean and Raider. These latter cultivars are not suitable as winter crops for other agronomic reasons. Only 19% of Grande showed LBV symptoms, while Oxley transplanted at the same time had 60% of the crop affected (Fig. 6). Similar disease progression was noted in crops transplanted in July but the incidence of LVB was higher than the May transplants (Fig. 7).

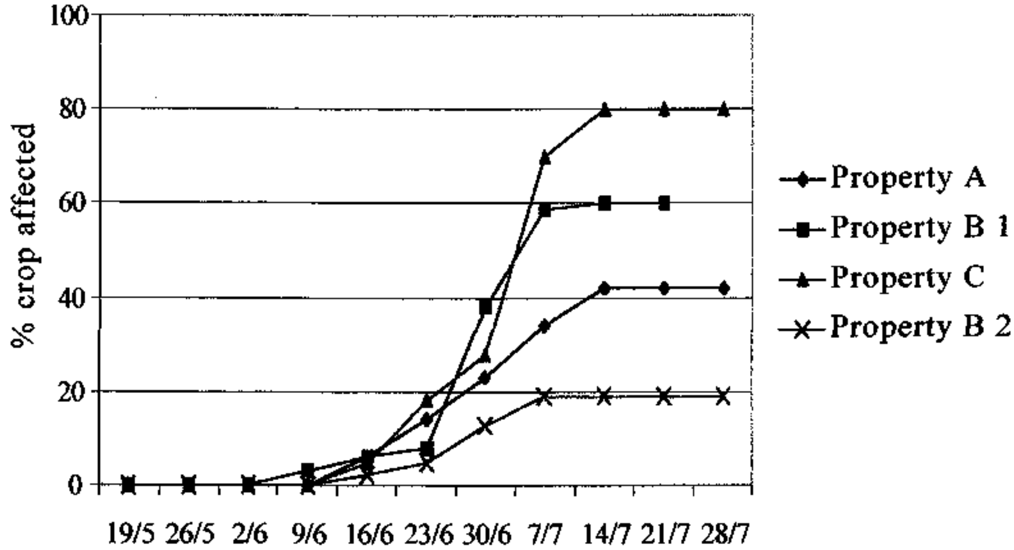


Figure 6: Severity of Lettuce big vein virus on transplanted lettuce. Properties A and C had cultivar Oxley while B1 and B2 on property B represent cultivars Oxley and Grande, respectively.

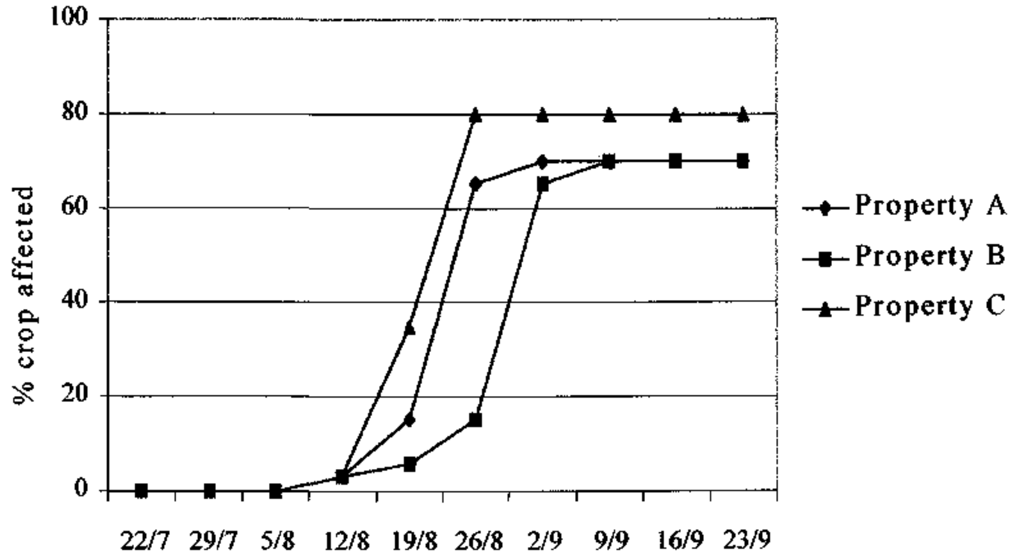


Figure 7: Incidence of lettuce big vein virus on lettuce (cultivar Oxley) on 3 properties.

Soil treatment with metham-sodium did not appear to affect the severity of LBV. The efficacy of this on the virus vector in soil is not known.

It was generally observed that the lettuce heads affected by LBV were slower to mature and appeared to be smaller than unaffected ones. Preliminary results show a trend where greater severity of LBV led to lower the harvest weights (Fig.8).

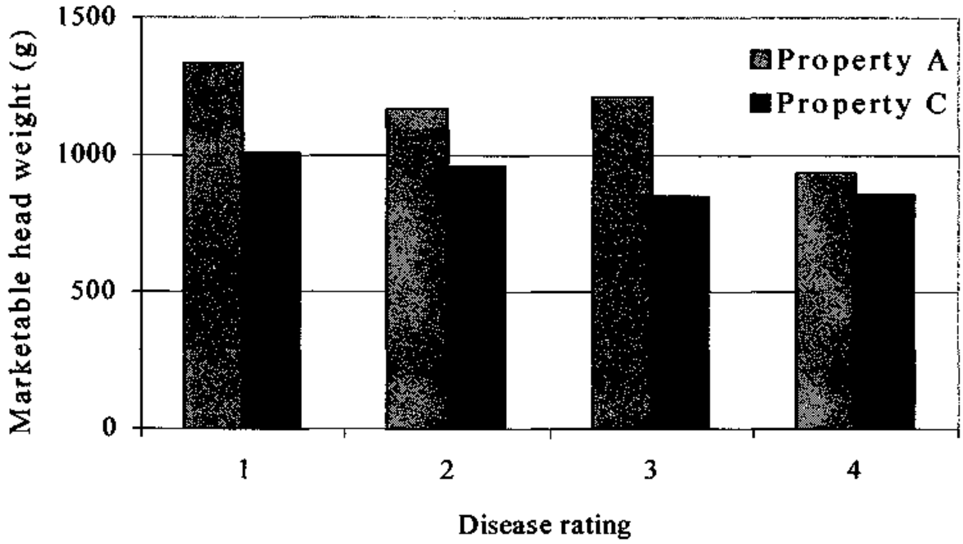


Figure 8: The effect of lettuce big vein virus on marketable weight of lettuce. The plants before harvest were rated as follows; No symptoms (1), slightly affected (2), moderately affected (3) and severely affected (4).

Based on field observations in 1999 the most severe symptoms of LBV were noted on lettuce from the end of June to end of September (Fig. 9). There was a general trend where incidence of LBV was positively correlated to lower winter temperatures. It appeared that the maturity of the lettuce was delayed by at least a week and those plants that were very severely affected formed smaller heads. Lettuce big vein symptoms were evident on direct seeded winter lettuce as early as 2 weeks after germination which led to a higher incidence of LBV, thus a lower percentage cut at harvest. A current HRDC funded vegetable project VG99015 is investigating the quantitative and qualitative loss in lettuce due to LBV.

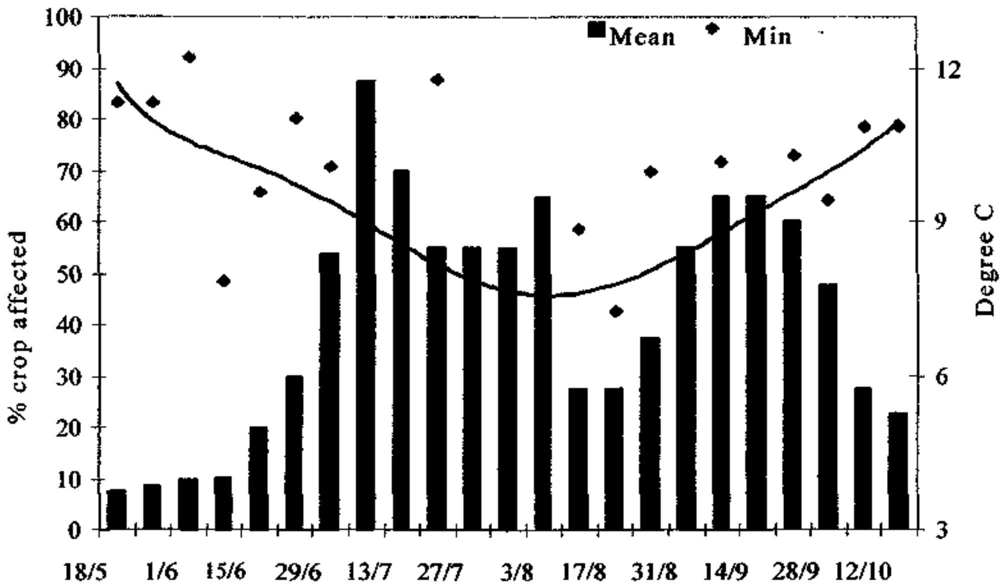


Figure 9: Increase in incidence of lettuce big vein symptoms on cultivar Oxley on property C in 1999 with reduction in ambient temperature.

Dry leaf spot (Xanthomonas campestris pv. vitians)

The incidence of dry leaf spot in 1998 was low. There were no symptoms present on Property A which was a new garden. Property C used cultivar Oxley as an autumn crop, which has high levels of tolerance to dry leaf spot. On property B autumn crops of cultivar Grande and Napean showed some symptoms of the disease, however the yield and quality of lettuce was not affected.

There was a severe outbreak of dry leaf spot in autumn 1999. This was basically attributed to cultivar Assassin, which is very susceptible to the disease. On property B, 2 successive plantings of 0.75 ha each were ploughed in due to the severity of infection near maturity in mid April. Spot checks on 6 other properties at the same time revealed that 50-80% of near-mature Assassin crops were affected severely. Growers who did not use the cultivar Assassin had minimal crop loss. Most of the older gardens are expected to have some carry-over inoculum from past years, however, the incidence of the disease could be attributed to the susceptible cultivar and heavy rains in April/May 1999. The possibility of seed-borne infection was not established.

Other viral diseases

Apart from LBV, tomato spotted wilt virus (TSWV) and lettuce necrotic yellows virus (LNYV) appearred sporadically on lettuce in Western Australia. Infection rates by both the viruses noted during grower survey ranged from 0-8%, with higher levels recorded in spring when the thrip and aphid vectors are high in numbers. One of the contributing reasons for low levels of arthropod vector transmitted viral diseases is the use of regular insecticidal sprays. An unfamiliar virus-like symptom was noted on property C in the winter of 1998. This symptom was again noted on property B, C and D in winter 1999. Plants having these symptoms were negative for ELIZA tests for TSWV, lettuce mosaic virus (LMV), Turnip mosaic virus (TMV), beet western yellows (BWV) and LNYV. Further work on ELIZA tests and electron-microscopy will be carried out by HRDC funded project VG 99015.

Downy mildew

Downy mildew of lettuce was only noted to be of major concern on Property A in the spring crop of 1998 when cultivars Napean and Raider were planted. The other properties at the same time recorded low to negligible levels of downy mildew on the same cultivars. It appears that the weather conditions in this part of Western Australia may not favour high incidences of downy mildew as reported elsewhere in the country or the widespread adoption of resistant cultivars may be minimising disease expression.

Conclusion

The urbanisation in Perth is taking up a lot of available land for horticultural activities around the Perth Metropolitan areas. This has led to more intensive farming of existing land. The high monetary value and a regular market supply does not encourage crop rotation. This has seen an increase and persistence of common diseases associated with lettuce.

There are a range of diseases that affect lettuce in Western Australia. Of all lettuce diseases, sclerotinia rot and LBV are widespread in Perth metropolitan lettuce growing areas. The crop is susceptible to these and others highlighted in this report from transplanting to harvest. Sclerotinia rot leads to a direct reduction in yield while LBV contributes to both quantitative and qualitative losses.

Both Sclerotinia rot and LBV are hard to control. Despite a regular prophylactic fungicidal spray and the use of metham-sodium, the incidence of sclerotinia rot and LBV is very high, especially on older properties. This disease survey has led to the initiation of an HRDC funded project (VG99015) which will look at novel methods of reducing the impact of sclerotinia rot and LBV on lettuce.

5.2 Pest Monitoring

E.C. Steiner, D.G.Gatter and L.K. Teasdale

Summary

A survey of lettuce pest and beneficial insect incidence in commercial crops was undertaken in the northern metropolitan region of Perth Western Australia from November 1998 to October 1999. The aim of the survey was to find out which pests caused crop losses, when they occurred and how severe the damage was so that we could plan future research and development projects to control them. A knowledge of abundance and presence of natural enemies (beneficials) of commonly occurring pests was considered to be a useful starting point for future integrated pest management approaches to pest control.

Thrips were the most abundant pests found and were present at moderate to high levels all year round. Aphids dominated in winter and Rutherglen bugs and leafhoppers in summer. Moths of native budworm (cutworm) *Helicoverpa punctigera* and tomato grub (*Helicoverpa armigera*) were both present in the lettuce crops. A greater number of the more difficult to control tomato grub moths were trapped in March and April than native budworm. All pests were effectively controlled by frequent applications of insecticides and there was no damage of economic significance in any of the crops monitored.

Although regular spraying achieved good control, the tomato grub has a history of rapid insecticide resistance development. Continued exposure to insecticides will hasten the onset of resistance, particularly if products from the same group of chemicals with a similar mode of action are used in rapid succession. This has already become a problem in lettuce production districts in Queensland, New South Wales and Victoria.

Future research work needs to investigate the potential for integrated pest management techniques and whether the pesticide resistance problem in the tomato grub population encountered Eastern Australia is also developing in W.A.

Introduction

Lettuce pests and control practices in Western Australia

Insect pests such as aphids, Rutherglen bug, cutworms and plague thrips were known to be commonly occurring in lettuce crops before commencement of this study and part of this project was thus devoted towards getting better information on the impact of these pests on the industry as a whole. Grower pest control practices are largely based on routine spraying with pesticides from all of the chemical groups. At the commencement of this project, there were few if any IPM practices employed by commercial growers and little known about the abundance of pest beneficials in lettuce fields. With a steady reduction in insecticides registered for pest control in lettuce, and the ever present threat of insect resistance to pesticides developing, there was a perceived need to establish baseline data about pest and beneficial status in commercial crops. This information could form the basis for future IPM research work on the crop.

Materials and Methods

The relative abundance of several lettuce pests and crop damage was measured at three lettuce producing properties. Pest monitoring traps set in Wanneroo, Carabooda and Bullsbrook were serviced and inspected weekly over 11-12 months. Monitoring was also conducted for a brief period at two properties in Landsdale and Yanchep when lettuce crops became available.

Weekly monitoring commenced in November 1998 and concluded in October 1999. Pest trapping and crop inspections were the two measurements of pest abundance routinely conducted. Crop scouts were provided with a pest identification chart and a standard recording sheet to facilitate monitoring. Ten plants from each of 3 crop stages of growth were scored for pests and damage at each site. The presence of beneficial insects was also recorded.

Heliothis monitoring

A pheromone trapping system was used to capture moths of the tomato grub (*H. armigera*) and native budworm (*H. punctigera*) in lettuce crops. Moths were attracted by pheromone into a funnel type trap suspended about 1.5

meters above the ground on a post. Each heliothis species had its own distinctive pheromone lure that was renewed every 4 weeks. The moths were killed inside the trap by an insecticide (dichlorvos) strip.
Traps for *H. punctigera* were first set in November 1998. Trapping for *H. armigera* commenced in March 1999 when the appropriate pheromone became available. All samples were collected weekly and frozen until scored.

Other Pests

Yellow sticky traps were used to monitor other pests associated with lettuce crops. Three stages of crop growth were monitored, 1) transplanting to thinning 2) thinning to head formation and 3) head formation to harvest. The traps were set weekly within the rows of lettuce. They were attached at crop height to upright sprinkler pipes or to short wooden stakes. The sticky traps were collected weekly and stored in a freezer (-15°C) until scored.

Results

Heliothis

The combined trapping results for three properties are shown in Figure 1.

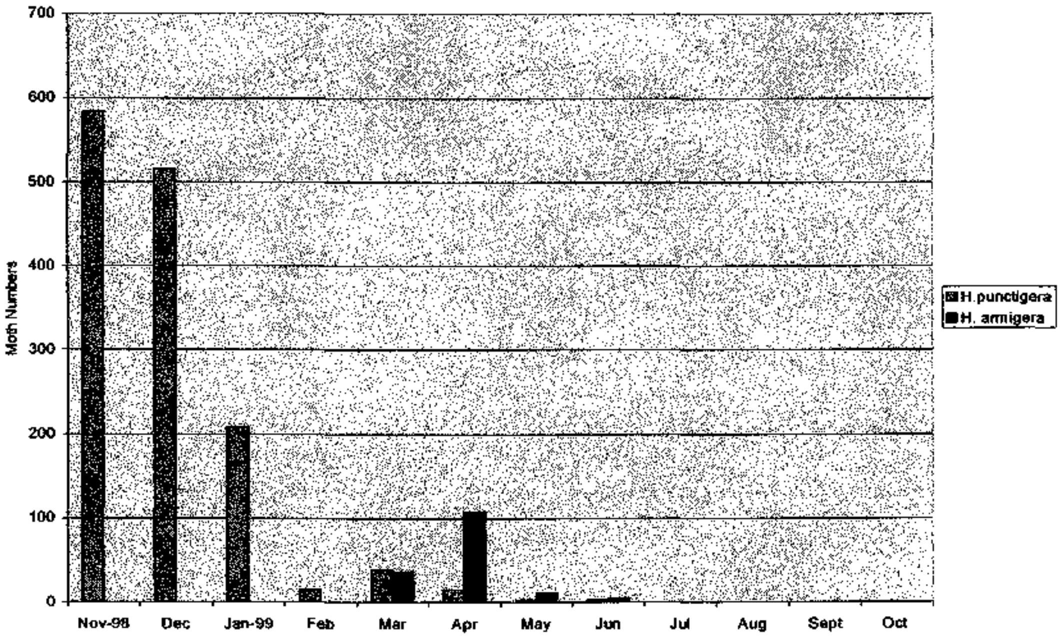


Figure 1: Heliothis moths trapped at three lettuce producing properties in the northern Perth region.

H. punctigera moths were captured from November until June. The highest populations were recorded from November until the end of January.
H. armigera populations were greatest from March until June. In April all three of the main trapping sites yielded a large number of *H. armigera* moths. In comparison, the number of *H. punctigera* had declined significantly from the summer months. There were still a large number of *H. armigera* at the start of autumn reaching a small peak in April. They persisted in lower numbers in May and dropped to a small population by June.

Other Pests

Figure 2 shows pest presence and population peaks. There were no differences in the three crop stages for the type or number of other pests caught on sticky traps. Rutherglen Bug, leafhoppers, thrips and aphids were the pests caught most frequently at all sites. Crop scouts observed beet webworm (*Hymenia recurvalis*) damaging lettuce in April and May.

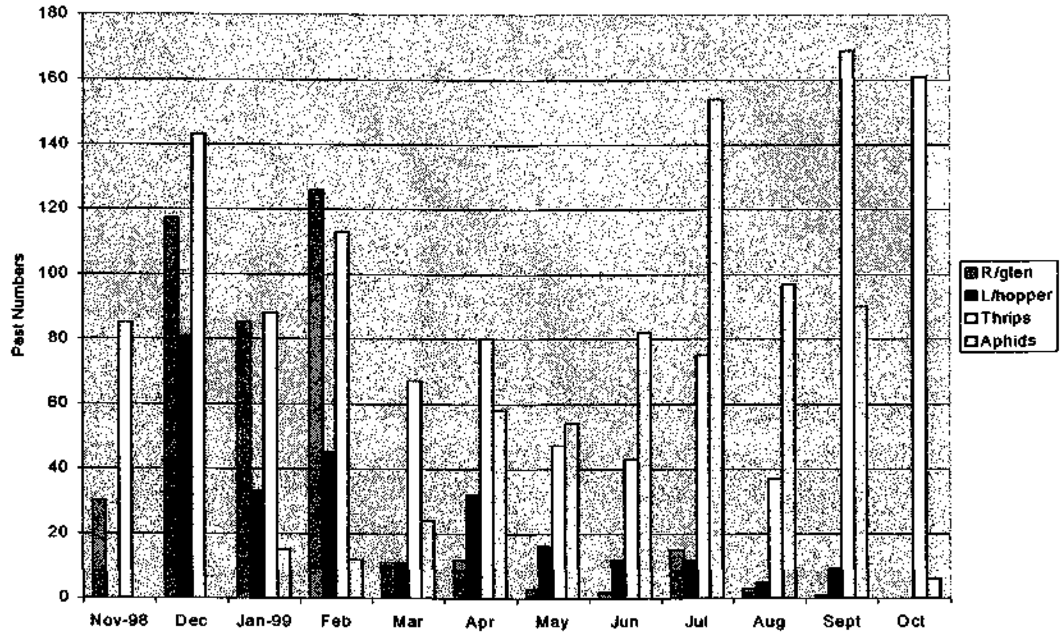


Figure 2: Pests caught on sticky traps at three lettuce producing properties in the northern Perth region.

Beneficial Insects

Ladybirds (Coccinellidae) and lacewings (Neuroptera) were occasionally noticed in the crops.

The insect counts presented in Figures 1 and 2 are summarised in terms of seasonal abundance in Table 1. Notably, pests are present all year round in lettuce crops, necessitating control measures. Thrips were the most abundant pests and are present at moderate to high levels all year round. Aphids dominate in winter and Rutherglen bugs and leafhoppers in summer.

Table 1: The seasonal abundance of lettuce pests caught on sticky traps on 3 properties in the north of Perth, 1998-99.

Season	*Rutherglen Bug*	*Leafhoppers*	*Thrips*	*Aphids*
Summer	328	159	344	27
Autumn	26	59	194	136
Winter	20	29	155	333
Spring	31	9	415	96

Discussion

Heliothis

The large November population of *H. punctigera* suggests it would have been present in October prior to the commencement of trapping in 1998. Although lettuce growers may not expect a problem with heliothis in April, the results indicate there is still some risk of damage at that time of the year. Visual crop inspections did not detect many heliothis grubs or significant damage but this was symptomatic of the frequent use of chemical sprays to control pests on the crop.

Although regular spraying currently achieves good control, *H. armigera* has a history of rapid insecticide resistance development. Continued exposure to insecticides will hasten the onset of resistance, particularly if products from the same group of chemicals with a similar mode of action are used in rapid succession.

Other Pests

Although visual assessments of the crops did not detect any significant damage from the four main pests, the monitoring showed the potential for pest damage. Rutherglen bug, leafhoppers, thrips and aphids were all noticeable at various times. Rutherglen bug and leafhoppers were most numerous in the summer months whereas most aphids were trapped in winter and early spring. Thrips were present all year with the majority being trapped over spring and summer. Aphids were most prevalent during winter. Cover sprays however are at present achieving good control of these pests. Table 1 shows the seasonal abundance of these four pests.

Beneficial Insects

The low number of beneficial insects observed can be attributed in part to the regular use of organochlorine, organophosphate, synthetic pyrethroid and carbamate insecticides on the crop. Routine spraying of these pesticides is a consequence of persistent pest presence throughout the year.

5.3 Nutrition, Irrigation and Sap Testing 1998

L.K. Teasdale, D.R. Phillips, D.G. Gatter

Summary

Irrigation practices employed by two commercial lettuce growers were monitored during October, November and December of 1998. Total precipitation (irrigation and rainfall) was measured weekly with rain gauges and compared with lysimeter volumes to calculate through-drainage percentages. Daily evaporation data ('E pan' - source Perth Bureau of Meteorology) was collected to estimate actual irrigation replacement (crop factor). Additionally, lysimeter leachate were tested weekly for nitrate content in order to assess nitrogen loss from the crop. Lettuce petioles from the crops were also tested on a weekly basis to track plant nutritional status. Irrigation water from bores on the two properties was tested for background nitrate levels on 8th December.

The data revealed that the growers were irrigating with crop factors between 120% and 190% and this resulted in through-drainage of about 30% to 80% of the total water applied.

Petiole sap nitrate levels were recorded in the range of 900 - 1700 mg/l (200 - 380 NO_3-N). Lysimeter leachate nitrates were in the range of 114 to 484 mg/l (26 - 110 NO_3-N). This equates to losses from the cropped area of up to 50 kg/ha of Nitrogen per week.

Introduction

Sustainability of lettuce production on the sandy soils of the Swan Coastal Plain is critically dependent on efficient irrigation and fertiliser practice. Excessive irrigation adds to pumping costs and can cause loss of fertiliser and groundwater pollution. Monitoring of current commercial grower practice is a first step in developing an optimum irrigation and fertiliser regime for this time of year. The results of crop monitoring can be used as a benchmark against which future improvements in efficiency and crop performance can be measured.

Research at Medina research centre in the autumn of 1998 showed that the optimum irrigation rate for iceberg lettuce grown with overhead sprinkler irrigation was around 140% Epan. Under all irrigation regimes, there was significant ' through drainage' below the root zone of the crop which resulted in proportionate losses of soluble nutrients, particularly nitrate. The research also defined an optimum sap nitrate range for maximum yield.

Aim

This study aimed to compare irrigation schedules applied by growers to the research results from Medina to estimate the water savings possible from commercial adoption of the research results. We also aimed to test the sap nitrate guidelines in commercial crops and assess their potential for adoption.

Materials and Methods

Two commercial lettuce growers were selected as monitoring sites for the spring production period. Site 1 was a grey Bassendean sand with a shallow water table in the Bullsbrook district and site 2 was a yellow phase Karakatta sand in the Wanneroo district. The sites were typical of the lettuce production area of the Swan Coastal Plain. Both crops were irrigated using overhead sprinklers and the sites had been cropped with vegetables for more than 10 years. Both crops were direct sown in late October 1998.

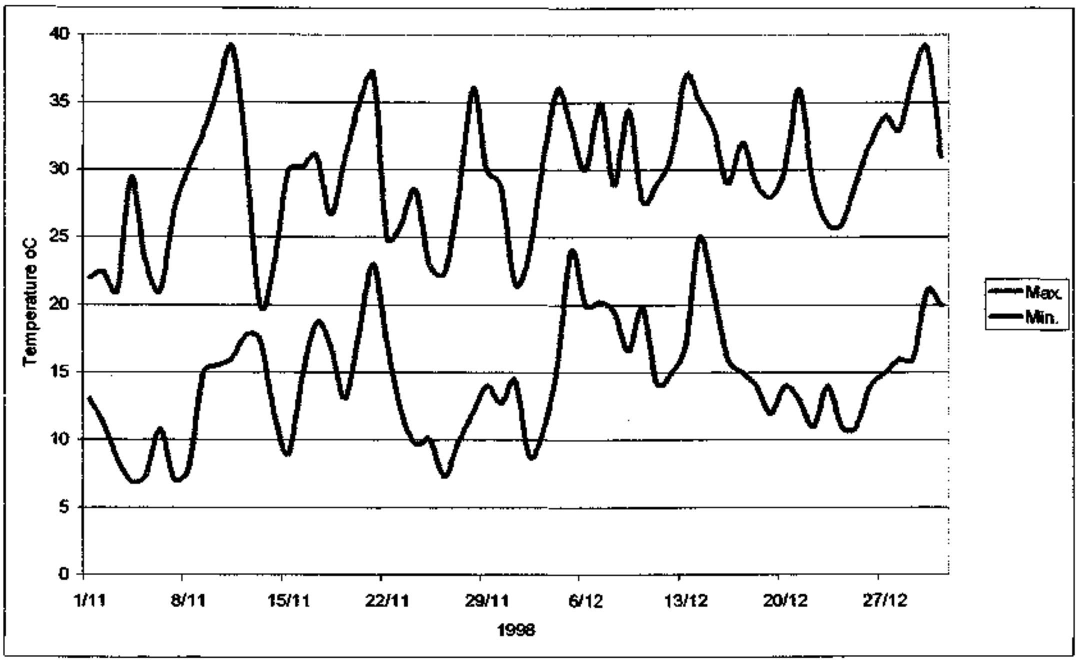
Rain gauges were placed within the crop and read weekly. Daily evaporation figures provided by the Perth Bureau of Meteorology were collated and a crop factor figure for each site was calculated.

Drainage lysimeters made of galavanised steel and with a collection area of 40cm by 40 cm were buried 40cm underneath both crops, pumped out weekly and leachate volumes recorded. The leachate volume was converted to a per hectare basis and then compared to the irrigation figure for the same period so that a through-drainage percentage could be derived.

Samples of lysimeter leachates were tested for nitrate levels using a Merck Rqflex® reflectometer. Nitrate readings were converted to nitrate-N (NO_3-N) on a per hectare basis so that weekly loss of nitrogen from the crop could be calculated.

Plant samples were taken on a weekly basis from both sites. The petioles of young, fully expanded leaves or wrapper leaves were removed and crushed for petiole sap extraction and then tested for nitrate levels using a Merck Rqflex® reflectometer. Plant nutritional status can be effectively tracked using this method.

Daily maximum and minimum temperatures, rainfall and evaporation for the study period are shown in the following Figure 1.



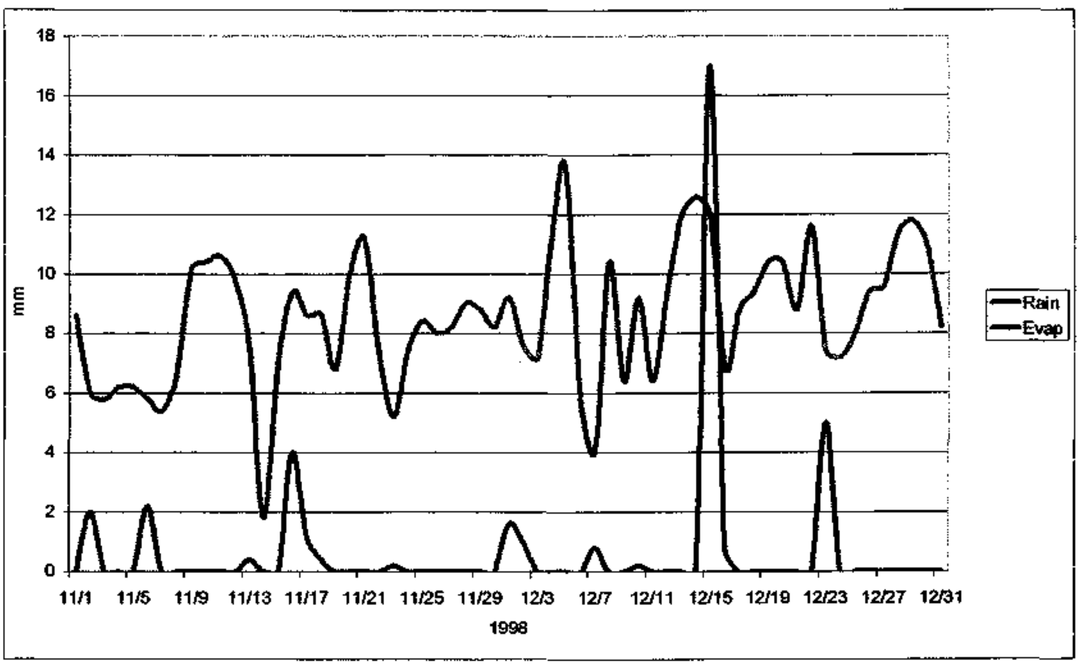


Figure 1: Daily maximum and minimum temperatures, rainfall and evaporation for the period of the study.

Note: Weather data as gathered by the Perth Bureau of Meteorology from the following locations:
Rainfall - Wanneroo
Evaporation - Perth airport
Temperatures - Pearce.

Results

Crop factor levels (% Epan) applied by the grower at Site 1 were in a similar range to those tested in the Medina research and the percentage leached into the lysimeters was also similar (Table 1).

Table 1: Evaporation, irrigation and volumes leached at site 1 (planting date 28/10/98).

Date 1998	*Days*	*Evaporation mm*	*Raingauge mm*	*Irrigation ML/ha*	*Crop Factor %*	*Lysimeter Volumes*		*Through - Drainage %*
						L	*ML/ha*	
10/11	13	75.7	90.0	0.900	119%	7.10	0.444	49.3
17/11	7	56.7	85.5	0.855	151%	9.05	0.566	66.2
24/11	7	57.8	74.0	0.740	128%	5.80	0.362	49.0
1/12	7	58.0	79.5	0.795	137%	5.77	0.361	45.4
8/12	7	58.6	99.0	0.990	169%	5.40	0.338	34.1
Total	41			4.280			2.071	

The total nitrogen in nitrate form leached from this site exceeded 100kg/ha for the life of the crop (Table 2) and nitrate levels in leachate were consistently high throughout the life of the crop. At the same time, levels of nitrate in plant sap were consistently below the optimum levels derived from Medina research.

Table 2: Leachate nitrates and petiole sap nitrates at Site 1.

Date 1998	*Crop age Days*	*Lysimeter Leachate*		*N loss Kg/ha*	*Petiole Sap*	
		NO_3 mg/l	*NO_3-N mg/l*		*NO_3 mg/l*	*NO_3-N mg/l*
10/11	13	199.5	45.1	20.0		
17/11	20	322.0	72.8	41.2		
24/11	27	302.0	68.3	24.7	1200	271
1/12	34	207.0	46.8	16.9	900	203
8/12	41	114.0	25.8	8.7	1080	244
15/12	48				1150	260
22/12	55				1000	226
Total				111.5		

Irrigation levels at site 2 were again in a similar range to those from the Medina research with levels exceeding the optimum crop factor replacement late in the life of the crop. Leaching was in direct proportion to irrigation rate and exceeded the highest leaching rates recorded at Medina with the highest rates of irrigation (Table 3).

Table 3: Evaporation, irrigation and volumes leached at Site 2 (planting date 29/10/98).

Date 1998	*Days*	*Evaporation mm*	*Raingauge mm*	*Irrigation ML/ha*	*Crop Factor %*	*Lysimeter Volumes*		*Through - Drainage %*
						L	*ML/ha*	
10/11	12	68.0	83.8	0.838	123%	4.15	0.259	31.0
17/11	7	56.7	75.0	0.750	132%	7.60	0.475	63.3
24/11	7	57.8	85.0	0.850	147%	6.00	0.375	44.1
1/12	7	58.0	85.0	0.850	147%	7.50	0.469	55.1
8/12	7	58.6	113.0	1.130	193%	14.90	0.931	82.4
15/12	7	34.9	60.0	0.600	172%			
Total	47			5.018			2.509	

The nitrogen loss through nitrate leaching at this site exceeded 160kg/ha for the life of the crop, reflecting the higher irrigation rates applied by this grower late in the life of the crop. Sap nitrates were in the optimum range early in the life of the crop but fell away as the crop matured (Table 4).

Table 4: Leachate nitrates and petiole sap nitrates at Site 2.

Date 1998	*Crop age Days*	*Lysimeter Leachate*		*N loss Kg/ha*	*Petiole Sap*	
		NO_3 mg/l	*NO_3-N mg/l*		*NO_3 mg/l*	*NO_3-N mg/l*
10/11	12	149.5	33.8	8.8		
17/11	19	316.0	71.4	33.9	1700	384
24/11	26	470.0	106.2	39.8	1650	373
1/12	33	484.0	109.4	51.3	1300	294
8/12	40	156.5	35.4	32.9	1010	228
15/12	47					
Total				166.7		

There was evidence of considerable nitrate accumulation in the groundwater at site 2 in bores 1 and 2 but little was found in the bore at site 1 (Table 5).

Table 5: Irrigation water Nitrate levels for sites 1 and 2 on 8th December 1998.

	Site 1.		*Site 2.*	
	NO_3 mg/l	*NO_3-N mg/l*	*NO_3 mg/l*	*NO_3-N mg/l*
Bore 1.	<3	<3	62	14
Bore 2.			38	9
Bore 3.			<3	<3

Conclusion

Irrigation regimes applied by growers who did not use any formal scheduling technique other than judgement and experience were in a similar range to the treatments tested in Medina research. The crop factors resulting from a lack of planned scheduling ranged from levels below the optimum range derived from research to levels well above optimum.
Both growers tended to increase irrigation rates as the crop approached maturity and the rates overall were higher at site 2 than site 1.

Water loss through leaching below the crop was of a similar order to the higher irrigation treatments from Medina and increased in direct proportion to the rate of irrigation applied. Nitrate was detected in leachate water throughout the growth period at levels similar to Medina research plots. This observation verified that nitrogen loss below the root zone of the crop was an inevitable consequence of irrigating the crop.

5.4 Nutrition, Irrigation and Sap Testing 1999

L.K. Teasdale, D.R. Phillips, D.G. Gatter

Summary

Fertiliser practices employed by five commercial lettuce growers were monitored during May to October of 1999. Complete fertiliser application schedules were obtained from four of the five growers. Levels of applied fertilisers were compared with recommended rates for the Swan Coastal Plain derived from Medina research.

Additionally, petioles from the crops were tested on a regular basis to track plant nutritional status. Results of petiole sap testing were compared with recommended standards from previous nutritional research (Medina 1998) and with the results from a field demonstration run concurrently with this study (see Chapter 4.1).

The study showed that all growers used more nitrogen than the recommended optimum. Sap testing suggested a tendency to overfertilise crops with nitrogen in the early and mid growth stages and underfertilise in the later stages of growth. Sap testing proved to be a potentially valuable tool for managing fertiliser programmes for lettuce to maximise yield.

Introduction

Successful commercial lettuce production on sandy soils of the Swan Coastal Plain depends on a high level of skill in managing irrigation and fertiliser inputs. Research in 1998 and 1999 defined the optimum combinations of irrigation and nitrogen nutrition for maximum yield in autumn and summer. Limited commercial crop monitoring in 1998 showed that grower irrigation schedules were variable but slightly above the recommended crop factor levels. The work also showed that sap nitrate levels in crops grown by these growers fell below the standard derived from our research for part of the crop's life.

Aim

This study aimed to use crop monitoring to assess the adequacy of commercial nutrition schedules by comparing them with the optimum sap nitrate guidelines, and in doing so identify the opportunity for industry wide yield and productivity improvement. Crop monitoring offers the dual benefit of providing a benchmark for future performance improvement and allows growers to compare their practices with the results of research.

Materials and Methods

Five commercial lettuce growers were selected as monitoring sites for the winter production period. Sites A and C were grey Bassendean sand with low nutrient retention properties and a shallow water table in the Bullsbrook district. Site B was a yellow phase Karakatta sand in Carabooda, site D was the same soil type in GinGin and site E was a slightly poorer Karakatta sand in the Wanneroo district. The sites were typical of the lettuce production area of the Swan Coastal Plain. All crops were irrigated using overhead sprinklers.

Plant samples were taken on a weekly or fortnightly basis from all sites. Petioles of young fully expanded leaves or wrapper leaves were removed and crushed for sap extraction and then tested for nitrate, phosphate and potassium levels using a Merck Rqflex® reflectometer. Plant nutritional status can be effectively tracked using this method.

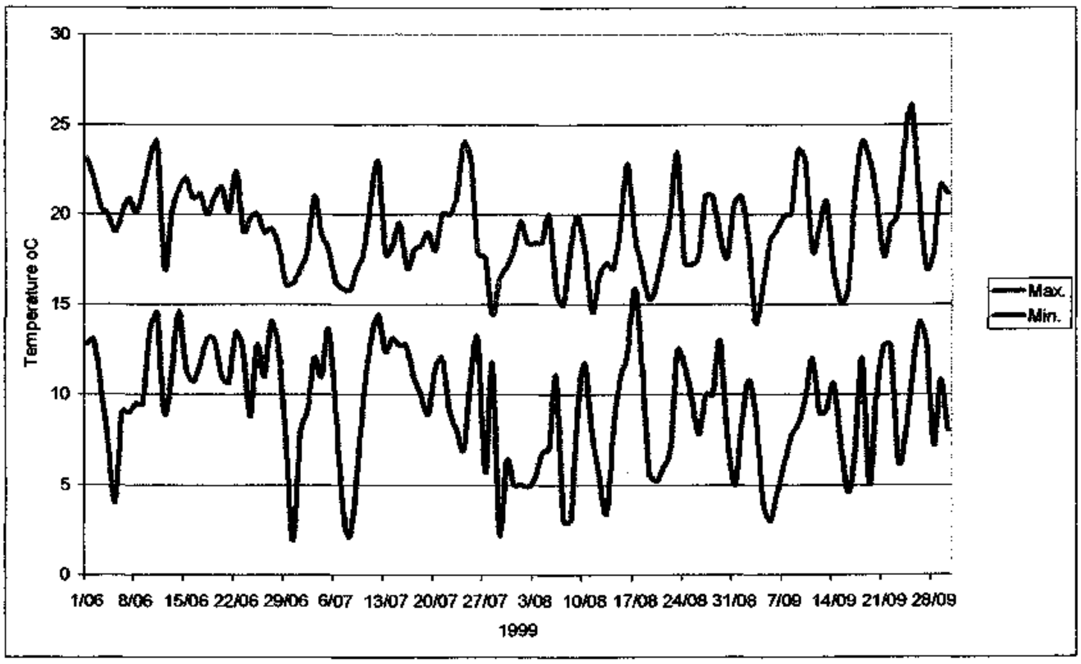
Mini drainage lysimeters were sited under several crops to record nutrient leachate. They were only partially successful and need modification for future use. Some useful data was obtained comparing adjacent crop areas on the same property with and without poultry manure (deep litter).

The cultivar Oxley was grown at four of the five sites (Table 1.) Three of the five crops were direct sown (sites A, C and D) and the others grown from transplanted seedlings. This produced differing maturity times and fertiliser programmes as shown in Table 1. Direct sown crops matured around 100 days and transplanted crops at about 80 days.

Table 1: Varieties grown, planting methods and times.

Site	Lettuce Variety	Direct sown or Transplanted	Approximate Date
A	Cool Breeze	Direct Sown	22/06/99
B	Oxley	Transplanted	4/07/99
C	Oxley	Direct Sown	7/07/99
D	Oxley	Direct Sown	4/06/99
E	Oxley	Transplanted	22/06/99

Weather variables for the duration of the study are shown in Figure 1. Temperatures and evaporation were lower than the 1998 study because it was conducted in late spring and this study in winter.



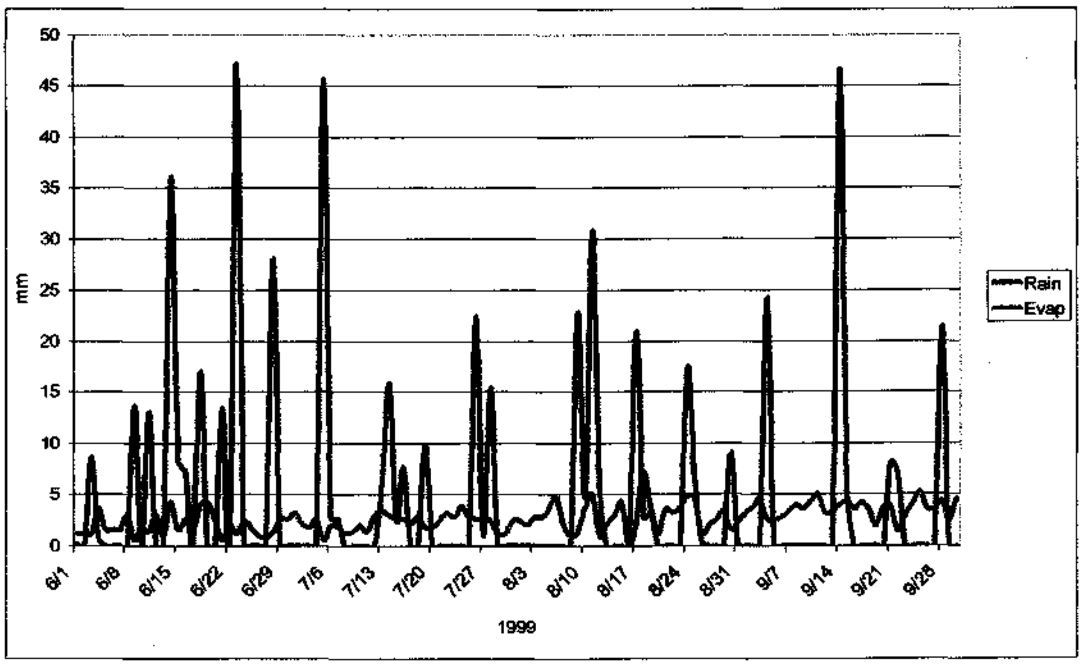


Figure 1: Daily maximum and minimum temperatures, rainfall and evaporation.

Note: Weather data as gathered by the Perth Bureau of Meteorology from the following locations:
Rainfall - Wanneroo

Evaporation - Perth airport
Temperatures - Pearce.

Results

There was a 190% difference in applied nitrogen rate between the highest user and the lowest and up to 250% difference in potassium rate. Poultry manure was the most commonly used fertiliser , contributing up to 60% of total nitrogen at sites B and E and up to 100% of phosphorus at sites C and E. (See Table 2.).

Best practice nitrogen programmes derived from Medina research were validated in a field demonstration run concurrently with this monitoring study (see Chapter 4.1). This demonstration showed that high yielding lettuce (cv Oxley) could be grown with a crop life total of 325 kg/ha of nitrogen applied in regular applications at 7 day intervals.
This rate was in good agreement with programmes at sites A and B but was exceeded at the other three sites. Two of these higher rate sites were direct sown crops, justifying some extra fertiliser application.

Table 2: Fertiliser programmes followed at the 5 sites.

1999	*Nitrogen applied kg/ha*					*Phosphorous applied kg/ha*					*Potassium applied kg/ha*				
Sites	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**
22/05				164.0					88.0					98.0	
5/06				16.0											
9/06					204.0					102.0					122.4
12/06				16.0											
16/06															
19/06				29.0					4.0					15.0	
23/06	35.0		83.0		7.3			78.0			22.0		29.0		4.7
26/06				29.0	9.8				4.0					15.0	4.8
30/06	42.5				153.0					76.5	32.0				91.8
4/07	42.5	20.0		29.0	9.8		8.0		4.0		32.0	23.0		15.0	4.8
8/07	42.5		18.0		11.6						32.0				13.4
11/07	42.5	210.0			17.9		76.0				32.0	91.0			17.9
15/07	42.5		18.0		11.6						32.0				13.4
18/07	42.5			13.0	17.0				4.0		32.0			15.0	20.2
22/07	42.5		18.0		11.2						32.0				15.0
25/07	42.5	25.0		29.0	14.9		4.0		4.0		32.0	27.0		15.0	20.2
29/07			18.0	29.0	14.9				4.0					15.0	20.2
3/08		25.0			10.9		4.0					27.0			15.0
7/08			83.0		14.9			54.0					29.0		20.2
10/08				115.0					4.0					15.0	
14/08			29.0	22.0	17.0								43.0		23.9
17/08					12.3										17.7
21/08		34.0	29.0	22.0	17.0							41.5	43.0		23.9
24/08					12.3										17.7
28/08		34.0	29.0	22.0	17.0							41.5	43.0		23.9
31/08															
3/09			29.0										43.0		
7/09		22.0													
10/09			29.0										43.0		
14/09															
17/09			29.0										43.0		
21/09															
24/09			29.0										43.0		
Totals	375.0	370.0	441.0	535.0	584.4		92.0	132.0	116.0	178.5	278.0	251.0	359	203.0	491.1

Notes from Table 2. The **P** record for site A is not available.

Leaching

Concentrations of nitrate recovered from drainage water below crops receiving dressings of poultry manure were high in every case but lower without it (site 4). Phosphorus also leached readily at site 3 (Table 3).

Table 3: Mini lysimeter leachates: nitrates and phosphates recorded at Site E.

Date	*Grower E*	*Nitrate (NO_3) mg/l*	*Nitrate N (NO_3-N) mg/l*	*Phosphate (PO_4) mg/l*
8/06/99	Site 1 (with poultry manure)	254	57	26
	Site 2 (with poultry manure)	368	83	23
15/06/99	Site 1 (with poultry manure)	243	55	22
	Site 2 (with poultry manure)	330	75	19
10/08/99	Site 3 (with poultry manure)	253	57	135
	Site 4 (No poultry manure)	85	19	28

Notes from Table 3. Sites 1 & 2 were adjacent in one crop and sites 3 & 4 were adjacent in a later crop on the same property

Petiole Sap

Sap testing commenced when most crops were about half way through their life. Insufficient sap could be extracted from small plants before then. Sampling continued through to maturity for most crops, giving 7 to 8 points on the sap nutrient profile for each crop in this growth phase. These were compared to a control profile (Figure 2 - Study 1) from a demonstration on another property reported in chapter 4.1. The fertiliser schedule for the control (Study 1) is shown in Table 4 of Chapter 4.1 - denoted F1(1).

Table 4: Petiole sap phosphate and potassium levels.

1999	*Sap Phosphate (PO_4) mg/l*					*Sap Potassium (K) mg/l*				
Sites	*A*	*B*	*C*	*D*	*E*	*A*	*B*	*C*	*D*	*E*
11/07	330					4350				
18/07	408					5200				
25/07	335			305		5000			4450	
1/08	385	310			380	4200	4700			4600
8/08	455	330		290	365	3400	3900		3900	3950
15/08	385	305	240		380	4000	4500	4350		3700
22/08	365	370	300	425	430	3100	4350	4300	3700	4200
29/08		435	385		430		3700	4800		3650
5/09		435	465	325	445		4200	5200	3500	3550
12/09		375	368		385		3800	4650		2750
19/09			390					3650		
26/09			365					3850		
3/10			345					3550		

Sap phosphate and potassium levels recorded at all sites were in a similar range throughout the life of the crops and the levels were also mostly within the range experienced in Medina research. Sap nitrates were within the optimum range for most crops early in their life but declined progressively in all crops from about the mid way point of their life to be below the optimum standard by maturity (Table 5). This point is illustrated more clearly in Figure 2.

Table 5: Petiole sap Nitrate (NO_3) and Nitrate-N (NO_3-N).

1999	*Sap Nitrate (NO_3) mg/l*					*Sap Nitrate N (NO_3-N) mg/l*				
Sites	*A*	*B*	*C*	*D*	*E*	*A*	*B*	*C*	*D*	*E*
11/07	1670					377				
18/07	2160					488				
25/07	2020			1660		457			375	
1/08	1285	2120			1455	290	479			329
8/08	1590	2110		1655	1330	359	477		374	301
15/08	1290	1550	1670		770	292	350	377		174
22/08	970	1335	2230	1380	985	219	302	504	312	223
29/08		1800	1960		815		407	443		184
5/09		810	1440	1120	395		183	325	253	89
12/09		890	1695		71		201	383		16
19/09			1340					303		
26/09			1135					257		
3/10			840					190		

Figure 2 shows that a typical pattern at all grower sites was for sap nitrate to fall below what is considered to be the lower optimum (1700 mg/l NO_3 or 390 mg/l NO_3-N) for the last 4 to 7 weeks of the crop's life. This was most noticeable at site E where sap nitrate was below the minimum for the last 7 weeks of crop life. In this period grower E applied 189 kg/ha of nitrogen to the crop compared with a recommended level of 245 kg/ha (N).

At site A, the crop remained within the optimum range for sap nitrate for all but the last 4 weeks, during which time fertiliser applications were discontinued due to a severe infection with *Xanthomonas campestris* (pv vitians).

Sap nitrate levels at site B fell below the standard for 3 of the last 4 weeks of the crop's life. In this period, only 90 kg/ha (N) was applied compared to the recommended level of 140 kg/ha (N).

Sap nitrate levels at site C were below the recommended minimum for 4 of the last 5 weeks before harvest. In this period 116 kg/ha (N) was applied compared to the recommended 175 kg/ha (N).

At site D, sap nitrate levels were below recommended for the last 3 weeks of crop life. In this period 44 kg/ha (N) was applied compared to the recommended 105 kg/ha (N).

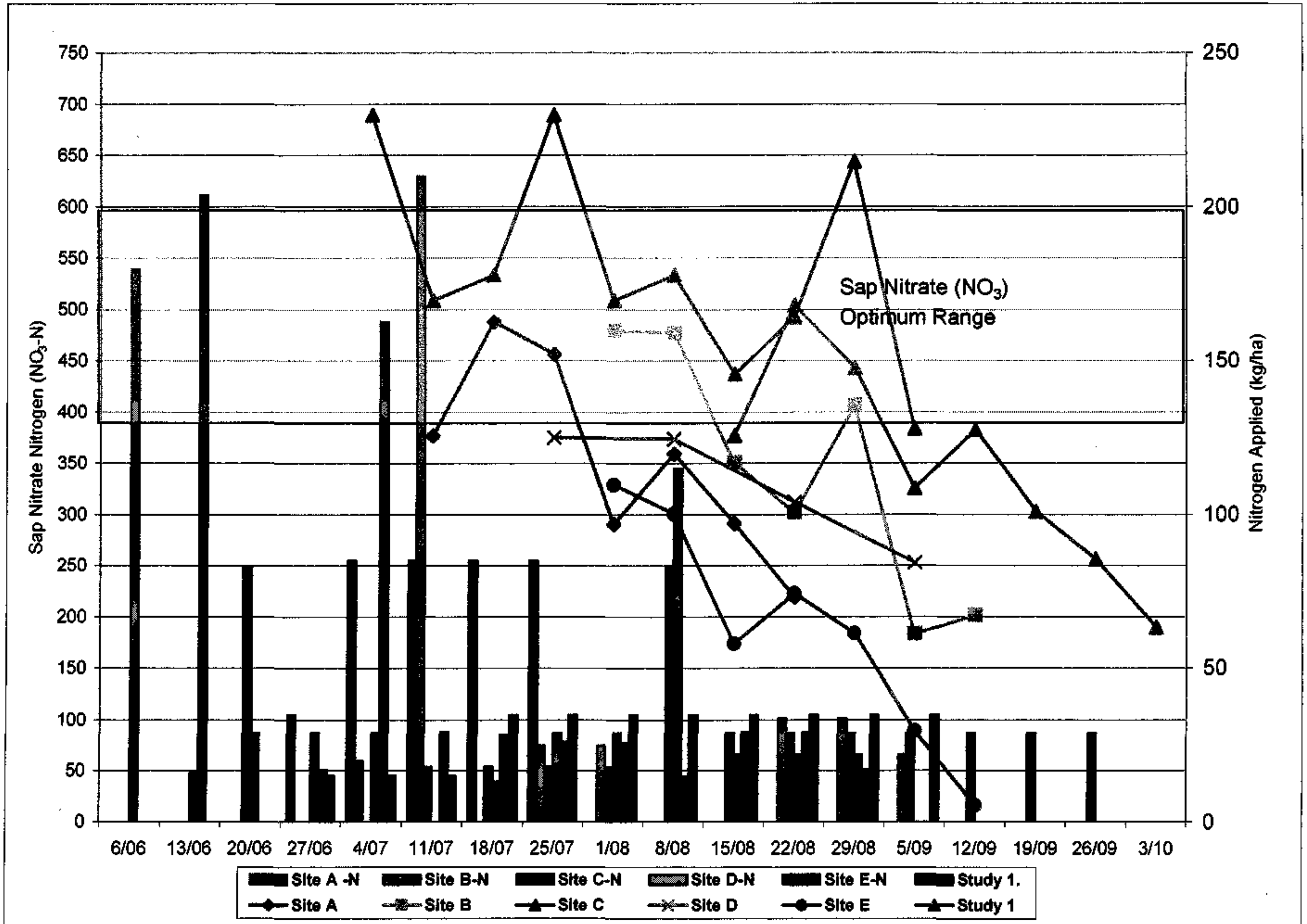


Figure 2. Sap nitrate profiles for 5 commercial lettuce crops compared to an experimental control (Study 1) and fertiliser programmes for all sites.

Discussion

The monitoring study showed a wide variation between fertiliser programmes used by participating growers to achieve similar results. Yields were not compared between sites but sap nitrate profiles indicated that crop nutritional status diverged between crops as they approached maturity.

The results suggested that all growers had a tendency to overfertilise with nitrogen in the early and mid growth stages and underfertilise later. The validity of this conclusion and the yield consequences require further study. Sap testing showed potential as a tool to manage fertiliser programmes better than the current methods used by growers.

Lettuce Cropwatch

6. Project Extension

Growers NewsLetter

No.1 Winter 1998

Lettuce Cropwatch

Management Program for Sustainable Lettuce Production

Agriculture WESTERN AUSTRALIA

HRDC

Dear Grower

This is to follow on to my last correspondence dated 27/1/98 in regards to the **HRDC funded Lettuce Project**. I am pleased to inform you that a Project Officer "Satendra Kumar" has been appointed for two years. We have also got some volunteer Growers who will be working closely with the Project Officer, and by now you may have seen some publicity about the Project in the local and rural press.

The objective of this Project is to improve the quality, yield, reliability, product uniformity and profit from lettuce production for domestic and export markets through adoption of new management practices. This will be done via Nutrition and Irrigation research trials at Medina Research Station and active on-farm monitoring on volunteer Grower properties.

The Project aims to :-

1. Provide a target group of growers with a better information base from which to make business decisions.

2. To develop simple record keeping practices for budget preparation with the grower group These budgets can be used as an aid to decision making. The records collected should also allow the retailers and marketers to 'trace back' the production techniques used should it be required.

3. To introduce and test a range of other decision making aids to the 'pilot' group including:

Rapid plant sap analysis techniques and standards.

Routine soil and plant testing.

Irrigation monitoring equipment and scheduling guidelines (including EPan, tensiometers and lysimeters).

Pest and disease scouting and problem identification.

Computer based budgeting aids.

Post harvest cool chain monitoring.

4. To provide regular feedback of results to the pilot group on a 'one to one' basis and in a group setting at demonstrations and field days.

5. To encourage adoption of decision-making aids by the wider industry through demonstration of the principles involved with the volunteer group.

6. To identify the pest, diseases and other problems associated with commercial lettuce production over the course of the year and measure crop loss as an aid to future research planning.

7. To test the technique of intensive monitoring and support as a means of ensuring adoption of better management practices, which are both more profitable and minimise adverse effects on the environment.

8. To get the growers used to the idea of actively participating in a development project for the benefit of the whole industry.

To start-off the Project, a Nitrogen and Irrigation experiment was conducted at Medina Research Station in March/April this year to determine the optimum combination of watering and nitrogen fertiliser for different stages of lettuce growth. Very encouraging results were obtained which were shown to the interested growers on 20/4/98 during a Farm Walk conducted at the trial site.

It was demonstrated that irrigation rates as low as 40 to 60% of Evaporation was sufficient in the first 3 weeks after transplanting. From week 4 onwards and up to harvest, a minimum of at least 100% evaporation replacement was necessary (see Fig. 1). It was demonstrated that good quality lettuce could still be grown without any poultry manure. Monitoring the lettuce plant weight weekly showed that 40kg/ha/wk of nitrogen was adequate for the whole life of the crop provided irrigation was managed well. Irrigation less than 98% Evaporation replacement was not enough and rates above 128% led to excessive leaching.

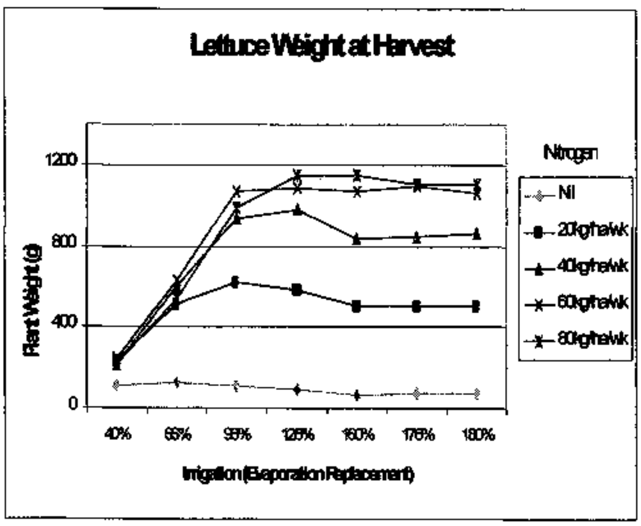


Figure 1. Effect of irrigation and nitrogen on individual plant weight of transplanted lettuce at harvest.

The nitrogen requirement in winter months would be higher and this will be dependent on the rainfall and irrigation amount.

The rate of nitrogen leaching below the root zone with different rates of irrigation was also demonstrated. It can be seen in Figure 2 that excessive water usage led to a lot of nitrogen (represented as kg of Nitrogen per hectare on the left side of the graph) lost as leachate. This increases direct on-farm costs and the potential for ground water pollution. If watering was too low (right hand end of the graph) plants did not use the fertiliser applied and more was lost. Nitrogen was most efficiently used at 110% replacement.

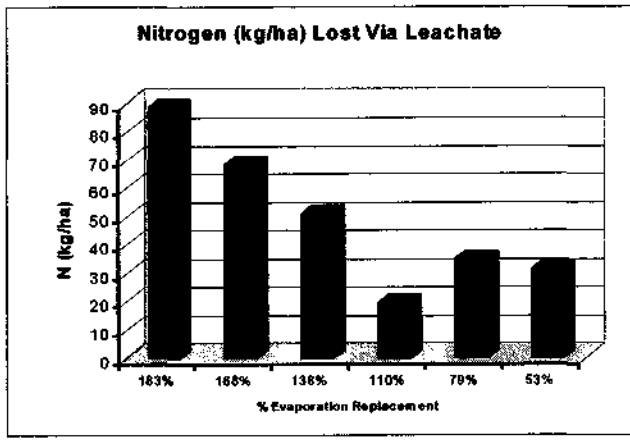


Figure 2. Effect of watering regime on loss of Nitrogen due leaching below the root zone.

The weekly monitoring of lettuce crops on 3 grower properties in Wanneroo and Bullsbrook has started. This will be extended to other volunteer growers in time. All lettuce growers will be kept informed of the progress of the Project and it is hoped that useful ideas will be adopted to help maximise farm profits while minimising ground water pollution.

If you need any further information please contact Project Manager Dennis Phillips or Project Officer Satendra Kumar at Midland District Office on phone 9274 5355.

Growers NewsLetter

No.2 Spring 1998

Lettuce Cropwatch

Management Program for Sustainable Lettuce Production

Dear Grower

This newsletter is the second in a series which aims to keep you up to date with results of the HRDC lettuce industry development project which is funded by your vegetable levy.

The project has been underway since February and work so far has been directed towards identifying optimum nitrogen and irrigation for producing the crop. An experiment completed at Medina Research Station last autumn, which a number of you inspected at a field day in May, has continued to produce vital information. *In this edition of the newsletter we report some more of the results and take **a look at** what has been happening to our lettuce exports.*

1. *Irrigation and Fertiliser Results*

We set out to answer a number of questions when we commenced this work, including;

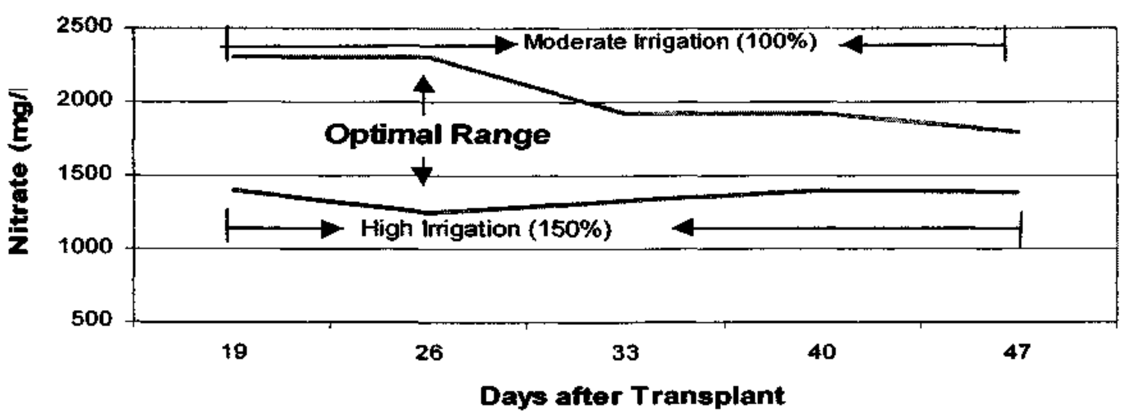
- **Can 'do-it-yourself' plant sap tests be used to help plan and monitor a fertiliser program for lettuce?**
- **Can we reduce water use for this crop without loss of yield or quality?**
- **Will reduced irrigation also save fertiliser use and wastage without loss of yield or quality?**

The answer to all these seems to be **yes** but it is not all as simple as it sounds.

The first objective of being able to do a simple test in the field and decide on the spot whether the crop needs more fertiliser or not has a lot of appeal. Growers who have tried plant tests over the years have been disappointed by having to wait weeks for the results of a laboratory test by which time it is too late to take action. Also when the results came back they were sometimes mystifying in their conclusions.

Sap testing has the promise of overcoming those barriers but our results show that tests for nitrate are only useful if your irrigation practice is good and better still that you irrigate to a known formula.

Lettuce Sap Nitrate Profile



Two important factors that came from the research which make interpretation of these test results difficult were:

- Crops that were **under irrigated** showed very **high levels** of nitrate in sap and you could be fooled into believing that everything was OK when in reality it couldn't have been worse.

- Even when crops were adequately irrigated, sap levels varied depending on the rate of irrigation.

The latter discovery is shown in the graph on Page 1. At a moderate rate of irrigation which grew a crop as good as the best in the trial, the sap nitrate levels followed the trend shown by the upper **(green) line** on the graph. This treatment had 100% of evaporation replaced as irrigation throughout its life i.e. for every millimetre of water that evaporated, a millimetre was put back as irrigation.

If 50% more water was applied to the crop, more fertiliser was also needed to get maximum yield. When that was done, it resulted in sap levels that followed the bottom **(red) line**. The optimum sap levels were **lower** but the crop was just as good. The only problem was that fertiliser and water were wasted to achieve it.

Our conclusion is that a recommendation for using sap testing must be based on operating within the range between the two lines on the graph for the life of the crop and irrigating to a known formula.

We are currently evaluating the nitrate levels and irrigation levels in commercial lettuce crops with the help of a **Cropwatch** volunteer group of lettuce growers. These growers are also keeping good records of other practices so that pest and disease problems in the crop can be mapped over the course of a season. At a later stage, these growers and others who are interested will be helped to adapt the irrigation method to their situation and to use the sap test method to manage crops.

2. *Exports – What has happened to your market*

Lettuce growers who have had difficulty making ends meet supplying the local market in recent years could look to what has happened to our export market for an answer. It may come as a surprise to many in the industry that lettuce production in WA has contracted in the last 5 years and loss of export markets in particular has been a significant factor. The graph at the **end of this page** shows how our export market in South East Asia has eroded over the last 5 years compared to the rest of Australia.

Although many say we have lost out to US producers in Singapore in particular because we are not price competitive, a detailed analysis of the figures suggest that we have more likely lost these markets to other Australian growers.

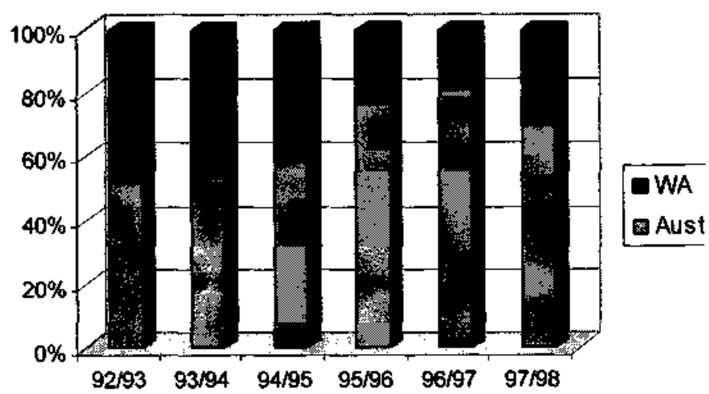
The good news is that in the latter half of 1997/98 the Singapore market bounced back for WA producers due to the combined effects of floods in California and a weakening Australian Dollar. Since then, floods in NSW have given us another opportunity.

The 64 dollar question is **'Can we hold onto these gains?'**

What we can and should do about this situation is the subject of a new R&D project application which your lettuce project team has just submitted for funding next year. The outcome of that proposal and more details will be provided in our next newsletter around Christmas time.

Until then, your feedback on this newsletter or questions can be directed to Project Officer Satendra Kumar or Project Manager Dennis Phillips at Agriculture WA Midland on phone 92745355.

WA's Market Share of Total Lettuce Exports



Growers NewsLetter

January 21st 1999

Management Program for Sustainable Lettuce Production

Growers Seminar

When : Friday 26th February 1999

Where : Wanneroo Recreation Centre

"Coffee Lounge" cnr Church St

and Scenic Drive, Wanneroo

When : From 2.00pm

All Growers welcome,

details in this newsletter

This newsletter is the 3rd in a series which aims to keep you up to date with results of the HRDC lettuce industry development project which is funded by your vegetable levy.

Growers Seminar

A ***Lettuce Cropwatch*** Growers seminar will be held at the Wanneroo Recreation Centre (cnr. Church St & Scenic Drive), Wanneroo (phone 94051961) on **Friday** the **26th February** starting **2.00pm.** All growers are welcome.

A range of issues relating to the lettuce industry will be discussed which include :-

Research on optimum irrigation and nitrogen requirements for lettuce.

Findings of current ***Lettuce Cropwatch*** activities at volunteer grower properties, which include pest and disease, fertiliser and irrigation monitoring.

Highlights of a study-tour to lettuce grower properties in Victoria and New South Wales.

Future project work on lettuce.

Formation of **"Grower Advisory Group"** to oversee the present and future lettuce R&D projects and identify development needs of the lettuce industry.

Lettuce harvest aid in operation in Hay, NSW

Irrigation and Nitrogen

The experiment conducted at Medina Research Station last year showed that lettuce could be grown with less water and nitrogen than many growers are using currently. The ***Lettuce Cropwatch*** team will repeat this experiment in February this year in order to have more confidence in future recommendations. A Field Day will be organised to present the results. The date of this will be announced in future.

Study-tour of Lettuce growing Areas in Victoria and New South Wales

Dennis Phillips and Satendra Kumar attended and presented papers on the current work at the 4th Australian Horticultural Society's conference in Melbourne from 14th to 17th October 1998. This trip also allowed us to visit lettuce growers in Werribee in Vic, Hay and Hawkesbury/Sydney Basin in NSW. Some of the highlights of interest to WA growers will be presented at the **Growers Seminar** on 26th February.

Heliothis problem on lettuce.

Recent pheromone trapping work done in the Wanneroo area by the ***Lettuce Cropwatch*** team has revealed high activity of Heliothis in this area. One larva of this pest can make lettuce unmarketable. The trapping work will continue throughout the summer to determine the pattern of activity of Heliothis. More details will be provided at the **Growers Seminar** on 26th February. A temporary permit for off-label use of a number of Bt's on all lettuce for control of Heliothis has been approved by the NRA. The permit is valid from 22/10/98 until 30/6/99 and is held by the Queensland Fruit and Vegetable Growers and applies nationally for all lettuce growers.

Future Work on Lettuce in Western Australia

The current ***Lettuce Cropwatch*** project has give us a good snapshot of the problems facing the industr and what needs to be done in future. The team has pu 2 proposals to HRDC for future funding to work on (development of the export and processing sectors and (ii) management of lettuce big vein and Sclerotinia r

Our leafy crop representative on the HRDC committee, Mr Mick Nanovich, was able to muster a lot of support when he attended the HRDC meeting i Melbourne in October 1998. These projects have made it through the first round of the approval proces and full proposals have been submitted. We will kno if the applications have been successful by March 1999.

Your feedback on this newsletter or questions can be directed Project Manager Dennis Phillips or to Projec Officer Satendra Kumar at Agriculture WA Midland on phone 92745355.

Lettuce in Mornington Peninsula, Victoria

Growers Newsletter

Winter 1999

Dennis Phillips, Linda Teasdale and Satendra Kumar
Agriculture Western Australia

Lettuce CropWatch

Management Program for Sustainable Lettuce Production

This newsletter is the 4th in a series which aims to keep you up to date with results of the HRDC lettuce industry development project which is funded by your vegetable levy.

As part of our CropWatch project for Sustainable Lettuce Production on the Swan Coastal Plain we have been monitoring crops for pests and diseases. Pest monitoring began in November last year and will continue to October 1999, to gain a full year cycle of lettuce pests.

As diseases are more common in winter monitoring began in May 1998 through the winter and began again in May 1999 and will continue through to November 1999.

DISEASES

The results of last years monitoring showed that Sclerotinia rot, bacterial leaf spot, downy mildew and Big Vein virus are of common concern to a lot of market gardeners on the Swan Coastal Plain.

Sclerotinia Rot

Sclerotinia Rot is caused by soil-borne fungi *Sclerotinia minor* and *Sclerotinia sclerotiorum,* they also have an airborne phase for disease spread within the crop. Lettuce of all ages, from transplanting to harvest, and many other vegetables are susceptible to the two species of *Sclerotinia.* The disease symptoms are well explained in Agriculture Western Australia's Farm Note No 92 of 1991.

Figure 1 :Sclerotinia Rot

Dry Leaf Spot

This disease is caused by bacterium *Xanthomonas campestris* pv *vitians.* The appearance of the disease symptoms were very patchy last year. This year some properties had high incidences of dry leaf spot in April/May plantings. More details on this disease are given in Farmnote No 48 of 1991. Rain and overhead irrigation splash easily spread the bacterium. Infected seeds can also introduce the disease into new areas.

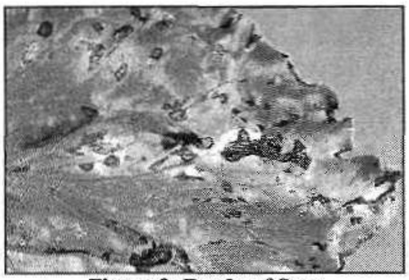


Figure 2: Dry Leaf Spot

Downy Mildew

Downy Mildew is caused by the fungi *Bremia lactucae*, it is capable of infecting any growth stage from seedling through to maturity. The first signs of Mildew are yellowish/light green areas on the upper side of the leaves, these occur within 5 – 10 days after infection. These lesions enlarge and the fungus produces downy growth on the underside of the leaf. The fungus does not survive long in the soil and is rarely transmitted through seeds. It is favoured by warm spring conditions. There are numerous strains of the disease and a new strain has recently been found in the Eastern States. Up to 16 different strains of the disease have been identified overseas. Downy Mildew rapidly mutates to attack resistant varieties and breeders are continually introducing new genes for resistance.

Figure 3: Downy Mildew

Lettuce Big Vein Virus

Big Vein is the most common disease of winter lettuce. Symptoms are vein clearing with pale green bands along the leaf veins. On many properties over 80% of winter lettuce is affected by Big Vein. In preliminary observations it has been found that severe big vein results in smaller lettuce heads and a delay in harvest by some two weeks. This disease is unusual because it is a virus which is spread by a soil inhabiting fungi *Olpidium brassicae*. The fungus is common in all market gardens.

Figure 4: Big Vein Virus

Despite a range of control measures used by growers such as rotation, fungicides and soil fumigation with Metham-Sodium to control *Sclerotinia*, the fungus seems to survive well in soil from season to season. These control measures also have little effect on *Olpidium*.

Seed companies are now offering varieties with varying degrees of resistance and tolerance to these diseases. Listed below are some winter varieties. Please contact your local buyer if interested.

Variety	Downy Mildew Resistant	Big Vein Resistant
CRISPHEAD		
Assassin	√	tolerant
Arrow	√	tolerant
Rubette RZ	√	
Iglo RZ	√	
Madras RZ	√	tolerant
Charger RZ	√	
Braveheart		strong tolerance
Casino	√	
Early Giant		tolerant
Greenfield		tolerant
Greenway	√	
LOOSELEAF		
Kublai RZ	√	
Kritair RZ	√	
COS		
Remus RZ	√	
Ronda RZ	√	
BUTTERHEAD		
Dynamo RZ	√	
Sniper	√	

PESTS

The results from pest monitoring over the summer months showed no extensive outbreaks of any particular insect. Although many different insects were sighted.

Rutherglen bugs were spotted quite often over the summer months, and were mainly seen in the middle to late stages of development. This is a small light brown sucking insect approx 2 - 4 mm long.

Cutworms (*Heliothis* grubs) were seen in the mature lettuces, causing major damage to the plant, in a few cases. *Heliothis* moths have been present in our collection traps most weeks. Both *Heliothis punctigera* and *Heliothis armigera* have both been collected. *H.punctigera* is common in Southern Australia and is a known lettuce pest. *H.armigera* is more common in northern climates and is a serious pest of lettuce in NSW and QLD. It is also know to develop resistance to pesticides more readily than *H.punctigera.*

Figure 5: Heliothis Grub

During the first week of April our monitoring showed a high incidence of Beet Webworms and moths among patches of mature lettuce. These worms are similar to cutworms. The moths eat the leaf tissue leaving a web structure out of the leaf veins. These moths are not considered a known lettuce pest and have not been sighted in similar numbers since.

Pests numbers have dropped considerably during the last month as the cold weather approaches. But monitoring will continue through to November to have an accurate account of lettuce pests.

OTHER NEWS

In our last newsletter in January, we told you about applications to HRDC for further project funding for lettuce from the AUSVEG vegetable levy. The lettuce project team submitted two project proposals and both were successful thanks to the good work and support of our WA committee members and Mick Nanovich in particular. Satendra Kumar and Simon McKirdy will commence work in the new year on a 2 year project aimed at Big Vein and Sclerotinia control. Dennis Phillips will commence a 3 year project on best practices for export, gourmet and processing lettuce. The work on both projects will be done in collaboration with researchers and extension officers in other states.

Minor Use Registration

A few new pesticides for lettuce have been registered for use in recent years because the crop is considered too small in comparison to broad acre agriculture to justify development costs. The National Registration Authority (NRA) in Australia have put an alternative system in place for crops, like lettuce called "Off Label Permits". A number of permits have been issued for lettuce including one which allows use of all BT products for heliothis control. More information is available on the NRA website. www.dpie.gov.au/nra

For Further Information on this project

Dennis Phillips : 9250 9432
Linda Teasdale : 9250 9404
Satendra Kumar : 9368 3263

Growers Newsletter

Spring 1999

Dennis Phillips, Linda Teasdale, David Gatter, and Ernie Steiner
Agriculture Western Australia

Attention : Lettuce Growers

Do you want to Know?

- How to grow lettuce with only chemical fertiliser?
- How to fertigate your crop and save time and money?
- How to simply and quickly test your crop to monitor its progress at low cost?
- How to minimise your fertiliser bill without the loss of production?
- What happens to fertiliser that isn't used by the crop?
- How to manage fertiliser in your irrigation water?

THESE QUESTIONS AND MORE WILL BE ANSWERED AT A:

Fertiliser Demonstration

Mick Monte's - cnr Elliot and Wyatt Rd Wanneroo
(Meet at Pump Shed on Wyatt Rd)

Wednesday 25th August
At 3.30pm

This newsletter is the 5th in a series which aims to keep you up to date with results of the HRDC lettuce industry development project which is funded by your vegetable levy.

In this edition of the "Lettuce Cropwatch" newsletter we focus on pest management in lettuce, and the results of 12 months intensive pest monitoring conducted in the Wanneroo/Bullsbrook area by the project team since November 1998. The aim is to provide a guideline for future integrated pest management (IPM) programmes for the crop.

Update On Pest Monitoring

Heliothis

In our last edition of the "Cropwatch" newsletter we told you about problems with pesticide resistance of Heliothis caterpillar in NSW and QLD.
The monitoring of moths in Wanneroo/Bullsbrook started in November 1998 for the **Native Budworm** (*Helicoverpa punctigera*) and in March of this year for the **Tomato Grub** (*Helicoverpa armigera*). Pheromone lures are used to attract males moths of both species.

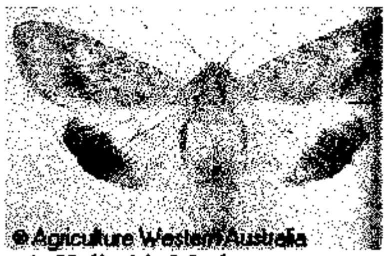


Figure 1: Heliothis Moth.

Most **Native Budworm** moths were caught in November, December and January. Numbers decreased from February to the end of April and reached near zero by the end of June.

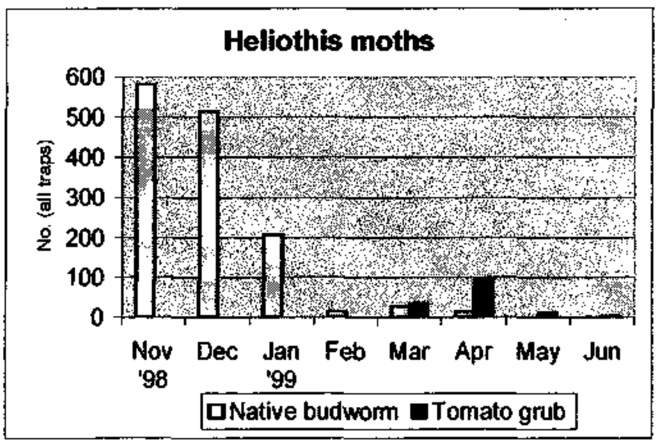


Figure 2: **Native Budworm** and **Tomato Grub** moths trapped in lettuce at Wanneroo, Yanchep and Bullsbrook.

Significantly more **Tomato Grub** moths were trapped in April than **Native Budworm**, with **Tomato Grub** moths reaching their highest numbers. Low numbers of **Tomato Grub** moth persisted to the end of June.

Regular plant inspections were also conducted by walking through the crops. Although several pests were in the lettuce, no economic damage was observed. Caterpillar damage to a small number of plants was not considered significant. However, if the crops were left unprotected or the pests develop resistance to insecticides there would no doubt be more damage.

The Office of Minor Use Permits is the new industry driven service that facilitates the approval of minor uses for pesticides. Several permits have been issued for lettuce including the use of all BT products for Heliothis control. More information is available on the NRA website. www.dpie.gov.au/nra

Other Invertebrate Pests

Yellow sticky traps were used to monitor potential pests in three growth stages in lettuce crops. Similar pests and numbers were found on the traps in all stages. Rutherglen bug and leafhopper numbers were highest from December to February.

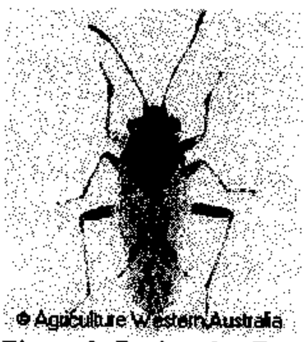
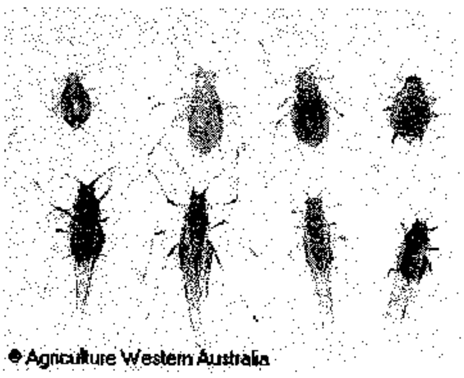


Figure 3: Rutherglen Bug.

Adult Rutherglen bugs are greyish-brown with dark markings and prominent black eyes. They have a narrow body 3-4mm long.

Aphids started appearing in January and their numbers rose steadily until the end of June.

Figure 4: Aphids.



There are many types of aphids that are associated with lettuce crops. The Green peach aphid (*Myzus persicae*) is the most important. It is 1-2 mm long and is shiny or waxy in appearance and can range from yellow through to green or pink. Most aphids are slow in their movements and adults can be winged or wingless. Lettuce aphids can cause problems by spreading Lettuce Neurotic Yellow Virus.

Thrips, the most common pests detected in the crops, were present throughout the trapping period from November through to the end of June. There were no Western Flower Thrips (*Frankliniella occidentalis*) present.

Because of their minute size and habit of hiding, thrips are difficult to notice. Symptoms of plant damage such as surface scarring and silvering are often seen before the pest is recognised. They can be yellow, yellowish-brown, brown or black. Both types can spread the serious disease Spotted Wilt Virus.

OTHER NEWS

Lettuce Project in Victoria

The "Lettuce Best Management Project" conducted at Lindenow, Somerville and Werribee in Victoria had the following findings from their first season:

Lettuce Cultivar Evaluation

- Cultivars were evaluated for marketable yield, tipburn and other disorders.
- Tipburn incidence was greater for December 98 planting than February 99.
- Tipburn in lettuce is considered a calcium deficiency disorder.
- Iceberg variety Silverado (a *Salinas* type) performed well.
- Cos variety Nero showed resistance in the first planting.
- *Helicoverpa* grubs caused significant crop damage during the previous summer (97/98).

For more details contact:
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FOR ANY FURTHER INFORMATION:
Dennis Phillips: 08 3274 5355
Linda Teasdale: 08 9274 5355
Ernie Steiner: 08 9368 3584

Lettuce Growers Seminar

When: Friday 26th February 1999
2pm to 5pm

Where: Wanneroo Recreation Centre (Coffee Lounge Ph: 9405 1961)
Corner Scenic Drive and Church St, Wanneroo

LATEST LETTUCE RESEARCH FINDINGS ON:-

★ Irrigation Requirements
★ Fertilizer Requirements
★ Pest and Disease Management
★ New HRDC Projects on Lettuce

All Growers Welcome

Lettuce Cropwatch

Management Program for Sustainable Lettuce Production

Agriculture

HRDC

All Growers are invited to

An inspection of research plots

AT

MEDINA RESEARCH STATION

Abercrombie Road MEDINA

(see map on back)

Friday March 26 - 2.30p.m. Sharp

Field research plots will demonstrate :

- **Latest irrigation and nutrition monitoring techniques**
- **Comparison of lettuce grown with fowl manure and chemical fertilisers**
- **Optimum combinations of irrigation and nitrogen for maximum production**

Lettuce Cropwatch

Management Program for Sustainable Lettuce Production

HORTICULTURAL RESEARCH & DEVELOPMENT CORPORATION
The Research Arm of the Australian Horticultural Industries

Agriculture WESTERN AUSTRALIA

WA Countryman Horticulture

JUNE 1998

Credit squeeze

Growers look for a hedge against shaky market agencies.

REPORT PAGE 3

Salad science

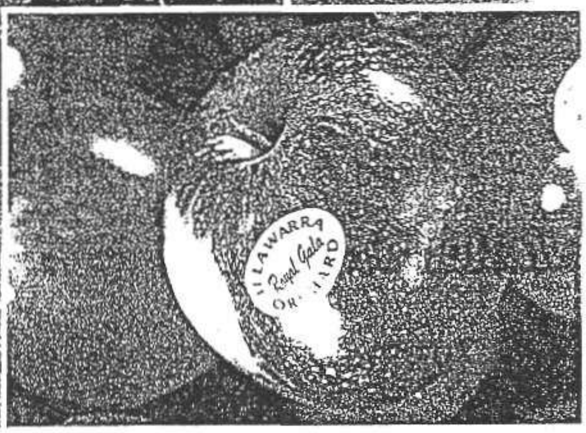
New lettuce 'technology' promises to turn the humble salad mainstay into a more sustainable growth crop.

REPORT PAGE 4

What's in a label?

New WA research has raised doubts about the effectiveness of apple labelling - much to the growers' delight.

REPORT PAGE 6



MONTHLY FRUIT AND VEGETABLE PRICES, PAGE 2

Profit, environment lead lettuce trial

A LETTUCE trial is showing horticulturists how to use watering techniques more efficiently and become more cost effective.

An added bonus is its benefit to the environment.

The trial is part of a management program called Lettuce Cropwatch and aims to determine the optimum combination of watering and nitrogen fertiliser at different stages of crop growth which maximises yield while minimising cost and environmental hazards.

Significantly, the trial is being carried out with money from the first round of funds made available through the recently introduced Horticultural Research and Development Corporation levy on vegetables.

Project officer Satendra Kumar has also been employed to carry out the trial and field work with growers.

Agriculture WA horticulture development officer Dennis Phillips said lettuce growers were finding it increasingly more difficult to make a profit.

"Demands on growers from all sectors are increasing and improved management skills are required to keep up," he said.

"The pace of these demands will increase and growers need to be better prepared to survive in business."

Demands for records of production and quality assurance by buyers (particularly supermarkets) was new to most lettuce growers, and coupled with falling profit margins, there was an ever increasing need to minimise costs by adopting new production methods.

Mr Phillips said to make things worse for vegetable growers, there was increasing competition for resources by other users, especially water which limited expansion.

Dennis Phillips, centre, with a lettuce grown using the optimum amount of fertiliser and water, left, and one planted on the same day that received the incorrect balance. Looking on is Anu Rangarasan, assistant professor at Cornell University in New York State, and Satendra Kumar.

In 1998 there was also increasing environmental constraints on use of inputs, especially pesticides, fertilisers and water, he said.

The trial aimed to help find answers to alleviate those problems to some degree.

Past research by Agriculture WA had shown that optimum yield of lettuce could be obtained by irrigating at a rate of 150 per cent of evaporation throughout the crop's life.

But the higher the watering rate, the more nitrogen fertiliser needed and the greater the losses through leaching.

Lettuce Cropwatch

Mr Phillips said growers traditionally applied water according to "gut feeling" and consequently were not always right.

"Many growers also use large amounts of poultry manure and chemical fertilisers as their source of nitrogen fertiliser," he said.

"And if watering is excessive, then so is nitrogen loss and potential for ground water pollution.

"But it is possible to grow vegetable crops successfully without poultry manure and reduce chemical fertilisers, thus saving the growers' money and the environment at the same time."

The trial at the Medina Research Station was being grown without any poultry manure or other organic manure because the nutrient content of manures was unpredictable and so difficult to manage in a tightly managed fertiliser program.

Chemical fertigation was used at weekly intervals to minimise wastage through leaching.

Irrigation rates between 40 per cent evaporation replacement and 200 per cent replacement daily were being compared in combination with rates of nitrogen from nil to 320kg per hectare, split into six weekly applications.

Mr Kumar said preliminary results were very encouraging, showing that rates as low as 40 per cent could be sufficient in the two weeks after transplanting.

Monitoring showed that by week three, a minimum rate of 100 per cent was required.

"We can see now that 40kg/ha of nitrogen a week may be enough up to week three but only at the optimum rate of watering," he said.

"These results show potential for considerable savings in water and fertiliser, reducing costs."

Sap nitrate levels were an integral component of this work, and with the cost being as little as $2 a sample, Mr Kumar recommended growers consider using them to manage their fertiliser programs.

Sap nitrate standards were now being established by the researchers for each growth stage so that growers could decide on fertiliser application rates based on plant uptake rather than sticking to a rigid rate per hectare program which was possibly not right for all situations.

The potential for fully-automated irrigation based on soil moisture monitoring was also being tested on vegetable crops with electronic tensiometers specifically designed for use in sandy soils.

Mr Kumar said this could be the future of high-efficiency irrigation.

AgWA expands horticulture aid

AGRICULTURE WA has appointed a new horticulture development officer at Midland to help vegetable production on the Swan Coastal Plain.

AgWA chief executive officer Graeme Robertson said Satendra Kumar was one of 16 new development officers appointed this year at various locations throughout the State.

Satendra Kumar

"The primary role of Mr Kumar's position will be to develop expertise in vegetable production by assisting growers with the management of soil, fertilisers, pests and diseases to enable sustainability in production systems," Dr Robertson said.

"The responsibilities of the position will include the establishment and monitoring of on-farm demonstrations and associated field days and workshops."

Mr Kumar will contribute to a lettuce industry project to help develop a framework for sustainable practices which are commodity focused. It will incorporate the measurement of inputs linking performance to budgets, and regular feedback to growers.

The initial project will be known as Lettuce Cropwatch and future versions for other vegetable crops will build on the Cropwatch model.

Mr Kumar studied agriculture at the University of South Pacific before moving to Queensland University to complete an honours degree in horticultural technology. He is now working towards a doctorate at the University of WA.

Look below lettuce plants to deliver more efficient inputs

MORE efficient use of water and fertiliser are two of the expected benefits for lettuce growers from research now entering its final stages.

The confirmation stage of a trial aimed at developing an integrated crop management system for lettuce production is underway at Agriculture WA's Medina research station.

The main part of the trial involves a regimen of irrigation and nutrition research and commercial crop monitoring using drainage lysimeters to determine leaching of water and fertiliser.

Drainage lysimeters are a box structure with a false floor comprised of a gauze membrane that collects water leaching through the initial layers of the soil. Analysis of the collected water can reveal the level and extent of water and fertiliser not taken up by the plant or evaporated.

The trial is a confirmation of a similar trial undertaken last year at Medina, although the start date has been set back a month to determine the influence of higher temperatures and higher evaporation rates.

According to Agwest vegetable industry development project manager Dennis Phillips, the objectives of the trial were to determine the maximum yield for minimum input in terms of the irrigation and nitrogen rate.

"The lettuce grown on the Swan coastal plain is valued at $7.5 million, with an annual export earning of more than $1 million," he said.

"In order to continue farming on soils that mainly comprise deep sands which are very poor in terms of nutrition, organic matter and water retention ability, farmers need a good grasp of ways of minimising the inputs going past the root zone.

"Efficient water use holds the key to efficient nitrogen fertiliser use."

Outcomes of the trial show that both nitrogen and water leaches below the root zone at all rates of irrigation, although fertiliser and water use efficiency can be maximised in the 60 to 130 per cent of replacement range without loss of crop yield.

■Agriculture WA technical officer Dave Gatter draws water out of the lysimeter tanks underneath a three-week-old crop of lettuce at the Medina research station.

It was also shown that nitrogen rates of application can be reduced below the 55 kilograms/hectare per week level in the first half of the crop's life by optimising irrigation.

Mr Phillips said these figures had the potential to offer a double bonus in decreased fertiliser application and therefore lower costs, as well as limiting the leaching of nitrogen into underground watercourses with the associated nitrate enrichment of groundwater.

An encouraging result of the trial was the realisation that the improved fertigation techniques appeared to be at least as effective as fowl manure with a lower level of leaching.

"Results from last year's trial indicated that high-yielding quality lettuce can be grown with no more than 55kg/ha per week nitrogen without the addition of fowl manure," he said.

The use of the lysimeters also allowed Agwest to test the performance of electronic tensiometers, which proved to be accurate in measuring the moisture content of the soil.

Researchers say this will lead to the development of accurate irrigation scheduling based on soil moisture measurement, a process which has the potential to make the growing of all irrigated vegetable crops more efficient through fine tuning of inputs throughout the whole crop cycle.