Enhancing fertiliser use efficiency for transplanted vegetables

Dennis Phillips
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ENHANCING FERTILISER USE EFFICIENCY FOR TRANSPLANTED VEGETABLES

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HORTICULTURE AUSTRALIA
PROJECT NO. VG04018

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The purpose of this report is to communicate the findings of Project VG04018 which investigated practical ways in which a range of leafy vegetable crops could be grown using more efficient means of applying fertiliser in order to reduce fertiliser leaching into the groundwater.

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Media summary

Project VG 04018 ‘Enhancing fertiliser use efficiency for transplanted vegetables’ showed that spraying highly concentrated solutions containing nitrogen over newly transplanted vegetable seedlings for between 14 and 21 days after planting can increase marketable yields by as much as 300% compared to other methods of fertiliser application. Crops that this method has been successfully tested on in this study by the W.A. Department of Agriculture and Food include iceberg and Cos lettuce, broccoli, cauliflower, Chinese cabbage (wombok), celery and cabbage.

The research was conducted on virgin sandy soils of the Swan Coastal Plain near Perth which are among the least fertile in Australia in their native state. This research has shown that high yielding crops can be achieved in this ‘worst case’ situation by ensuring that establishing crops are well supplied with nitrogen until they have formed a root system large enough to intercept banded top-dressings. The rates of nitrogen needed to produce high yields by spraying are typically as low as 20-25 kg/ha per week. The potential loss of nitrogen to groundwater from this practice could be of the order of only 10% of that in conventional commercial practice where poultry manure is routinely applied as a pre-planting treatment. The nitrogen requirements of the crops tested could not be practically met for longer than about the first 21 days after planting by spraying alone.

This project also investigated the merits of drenching seedlings with a concentrated fertiliser solution immediately before transplanting and compared a number of alternative top-dressing products to ammonium nitrate, banded at high rates from 14 days after planting until row closure. Seedling drenches were most effective for iceberg and Cos lettuce, but of little value for other crops while ‘low biuret’ urea proved to be the most cost effective top-dressing alternative to ammonium nitrate except for winter lettuce.

One of the aims of the work was to eliminate or minimise the need for top-dressing beyond ‘row closure’ to reduce fertiliser cost and wastage. This approach worked well for summer lettuce, cauliflower and broccoli, but was not optimal for winter cabbage, winter lettuce, Chinese cabbage or celery. Future work needs to ‘fine-tune’ these programs for crops grown at these difficult times of the year.

This work also needs to be extended to additional vegetable crops not yet tested with this protocol. Further work would also focus in intensive ‘one on one’ support for growers wishing to change to this method of growing to enable the program to be customised to individual circumstances.

Technical summary

From 2005 to 2006, the Department of Agriculture and Food Western Australia, with funding support from Horticulture Australia Ltd, investigated alternative methods of fertilising a range of transplanted leafy vegetable crops with the primary aim of reducing adverse environmental impacts on groundwater from fertiliser leaching. A secondary aim was to identify and test alternative nitrogen sources as potential substitutes for poultry manure and also granular ammonium nitrate, both subject to restricted use by law.

HAL project VG99014 (Phillips et al, 2003) showed that for iceberg lettuce, high rates of pre planting poultry manure could be replaced by low rates of mineral nitrogen, well placed, with no loss in yield and vastly reduced nitrate leaching to groundwater. The methods included a concentrated fertiliser drench of seedlings in trays immediately before planting, followed by twice weekly spraying with concentrated nitrogen solutions in the 2-3 weeks after planting. Top-dressing commenced at 14 days and continued until practical 'row closure'. This project tests these principles of fertilising for other transplanted leafy and heading crops including celery, broccoli, cauliflower, cabbage, Cos lettuce and Chinese cabbage.

The crops were grown sequentially on virgin sites to avoid carryover from residual fertiliser. Each trial consisted of three or four replicates and compared combinations of initial spray treatments followed by banding/fertigating with one of four nitrogen fertiliser products. Commercial row-crop layouts were used, enabling mechanised fertiliser spreading and spraying where appropriate. All crops were irrigated with fixed sprinklers at 12 m spacings. The minimum size unit for a trial was a 'sprinkler bay' 12 m wide and 100 m long.

A preplant seedling drench (40 g/L potassium nitrate applied at 500 mL of solution per 100 cell tray) was followed by spray treatments applied 4 times in the 14 days after transplanting except in winter where we used six sprays over 21 days. A nil spray treatment was included in all trials. Other treatments were combinations of low biuret urea (LBU) at 11.3 or 22.5 kg/ha and potassium nitrate (KNO_3) at 20 or 40 kg/ha. Spray treatments were followed with top-dressing using either Nitrophoska Blue Special®, ammonium nitrate, 'low biuret urea' (LBU) or Spurt-N® to row closure.

The seedling drench did not prove beneficial for all crops. Cabbage and celery both exhibited some yield depression whilst for broccoli, cauliflower and Chinese cabbage there was no net effect. Both Cos and iceberg lettuce benefited from the pre-plant drench in a summer crop but the benefits were less clear in winter.

Response to spray treatments was positively correlated to the nitrogen rate such that the two highest rate spray combinations, 22.5 kg/ha LBU plus 20 kg/ha KNO_3 and 11.3 kg/ha LBU plus 40 kg/ha KNO_3 produced high yields in every case. The higher rate of LBU gave low levels of marginal scorching for most crops during the period of spraying, but the affected leaves were of no consequence by harvest time. The mixture containing the lower rate of LBU could be used as a safer alternative for a small yield penalty if preferred.

Frequently, there was little difference between top-dressing treatments but on a cost basis, LBU was the logical choice for most crops at the times of year we tested it, with the notable exception of winter iceberg and Cos lettuce where Spurt-N® appeared to be a safer choice with respect to the incidence of tip burn. Nitrophoska Blue Special® proved to be an high cost option, adding $1,000/ha to total cost in most cases. It seems the additional potassium and phosphorus conferred no obvious yield benefit and possibly contributed to leaching of nutrients into the groundwater. An advantage offered by Nitrophoska Blue Special® was that it supplied the leachable nutrients N and K throughout the crop's life and had the potential to reduce labour costs, as it did not require a separate potassium fertiliser be top-dressed (in this case potassium nitrate) in some weeks. This may have been the case for winter broccoli, the only crop where Nitrophoska Blue Special® produced higher yields .

This work shows conclusively, the importance of early nitrogen nutrition. Applications of only 20-40 kg N as sprays in the first two weeks after planting produce significant yield benefits at harvest. For some crops such as iceberg lettuce, this benefit can be of the order of $20,000 for an investment of between $40 and $200.

Further work is needed on some of the slower growing crops such as celery and winter crops of cauliflower, broccoli and cabbage. Yields for these were not optimal and likely reflect the need for additional fertiliser application beyond row closure when the time period from row closure to harvest is lengthy. In these cases, further application of liquid fertiliser, either sprayed or fertigated may be necessary. Additional trials would also clarify whether this would need to increase the total amount of nitrogen supplied or if redistribution over time is sufficient.

1. General introduction

The irrigation and nutrition practices of vegetable growers are increasingly being scrutinised by environmental regulators in all states of Australia as potential polluters of the environment. This is particularly so in relation to the effects that excessive fertiliser applications have on water quality where the water is used for irrigation as well as for public water supply.

Protection of the environment is an important issue for consumers of our vegetables in Australia and our overseas markets. These concerns are increasingly being addressed by major retailers in Australia and overseas by the introduction of quality and environmental assurance schemes for their grower suppliers. AUSVEG has attempted to pre-empt this trend in Australia by introducing the 'Enviroveg®' program (www.ausveg.com.au) for it's grower members and Horticulture Australia is taking it a step further with the 'Horticulture for Tomorrow®' program (HAL, 2006).

To have credibility with consumers, these schemes will ultimately need to be 'third party audited'. Auditors and growers will need tangible targets for good agricultural practice, including nutrition practice, against which to audit.

- This project aims to establish achievable targets for good nutrition practice for transplanted crops grown under sprinkler irrigation which are applicable throughout Australia. These targets are being derived from properly designed and implemented field research.

An added complication for growers that has emerged in recent times has been the unreliable supply of one of the cheapest and most effective nitrogen fertilisers for vegetable growing, ammonium nitrate. Access to this granular fertiliser will be regulated in the future, adding extra costs to vegetable production (DOCEP, 2007).

- This project aims to test alternative nitrogen based fertilisers as possible substitutes for ammonium nitrate.

A third factor motivating the research was the widespread use of poultry manure as a pre-plant fertiliser for vegetable growing on sandy soils of the Swan Coastal Plain. The use of raw poultry manure is banned in most production districts in WA because of fly breeding and the nuisance that causes to other landholders (Health (Poultry Manure) Regulations 2001; Environmental Health Newsletter, March 2007). 'Conditioned' manure with reduced levels of fly breeding is permitted at some times of year but even this has the disadvantage that it is a bulky fertiliser used at high rates per hectare and much of it's nutrient content is not used by crops to which it is applied. This method achieves good early crop growth but much of this excess fertiliser is leached into groundwater below the crop within four weeks of application, polluting the water.
An HAL project completed in 2003 in WA (VG99014) showed that for iceberg lettuce, high rates of pre-plant poultry manure could be replaced by low rates of mineral nitrogen applied with accurate placement in the field with no loss in yield and vastly reduced nitrate leaching to groundwater. The methods included a highly concentrated fertiliser drench of seedlings in trays immediately before planting out followed by twice weekly spraying with concentrated nitrogen solutions in the 2-3 weeks after planting.

- This project aims to prove that the lettuce results were repeatable through properly designed replicated trials and that the placement methods and rates could be used on other transplanted leafy and heading crops including celery, broccoli, cauliflower, cabbage, Cos lettuce and Chinese cabbage.

Fertiliser loss to the environment in commercial practice on the range of crops studied here is usually greatest in the first two-three weeks after transplanting (Teasdale et al, 2000). This is because the root system at transplanting is confined to the small volume of potting mix in the nursery tray cell and it takes time and energy for the plant roots to get out into the soil. During this period, a lot of the fertiliser applied, by-passes the roots before the plant can use it. Sub-optimal growth for even a few days in this period can result in large yield losses by harvest time. Our research concentrated on this critical period where fertiliser savings were likely to be greatest and leaching losses could be minimised.

Conventional methods of applying mineral fertiliser to crops at this stage, such as broadcasting before or after planting, banding or fertigation do not stay long enough in the shallow root zone in sandy soils, or are too unevenly applied to be effective.

Previous research with lettuce (Phillips, unpublished; Teasdale et al, 2000)) showed the early growth response growers see when they use poultry manure is a response to the nitrogen in the manure. We found the most practical way to reproduce this effect with mineral fertilisers was through a combination of seedling drenching with potassium nitrate at planting time followed by nitrogen sprays twice weekly after transplanting. Safe products to spray at high rates proved to be potassium nitrate and low biuret urea (LBU). A practical aspect we considered important was that any spray or drench product we used would not cause crop damage if it was left on the foliage after spraying, i.e. there would be no urgent requirement to wash the product from the leaves.

General methods

The method used to test these fertiliser strategies established a series of field trials on virgin field sites at the Department of Agriculture's Medina Research Station. Each of these trials compared between 24 and 40 combinations of seedling drench, early spraying and banding/fertigating with four nitrogen fertiliser products (ammonium nitrate, LBU, Nitrophoska Blue Special® and Spurt-N®). The four fertiliser products were compared at the same rate of N and applied weekly to the crop from 14 days after transplanting until 'row closure'. Each treatment was repeated three or four times over (replicates) in the field. Each trial comprised up to 160 individual plots totalling around 5,000 plants, in which all fertiliser sprays were applied by hand.

Medina Research Station is located on the Swan Coastal Plain south of Perth, Western Australia (32º South latitude). Medina offered the advantages that it was located in a vegetable producing district in Western Australia, inputs to production could be carefully controlled and the work could be done on some of the least fertile sandy soils in Australia, with no previous vegetable cropping history, using irrigation water virtually free of fertiliser contamination.

The assumption in these trials was that fertiliser levels required to give high yields in this situation would be a 'worst case' scenario that growers on better soils in other parts of Australia should not have to exceed to get good results.

All field trials were 'row crop' layouts, typical of commercial production, enabling mechanised fertiliser spreading and spraying where appropriate. All crops were sprinkler irrigated using fixed sprinklers at 12 m spacings. The minimum unit size for a trial was one 'sprinkler bay' 12 m wide and 100 m long. Trial layouts and treatment combinations were constrained by the need to maintain uniform 'bay histories' for future trial work. The aim was to ensure only one crop was planted on a whole bay at any one time. Hence, the minimum unit size for a trial was one bay, increasing a full bay at time if more land was required. Within each bay the standard plot width was a tractor wheel spacing of 1.5 m (a bed). Six beds fitted across a bay, and the outside two beds were always planted as a 'buffer' around the reps in that bed. Row spacings for the crops tested ranged from two per bed for cauliflower to four per bed for lettuce.

The net effect of these constraints was that the number of plots available for use for each of the crops tested was not the same and compromises were made on the number of treatments and/or the number of replicates used for different crops at different times.

Sprays and drenches (0-21 days)

All trials compared a standard seedling drench treatment derived from past research with lettuce, this being 40 g/L of potassium nitrate at a rate of approximately 500 mL of solution per 100 seedlings. The base set of spray treatments was four levels of nitrogen containing solutions compared to an unsprayed control. The full set of five spray treatments was used on iceberg lettuce, Cos lettuce and celery where plant spacing allowed enough plots to be available. Four of the five spray treatments were compared for cabbage, Chinese cabbage and cauliflower while only three were compared for broccoli. Fertiliser sprays were applied four times in the 14 days after transplanting for spring summer and autumn planted crops, and extended to six sprays over 21 days for winter plantings to account for slower early growth rates in cool weather.

The spray treatment structure always included a zero fertiliser rate as S1. The highest spray rate (S5) was the same as the highest yielding treatment from past lettuce trials. This treatment was a mix of 22.5 kg of LBU plus 20 kg of potassium nitrate (KN) (greenhouse grade) dissolved in 1000 litres of water and sprayed at 1000 L/ha. This mixture applied 13 kg/ha N each time it was sprayed. There was considered to be a risk that this rate of

LBU may be phytotoxic to some crops, so a potentially safer alternative was tested as S4. This treatment was a mix of 11.3 kg/ha of LBU and 40 kg/ha of potassium nitrate supplying 10.4 kg/ha N each time it was sprayed. The two components of S4 were tested separately in S2 (40 kg/ha potassium nitrate – 5.2N per spray) and S3 (11.3 kg/ha LBU – 5.2N per spray).

The five spray treatments thus tested four rates of nitrogen, 0, 5.2N, 10.4N and 13N, as well as comparing the two sources of nitrogen, LBU and potassium nitrate at the same rate (S2 vs S3). It is generally accepted in the literature that LBU is more efficiently absorbed through plant foliage than potassium nitrate (Piggott, 1980(a); Piggott, 1980(b); Piggott and Male, 1980), and it was hoped that the comparison of the two products at the same rate of N (S2 vs S3) may help to show if foliar uptake enhanced growth responses compared to the level of nitrogen supplied alone.

An important practical consideration for choosing effective fertiliser sprays was that they did damage crops if left to dry on plant foliage. Previous research shown that potassium nitrate and LBU could be applied to lettuce foliage at very high concentrations with minimal or no plant damage. These fertilisers were used as the basis for all spray treatments for this reason.

Topdressing after 14 days

Past research with lettuce had shown that the crop had established a sufficient root system by 14 days after transplanting to respond to granular fertiliser applications banded between pairs of rows. Both potassium and nitrogen leached readily on these poor sandy soils, and both N and K needed to be top-dressed to ensure steady growth. A guiding principle behind this work was that fertiliser practices tested and developed should minimise labour cost for application, because time is money. All fertiliser strategies we tested required no fertiliser mixing before application, to save labour time and make machinery calibration simpler. Hence, each time a top-dressing was made, it was a single product. Potassium nitrate was used as the first application at 14 days after planting and a nitrogen source was used thereafter until one week before row closure when potassium nitrate was used again.

This strategy supplied adequate potassium at reasonable fertiliser cost and was compatible with single nitrogen sources including ammonium nitrate (AN) and LBU. A variation on this theme, tested throughout the series was to apply a pre-mixed granular NPK product for all topdressings at an equivalent N rate to that applied to other treatments. The product was Nitrophoska Blue Special® containing 12N:5P:14K and trace elements. This treatment cost more than the others, but offered the convenience of a single product throughout, allowing banding equipment calibration to be 'set and forget' as well as applying P regularly to the crop in a situation where it was expected to leach.

Some variations to the strategy outlined were applied as the project evolved. Four topdressing fertilisers were compared in all trials, commencing with a celery crop comparing two rates of ammonium nitrate to LBU and Nitrophoska Blue Special®. Ammonium nitrate became increasingly difficult to buy after that time and a liquid alternative known as Spurt –N® (32% N w/w) was used instead of the lower rate of ammonium nitrate thereafter. This product was not suitable for banded application and it was applied in diluted form as a 'simulated fertigation' using watering cans at a rate of 1 mm irrigation equivalent. It was immediately washed from the foliage after application with 'fertiliser free' water to avoid foliage damage at an equivalent rate of 2 mm of irrigation.

A guiding principle was to not apply fertiliser beyond 'row closure' because this had been shown to be sufficient in past lettuce research (Phillips 2003), with no increase in yields identified for applications later than this. However some crops such as cabbage and Chinese cabbage reached row closure much earlier than lettuce and it was considered that 'fertigated' top-dressing was required after 'row closure' for these.

Site preparation and general management

The sites for each trial were rotary hoed at least 3 weeks prior to transplanting, followed by fumigation with metham sodium at 500 L/ha, 14 days prior to planting, and aerating by hoeing 7 days later. Double superphosphate was broadcast over the site at 2500 kg/ha with 150 kg/ha of Hi Trace® and 200 kg/ha K-Mag®. These were incorporated with a rotary hoe. At the same time the beds were formed (1.5 m between bed centres) and levelled ready for transplanting.

Irrigation in the first 14-21 days after planting was planned to never exceed 3 mm at any one irrigation event, with a crop factor target for the period of 100 per cent evaporation (epan) replacement. This was done to minimise the rate at which sprayed nutrients leached from the shallow root zone of the crop, maximising the potential for nutrient uptake. After the initial spraying period, irrigation scheduling was based on a 140 per cent epan replacement for most crops and 160 per cent for celery, with two applications per day in hot weather and up to one per day in winter. Weather records, including evaporation data, for Medina research station are included in Appendix 1.

Pest, disease and weed control

Post emergence herbicides were used specific to each crop for weed control, applied immediately after planting and watered in.

Pest and disease control strategies were based on resistance management strategies for each crop, where applicable, and pesticides used were chosen from those registered for each crop. Specific strategies are shown in the methods section for each trial in subsequent chapters.

2. BROCCOLI

Introduction

Broccoli is a crop that is widely grown from 'tray grown' seedlings produced by specialist nurseries in Australia. In Western Australia it is almost exclusively grown this way in commercial practice, and it is grown year round on sandy soils of the Swan Coastal Plain, up to 200 km north and south of Perth. Broccoli is also grown on sandy loam soils in summer in the lower-south west of the State in districts such as Manjimup.

Where broccoli is grown on sandy soils, it is often in rotation with crops such as lettuce and celery. Traditional nutrition practice for these crops is to use poultry manure as a broadcast treatment before planting and/or banded between rows after planting. Mineral fertilisers are also routinely applied as topdressings on these crops. No research work had been done to test seedling drenches or fertiliser sprays as establishment treatments for broccoli prior to this research. The potential benefits of the drench/spray technique are reduced leaching of fertiliser into groundwater from lower fertiliser application rates and better placement and utilisation of fertiliser than achieved by current commercial practices.

Method

Site preparation and pre planting fertiliser applications were made according to standard practice as outlined in the 'General Methods'.

Seedlings (cultivar 'Endurance') for the trial were bought in from a specialist nursery and planted on 25 May 2005. Half the seedling trays were drenched with 40 g/litre potassium nitrate at 500 mL/tray (100 cells) within one hour of planting for the drenched treatments and the other half were drenched with water.

Seedlings were planted by hand in the field at three rows per bed with 450 mm between rows and 400 mm between plants. Each plot had one row of buffer plants at each end (i.e. six buffer plants in total per plot). Plots were 4.0 m long (30 plants) and the 24 plants between the buffers were harvested from each plot. The plots were un-buffered outside the rows, i.e. all three rows were harvested and only one of the three was an internal row with plants either side of it. The experimental design comprised four replicates of a split-split plot design with banding as the main plot, drenching as the split plot and spray treatment as the split-split plot.

Immediately after transplanting, Dacthal® was applied by boom-spray for weed control at 6 kg/ha and this was followed with 3 mm irrigation.

Two sprays only, were applied approximately one week apart for diamondback moth. Regent® (fipronil) was sprayed at 250 mL/ha and followed by Success® (spinosad) at 400 mL /ha.

Post-plant fertiliser treatments

Broccoli was planted at a lower plant population per hectare than some other crops tested in this series, and only 96 plots could be accommodated in the land area available. This compared to up to 160 plots needed to test all forty treatments in trials with other closer spaced crops. To accommodate the broccoli trial in the area available, the total number of treatments was reduced to twenty four and the number of replicates increased to four. Closer planted crops like celery and lettuce had three replicates. The number of spray treatments compared was reduced from the five used for higher density crops to three for broccoli. The three treatments retained from the full list were S1, S4 and S5.

A regime of spray treatments was commenced one day after planting which consisted of twice weekly applications of a range of the following spray treatments for three weeks (six applications in total).

S1 No spray.
S4 11.3 kg/ha LBU plus 40 kg/ha potassium nitrate (62.4 kg/ha nitrogen, 91.2 kg potassium in total)
S5 22.5 kg/ha LBU plus 20 kg/ha potassium nitrate (77.7 kg/ha nitrogen, 45.6 kg potassium in total).

This was followed by a series of one of four top-dressing treatments (designated B) as detailed in Table 2.1. The prilled or granular fertilisers were banded into a shallow furrow between the pair of rows of broccoli and Spurt-N® was simulation fertigated as described in the General Methods, commencing 16 days after transplanting and ending at row closure.

Table 2.1 Top-dressing treatments (B1-B4) applied to broccoli (kg/ha)

Top-dressing treatment	B1		B2	B3		B4	
Days after planting	Potassium nitrate (kg/ha)	Ammonium nitrate (kg/ha)	Nitrophoska Blue Special®	Potassium nitrate (kg/ha)	LBU (kg/ha)	Potassium nitrate (kg/ha)	Spurt-N® (kg/ha)
16	400		550	400		400	
22		200	550		150		200
30		200	550		150		200
35		200	550		150		200
44		200	550		150		200
49		200	550		150		200

Sap plant and tissue testing

Tests for sap nitrate, phosphate and potassium were done using an RQflex® reflectometer and Merckoquant® indicator strips on samples from all plots collected on day 75 after planting. All plots were rated for symptom severity on a scale of 1-5 to correlate symptom severity with sap level of nutrients. Typical examples of the severity scores are shown in Figure 2.7. Leaf blade and petiole samples were also taken from five plots representing the range of severity symptoms from score 1-5. These samples were tested for a range of elements on a dry weight basis by the Chemistry Centre of WA.

Results

The crop grew well with obvious size differences between the unsprayed treatment (S1) and the other spray treatments within the first two weeks. Over time, as the top-dressing treatments were applied, these differences became less obvious, but by the time of harvest, the unsprayed treatment was still visibly smaller than all other sprayed treatments. There were no obvious visual differences between the two treatments, S4 and S5 at any stage of growth. Differences in maturity at harvest between spray treatments were more pronounced. Visible size differences between drenched and un-drenched treatments were not obvious at any stage of growth, nor between top-dressing treatments.

The following photos show treatment differences between spray treatments over time.

Figure 2.1 Eight days after planting showing unsprayed broccoli (left) compared to sprayed (twice) with S5 spray rate (right). Both plots were drenched with potassium nitrate solution before planting.

Figure 2.2 Nineteen days after planting – all plots were hand sprayed with fertiliser.

Figure 2.3 Nineteen days after planting sprayed (S2) left, unsprayed (S1) right.

Figure 2.4 Thirty six days after planting, response to spraying is still highly visible (foreground right) compared to unsprayed low vigour plots in the background.

Figure 2.5 At fifty seven days, unsprayed beyond the white peg is still visibly poorer than sprayed (in front of peg).

The crop was harvested over three days (15, 19 and 26 August, days 82–93 after transplanting). The aim being to maximise the number of heads meeting export size parameters at each date of harvest. The optimum head size was considered to be around 400 grams. Heads smaller than about 200 grams were left for the following harvest. This harvesting method resulted in lower yields in tonnes per hectare than the maximum possible if the optimum head size was set larger than 400 grams.

The final harvest consisted entirely of unsprayed treatments, whereas the first two harvests were a mix of all treatments but primarily S4 and S5.

There was a significant difference between the unsprayed treatment and the two other spray treatments (3.2 t/ha cf 10.7 t/ha and 10.9 t/ha), showing the importance of early nutrition. There was a slight but not significant advantage from the pre-plant drenching (0.5 t/ha). There was no difference between banding treatments. The yield response at harvest from spraying nutrients for the first 21 days after planting is shown in Figure 2.6.

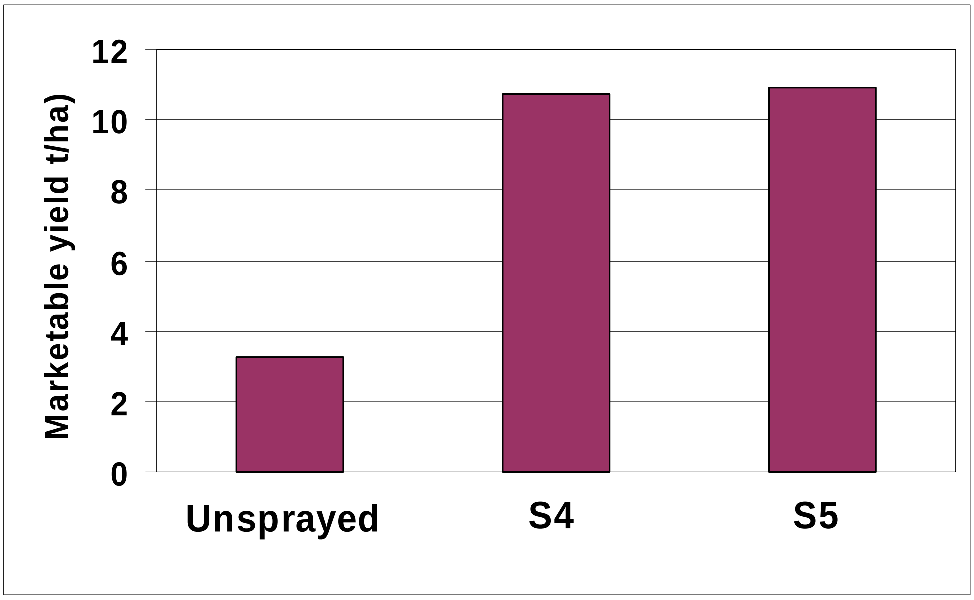


Figure 2.6 Effect of fertiliser spray rate on marketable yield of broccoli.

Sap plant and tissue testing

All treatments maintained a healthy colour from 49 days until the early stages of heading around 70 days without further topdressing. After this time, the leaves of most treatments became progressively yellow and developed marginal scorching of the old leaves. There was a difference in severity of these symptoms between treatments. The symptom appeared to be potassium deficiency.

(a) (b) (c) (d) (e)

Figure 2.7(a-e) Severity score ratings for leaf yellowing and scorching from 1-5 where 1 = symptom absent and 5 = symptom severe.

Results from the samples sent to the Chemistry Centre for analysis at harvest are tabulated in Table 2.2. There was a downward trend in the K level recorded in both petioles and blades with increasing severity score, with the result for both petioles and blades for rating 2 being anomalous. The data suggests that the critical level of K (measured on a dry weight basis) in petioles is around 2.5 per cent and for blades it is around 1.2 per cent.

Table 2.2 Analysis of samples sent to the Chemistry Centre

Sample type	Rating	K (per cent dry weight)
Petiole	**1**	**2.46**
Petiole	**2**	**4.21**
Petiole	**3**	**2.16**
Petiole	**4**	**1.7**
Petiole	**5**	**1.1**
Blades	**1**	**1.15**
Blades	**2**	**2.37**
Blades	**3**	**1.06**
Blades	**4**	**0.6**
Blades	**5**	**0.64**

The result of an analysis of the relationship between potassium sap levels and symptom severity score is depicted in Figure 2.8. There was a significant correlation between the two variables (r^2 = 0.69) with rising sap potassium levels being associated with less severe foliage symptoms. The trend shown in Figure 2.8 suggests that the critical level for potassium in sap at which foliage symptoms are absent may be around 1.4 g/L.

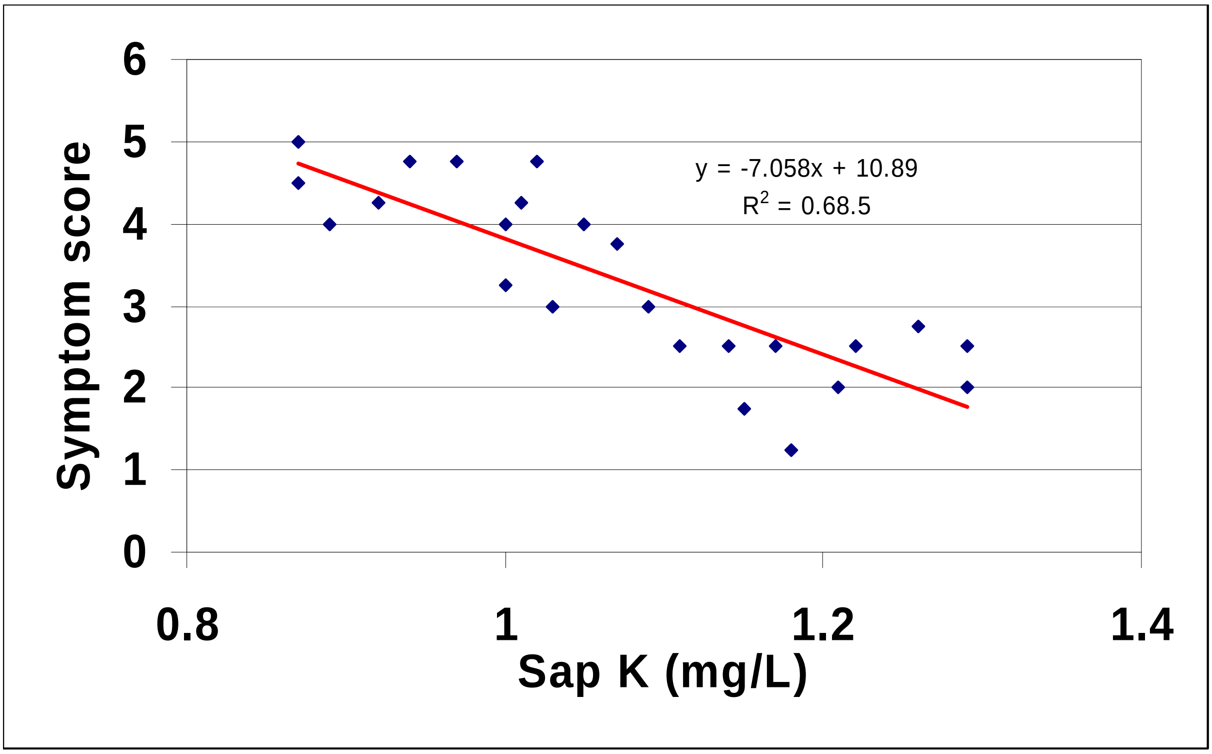


Figure 2.8 Relationship between sap potassium level and symptom severity score of broccoli leaf yellowing 75 days after planting.

Further analysis also suggested there may be a relationship between top-dressing treatment and foliage symptoms although there was no significant correlation between applied potassium and symptom severity. These results shown in Figure 2.9 suggest more severe foliage symptoms and lower sap potassium levels where ammonium nitrate and Spurt-N® were top-dressed than the other two fertilisers.

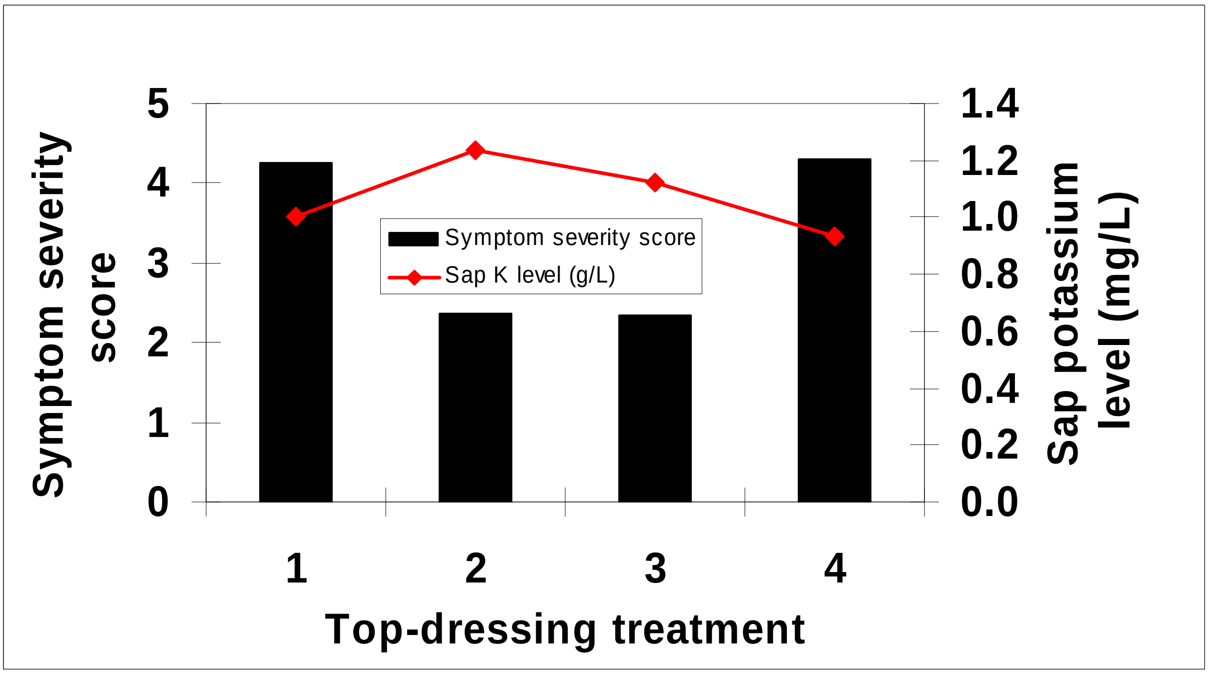


Figure 2.9 Relationship between symptom severity and sap potassium levels by top-dressing treatment.

Sap nitrate, phosphate and potassium levels from tests conducted on day 75 are shown in Table 2.3.

Table 2.3 Petiole sap test results for fertiliser treatments at 75 days after planting

	Sample	NO_3 (mg/L)	PO_4 (mg/L)	K^+(g/L)
Undrenched	B1 S1	2200	520	0.89
	B1 S4	1560	680	1.02
	B1 S5	2020	540	0.97
	B2 S1	480	1000	1.29
	B2 S4	1100	880	1.26
	B2 S5	560	960	1.29
	B3 S1	1340	740	1.18
	B3 S4	1000	720	1.17
	B3 S5	1180	720	1.11
	B4 S1	940	620	0.87
	B4 S4	620	880	0.92
	B4 S5	580	800	0.87
Drenched	B1 S1	900	600	1.07
	B1 S4	1360	560	1.05
	B1 S5	1240	600	1.01
	B2 S1	420	920	1.21
	B2 S4	440	900	1.14
	B2 S5	820	900	1.22
	B3 S1	740	640	1.15
	B3 S4	1120	620	1.09
	B3 S5	1100	560	1.03
	B4 S1	380	820	1.00
	B4 S4	380	760	1.00
	B4 S5	1120	680	0.94

Sap nitrate levels at 75 days, showed no consistent trends by treatment, while sap phosphate and potassium levels for the Nitrophoska Blue Special® (B2) were slightly higher than for the other treatments.

A complete nutrient analysis of dried leaves and petioles from 5 treatments spanning the range of foliage yellowing symptoms is shown in Tables 5.4(a) and (b).

Table 2.4(a) Nutrient analysis for selected treatments spanning the range of foliage symptoms for K deficiency. Where U = undrenched; D = drenched

Sample type and plot	Treatment	K score	N	N	P	K	Na	Ca	Mg
			(tot)	(NO_3)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)
			%db	%db	%db	%db	%db	%db	%db
Plot 78 petioles	U B3 S1	1	0.95	0.02	0.45	2.46	0.73	1.19	0.17
Plot 92 petioles	D B2 S1	2	0.92	0.01	0.55	4.21	0.25	0.84	0.13
Plot 30 petioles	D B1 S1	3	1.34	0.11	0.48	2.16	1.44	1.46	0.22
Plot 79 petioles	U B1 S1	4	1.47	0.13	0.53	1.70	1.59	1.57	0.22
Plot 86 petioles	U B4 S1	5	0.97	0.02	0.48	1.10	2.00	1.59	0.19
Plot 78 blades	U B3 S1	1	2.95	< 0.01	0.51	1.15	0.69	1.48	0.15
Plot 92 blades	D B2 S1	2	2.63	< 0.01	0.5	2.37	0.28	1.18	0.10
Plot 30 blades	D B1 S1	3	4.06	0.01	0.67	1.06	1.18	1.44	0.15
Plot 79 blades	U B1 S1	4	4.29	0.01	0.77	0.60	0.93	1.52	0.17
Plot 86 blades	U B4 S1	5	3.66	< 0.01	0.79	0.64	1.59	2.12	0.22

Table 2.4(b) Nutrient analysis for give selected treatments spanning the range of foliage symptoms for K deficiency. Where U = undrenched; D = drenched

Sample type and plot	Treatment	K Score	S	B	Cu	Fe	Mn	Mo	Zn
			(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)	(ICP)
			%db	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Plot 78 petioles	U B3 S1	1	0.3	23	2.3	24	11	22	11
Plot 92 petioles	D B2 S1	2	0.47	23	2.4	17	12	2	10
Plot 30 petioles	D B1 S1	3	0.32	22	2.2	25	21	26	15
Plot 79 petioles	U B1 S1	4	0.36	23	2.3	45	29	15	16
Plot 86 petioles	U B4 S1	5	0.32	22	1.7	24	21	16	15
Plot 78 blades	U B3 S1	1	0.49	24	3.9	66	31	68	30
Plot 92 blades	D B2 S1	2	0.81	30	3.6	97	30	6	27
Plot 30 blades	D B1 S1	3	0.49	28	4	79	42	69	34
Plot 79 blades	U B1 S1	4	0.57	30	4.6	81	63	42	39
Plot 86 blades	U B4 S1	5	0.66	34	4	70	64	50	46

The substantially higher result for K in both blades and petioles for Plot 92 is a reflection of the higher amount of K applied in Nitrophoska Blue Special® (554 kg vs 244 kg for the next highest treatment), however, little can be made of the remaining results since all other plots received the same amount of K. Several of the other nutrients appear to be marginal but all these analyses were taken from S1 (unsprayed) plots therefore their growth was impaired from the start and the reduced uptake of nutrients overall is probably a reflection of this.

Discussion

Key findings of this work are that winter broccoli can be grown successfully by using a drench/spray/banding/fertigation technique for applying mineral fertiliser on infertile sandy soil with no previous vegetable cropping history. As for lettuce, where the technique was first developed, the highly concentrated drench and spray solutions did not damage establishing seedlings, when left to dry on foliage without ‘wash off’.

No advantage could be shown for a seedling drench with potassium nitrate for broccoli planted in late May, but nitrogen based sprays applied six times in the first 21 days after planting gave marked increases in growth rate during the period of spraying. These early growth responses translated into a mean threefold increase in marketable yield at harvest for both spray treatments compared to the unsprayed treatment, across all banding treatments. The latter treatment was not top-dressed for the first 16 days after planting and the effect on subsequent yield of such a practice was catastrophic for final yield at harvest, despite these plots having good nutrition for the last 70 days of their life.

As an example of the importance of early nitrogen application to final yield, the total nitrogen rate applied over the life of the crop for the un-drenched, un-sprayed treatment top-dressed with ammonium nitrate and potassium nitrate was 392.6 kg/ha (N). The equivalent sprayed treatment which maximised yield (S4) had 455.96 kg/ha (N) applied in the same time. The difference between the two was 63.4 kg/ha (N) applied in the first three weeks after planting as sprays. This extra nitrogen resulted in the final marketable yield of the sprayed treatment being more than five times the unsprayed treatment.

This example illustrates the importance of early nitrogen on final yield, but also the importance of accurate placement and constant availability of nitrogen during this sensitive stage of growth when seedlings have poorly developed root systems. Looking at this another way, a fivefold increase in crop yield worth around $12,000 per hectare was achieved for an extra fertiliser cost of only $339 per hectare and at the same time, no more than around 60 kg/ha of nitrogen could potentially be leached into groundwater.

No differences could be found between the four top-dressing fertilisers at this time of year. There was, however, a substantial difference in the cost of some of these treatments. The purchase cost of Nitrophoska Blue Special® was up to $1200 more than some of the other better yielding treatments. A combination of potassium nitrate and either LBU, ammonium nitrate or Spurt-N® bandings would all produce acceptable yields for much less cost.

Nitrophoska Blue Special® was included in the trial because it supplied phosphorus as well as nitrogen and potassium each time it was top-dressed. Both of these nutrients are known to leach from sandy soils and it was thought that regular topdressing of these as well as nitrogen may give an additional yield benefit. This did not prove to be the case. The additional phosphorus applied after planting this way produced no extra marketable yield and may have eventually been leached into the groundwater. This result suggests that phosphorus was not limiting yield for any of the treatments.

The practice of ceasing banded fertiliser topdressings at row closure resulted in potassium deficiency symptoms appearing in the foliage close to harvest for all treatments. The levels of potassium in plant sap were greatest at harvest for the Nitrophoska Blue Special® treatments which had higher rates of K (up to 554 kg/ha K when combined with S4) applied than the other treatments. Foliage symptoms were also less severe for this treatment than the others. Despite this, there were no marketable yield differences between banding treatments. Although the foliage symptoms looked unsightly, the important determinate of yield by the stage of growth that the symptoms appeared was the size of the plant’s frame and the reserves available to ‘fill out’ the developing head. Plant frame sizes were all determined much earlier in the life of the crop when fertiliser was being applied.

Foliage symptoms near harvest were strongly correlated with the level of potassium in plant sap. There was strong evidence that the symptoms were primarily the result of a late potassium deficiency. Extrapolation from the sap potassium data suggested that a level of K in sap which would avoid the onset of this symptom is likely to be around 1.4 g/L. Levels of potassium in dried petioles and blades were more variable than the equivalent sap levels, but the trend for lower levels of K in leaves exhibiting severe symptoms added weight to the conclusion that the symptoms observed were primarily caused by a deficiency of potassium.

Levels of nitrate close to harvest were not different between treatments. This was not surprising given that fertiliser treatments had ceased 26 days before the crop was sampled. It is likely that nitrogen had leached below the root zone by the time this sample was taken. Phosphate and potassium by contrast were higher in the sap from the Nitrophoska Blue Special® treatment, reflecting the extra 172 kg/ha (P) and 310 kg/ha (K) applied by this treatment compared to the other three top-dressing treatments. The phosphate and potassium supplied by Nitrophoska Blue Special® was also applied with each top-dressing up to 26 days before the sap was sampled. This result suggests that phosphorus and potassium were probably more slowly leached from the root zone than nitrogen.

Future fertiliser strategies for broccoli at this time of planting need to consider extra and or later applications of potassium to avoid deficiency symptoms near harvest, as well as testing whether further yield increases are possible by applying nitrogen fertiliser closer to harvest than 45 days.

Conclusions

Winter broccoli responded positively to sprayed nitrogen for the first three weeks after transplanting, with 21 kg/ha per week applied in two sprays per week being enough to maximise marketable yield. No yield advantage could be demonstrated from drenching seedlings before planting.

Subsequent topdressing of N at 64 kg/ha per week to row closure was sufficient to produce a marketable crop, but more than one topdressing with potassium fertiliser would be required to avoid potassium deficiency symptoms in foliage at harvest. There was no yield advantage from using any of the four topdressing fertilisers, despite a higher P and K content in Nitrophoska Blue Special® and a significantly higher cost per hectare for this product. The most cost effective treatment would in most circumstances be to top-dress with LBU and supplement with at least two applications of potassium nitrate between transplanting and row closure.

Future work should investigate the merits of continued topdressing beyond row closure, spraying for longer and later commencement of topdressing treatments, to increase yields and/or reduce total nitrogen rates applied.

3. CABBAGE

Introduction

Cabbage is a crop that is widely transplanted in the field from 'tray grown' seedlings produced by specialist nurseries in Australia. In Western Australia the crop is almost exclusively grown this way in commercial practice, and production is year round on sandy soils of the Swan Coastal Plain.

Where cabbage is grown on sandy soils, it is often in rotation with crops such as lettuce, celery and broccoli. Traditional nutrition practice for these crops is to use poultry manure as a broadcast treatment before planting and/or banded between rows after planting. Mineral fertilisers are also routinely applied as topdressing on these crops. No research work had been done to test seedling drenches or fertiliser sprays as establishment treatments for cabbage on these sandy soils prior to this research. The potential benefits of the drench/spray technique are reduced leaching of fertiliser into groundwater from lower fertiliser application rates and more uniform placement and utilisation of fertiliser than achieved by current commercial practices.

Method

Site preparation and pre planting fertiliser applications were done according to standard practice as outlined in the 'General Methods'.

Seedlings for the trial (cultivar 'Kameron'), were bought in from a specialist nursery and planted on 14 July 2005. Half the seedling trays were drenched with 40 g/litre potassium nitrate at 500 mL/tray (100 cells) within one hour of planting for the drenched treatments (D) and the other half were drenched with water (undrenched = U).

Seedlings were planted in 'four row' beds with 300 mm between rows and 400 mm between plants. Each plot had a row of buffer plants at each end (eight buffer plants in total). Plots were 2.8 m long (28 plants in total with 20 plants for harvest). The plots were un-buffered outside the rows, i.e. all four rows were harvested, but the trial block was buffered with two beds planted as buffers either side of the four replicate beds. Immediately after transplanting Dacthal® was applied by boom-spray for weed control at 6 kg/ha and this was followed with 3 mm irrigation.

The experimental design comprised four replicates of a split-split plot design with banded fertiliser as the main plot (four fertiliser products), drenching as the split plot (drenched vs undrenched) and spray treatment (four spray rates) as the split-split plot.

The cabbage was harvested on 24 October, 102 days after planting. The crop grew very slowly, taking a long time to head up, but when harvested, the heads were dense and their weights were high.

Post-planting fertiliser treatments

A regime of spray treatments was commenced three days after planting (18 July) which consisted of twice weekly applications of a range of spray treatments (Table 3.1) for a total of three weeks (six applications in total).

S1 = No spray.
S2 = 40 kg/ha potassium nitrate only (31.2 kg/ha nitrogen and 91.2 kg/ha potassium in total).
S3 = 11.3 kg/ha LBU only (31.2 kg/ha N in total).
S5 = 22.5 kg/ha LBU plus 20 kg/ha potassium nitrate (77.7 kg/ha nitrogen, 45.6 kg potassium in total).

This was followed by a series of one of four top-dressing treatments (designated B) as detailed in Table 1. These treatments were banded into a shallow furrow between pairs of rows of cabbage commencing 18 days after transplanting and ending at row closure, except for Spurt-N® which was simulation fertigated as described in the General Methods.

Table 3.1 Top-dressing (banding) treatments (B1-B4) applied to cabbage (kg/ha)

Top-dressing treatment	B1		B2	B3		B4	
Days after planting	**Potassium nitrate (kg/ha)**	**Ammonium nitrate (kg/ha)**	**Nitrophoska Blue Special®**	**Potassium nitrate (kg/ha)**	**LBU (kg/ha)**	**Potassium nitrate (kg/ha)**	**Spurt-N® (kg/ha)**
18	400		550	400		400	
26			550		150		200
27		200					
34	500		550	500		500	

This program was supplemented with a foliar application of manganese sulphate on day 40. After day 40 there were two top-up applications of potassium nitrate (300 kg/ha) plus ammonium nitrate (80 kg/ha) on days 70 and 89. These applications were fertigated over all plots in the trial at the same rate because all treatments had reached row closure and differential treatment of plots would have been difficult or impossible, especially for the mixed granular product, Nitrophoska Blue Special®.

Samples of petioles were taken for sap analysis at intervals after row closure to determine the need for further top-dressing. These samples were taken from the buffer beds around the trial which were treated with the S5 spray treatment combined with B1 topdressing. At harvest, four petioles were taken from a middle row in each plot. Samples were bulked across replicates prior to sap extraction and analysis with an RQflex® reflectometer and Merckoquant indicator strips for nitrate, phosphate and potassium.

Pest and disease control

A treatment regime for control of diamondback moth was implemented using a rotation of Regent® (fipronil) at 250 mL/ha, Success® (Spinosad) at 400 mL/ha and Nitofol® (methamidophos) at 500 mL/ha. The trial was conducted almost entirely in cool wet conditions, and pests were not a problem until close to harvest.

Results

All treatments established well after transplanting, and differences between the spray treatments were clearly visible by 15 days after planting. The most obvious visual difference was between the unsprayed treatment and the others by this time with the former making poor growth and developing pale green foliage with purple tints. The effects of increasing spray rates from zero to the highest rate are illustrated in Figure 3.1 moving clockwise from the left.

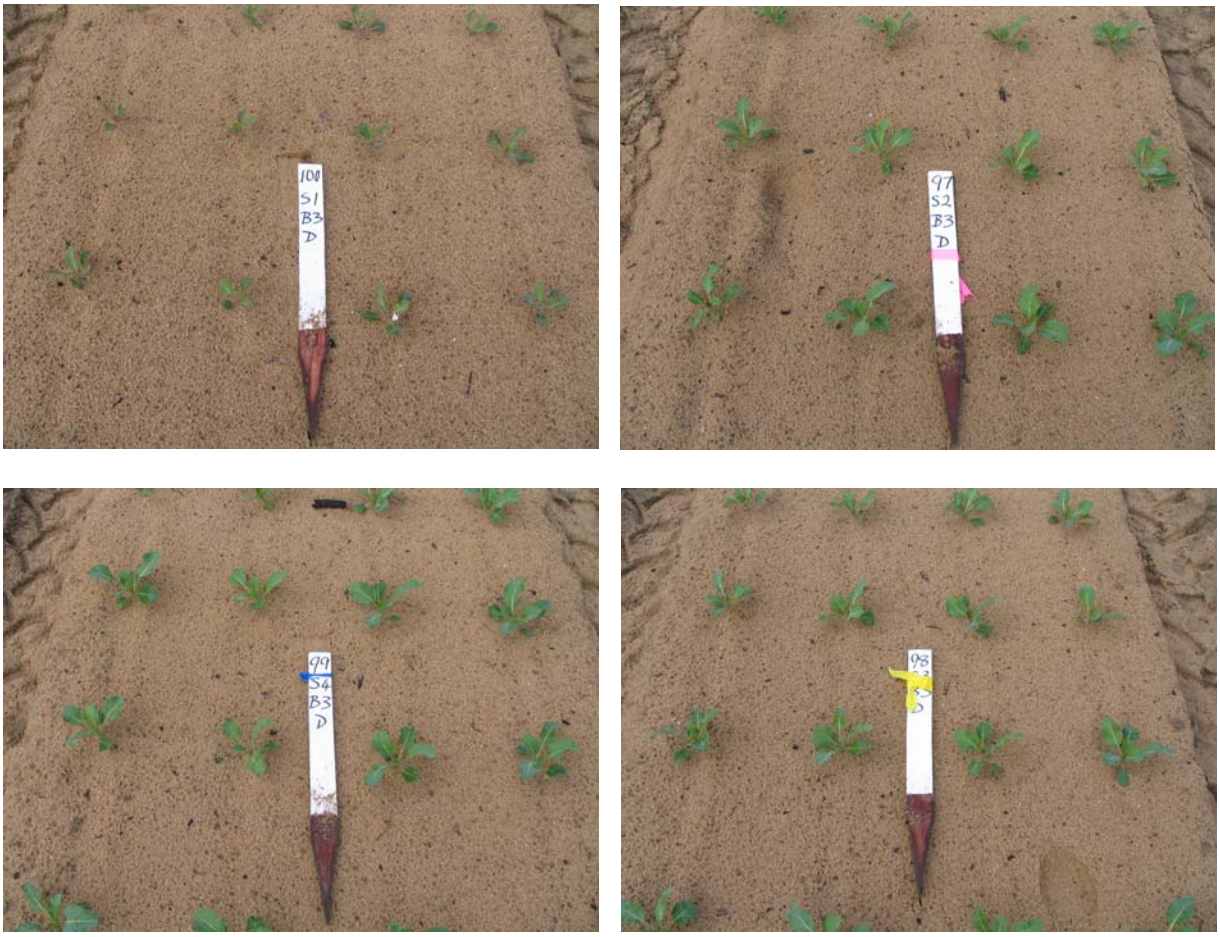


Figure 3.1 Comparison of spray treatments on cabbage at day 15 after four of the planned sprays had been applied and before topdressing commenced.

Differences between the sprayed treatments remained visible all the way to harvest, but they were less obvious than they were prior to row closure as illustrated in Figure 3.2, where the four spray rates are compared 36 days after planting. Spray rates increase from zero at the top left, moving clockwise to the highest rate at the bottom left for the Nitrophoska® banded treatment.

(a)

(b)

(c)

(d)

Figure 3.2 (a-d) Comparison of spray treatments on cabbage at day 36 after all spray and banding treatments had been applied, and row closure had been reached for the better treatments. Spray rates increase clockwise from the left.

As previously mentioned, the crop grew slowly after row closure and head sizes were small though extremely dense. There was a relatively high percentage of rejects (Table 3.2), mostly for insect damage and small heads, so the yields quoted are low compared to the yield potential of the crop.

Table 3.2 Percentage rejection rates for cabbage nutrition trial

Spray	Drench	Top-dressing treatment			
		AN	Nitrophoska Blue Special®	LBU	Spurt-N®
S1	**D**	49.2	32.9	46.6	47.4
	U	40.1	37.5	43.5	51.9
S2	**D**	27.3	25.3	28.6	39.6
	U	29.5	16.8	27.9	37.1
S3	**D**	29.5	22.0	33.9	32.8
	U	30.5	20.2	26.0	36.9
S5	**D**	20.2	16.0	19.0	28.2
	U	16.4	12.4	15.5	21.2

There were no visible differences between drenched and undrenched plots in the weeks immediately following transplanting, but the final harvest yield estimates showed that the pre-plant drench had a highly significant adverse effect on the seedlings (22.5 t/ha cf 27.4 t/ha).

There were highly significant differences between spray treatments with the combination of potassium nitrate plus LBU producing better yields than any of the other treatments. (see Figure 3.3). The response was in direct proportion to the rate of nitrogen applied by the sprays. The form in which the nitrogen was applied appeared to make no difference to the response when sprays 2 and 3 were compared. These two treatments both applied approximately 32 kg/ha of nitrogen in the first 21 days after planting, in the form of potassium nitrate or as LBU. Final harvest yields were not different for the two forms of nitrogen at the same rate of nitrogen applied.

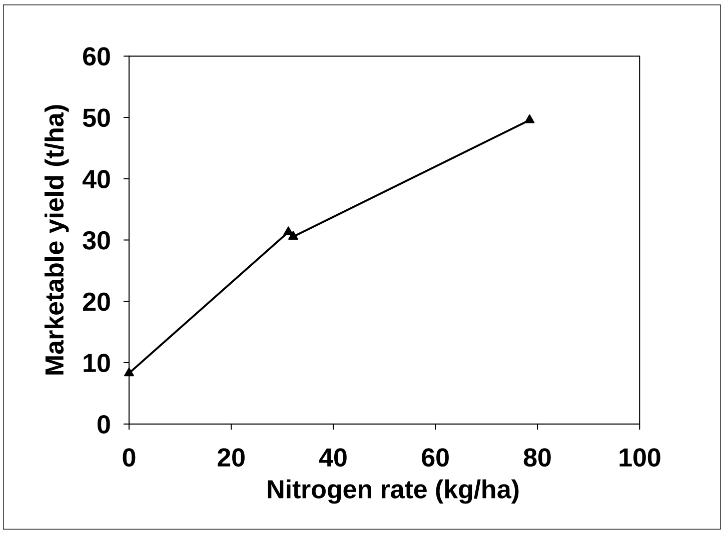


Figure 3.3 The effect of sprayed nitrogen on final harvest yield of cabbage.

The Nitrophoska Blue Special® treatment also performed better ($p < 0.012$) than the other top-dressing treatments (see Figure 3.4) and there were no significant interactions between topdressing, sprays and drench treatments.

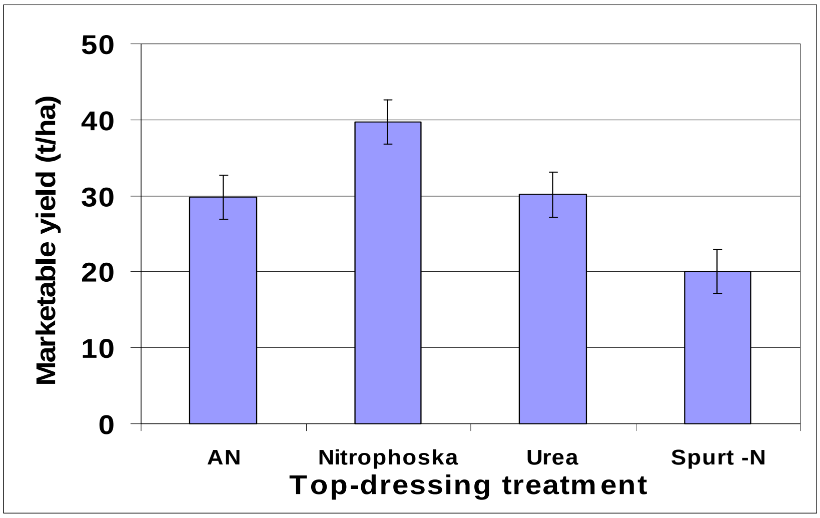


Figure 3.4 Effect of top-dressing treatment on yield of cabbage.

Sap tests

Sap tests conducted on the buffer beds at 61 days after planting and 98 days showed low levels of nitrate in sap at the first sampling and extremely low levels at the second. The action taken after the first test result was to top-dress the whole trial with nitrogen and potassium on day 70 as described in the methods section, and again at day 89. Neither of these applications proved sufficient to maintain an adequate level of nitrate in the plant sap, as evidenced by the very low levels at day 98 and at harvest.

Levels of phosphate and potassium did not fluctuate greatly between tests. Despite the additional potassium top-dressings at days 70 and 98, sap levels consistently in the range 1.0–1.1 g/L were considered to be low. No visible symptoms of potassium deficiency were noted in the cabbage foliage despite these levels being similar to those where broccoli exhibited symptoms in an earlier trial.

Results of sap tests are shown in Table 3.3 for means over time and Table 3.4 for the final harvest tests of all treatments.

Table 3.3 Mean sap nitrate, phosphate and potassium levels at two dates after row closure and at harvest for the main effects of drenching, top-dressing (B) and fertiliser spraying (S)

	13 September			20 October			26 October		
	(NO_3) mg/L	(PO_4) mg/L	K^+ g/L	$(NO_3)^-$ mg/L	(PO_4) mg/L	K^+ g/L	(NO_3) mg/L	(PO_4) mg/L	K^+ g/L
Undrenched	385	740	1.05	56.5	745	1.16	13	688	1.10
Drenched	445	685	1.10	159	740	1.14	24	805	1.09
B1	590	700	1.07	200	720	1.16	12	665	1.08
B2	400	710	1.10	3.5	710	1.14	11	738	1.09
B3	270	740	1.10	220	650	1.15	16	835	1.10
B4	400	730	1.09	7	890	1.15	17	853	1.09
S1							7	753	1.08
S2							26	738	1.09
S3							22	788	1.09
S5							19	708	1.13

Table 3.4 Sap nitrate, phosphate and potassium levels at harvest (October 26th) for all treatment combinations of drenching, top-dressing (B), Drench (D;U) and fertiliser spraying (S)

Treatment (Top-dressing: Drench:Spray)	(NO_3) mg/L	(PO_4) mg/L	K^+ g/L
B1 U S1	8	740	1.04
B1 U S2	0	620	1.04
B1 U S3	14	700	1.13
B1 U S5	8	540	1.08
B2 U S1	7	720	1.12
B2 U S2	44	720	1.09
B2 U S3	10	800	1.08
B2 U S5	46	680	1.21
B3 U S1	5	520	1.01
B3 U S2	7	720	1.09
B3 U S3	9	740	1.08
B3 U S5	14	700	1.17
B4 U S1	0	660	1.15
B4 U S2	5	740	1.12
B4 U S3	7	800	1.09
B4 U S5	22	600	1.10
B1 D S1	14	740	1.12
B1 D S2	24	640	1.07
B1 D S3	15	680	1.09
B1 D S5	13	660	1.07
B2 D S1	7	1340	1.08
B2:D:S2	16	1320	1.11
B2 D S3	27	720	1.07
B2 D S5	15	1240	1.14
B3 D S1	0	580	1.07
B3 D S2	0	640	1.10
B3 D S3	5	1260	1.07
B3 D S5	21	620	1.11
B4 D S1	14	720	1.07
B4 D S2	110	500	1.09
B4 D S3	90	600	1.12
B4 D S5	10	620	1.12

Discussion

The three nutrition factors tested, seedling drenches, sprayed fertiliser and band applied fertiliser all affected plant growth and crop yield independently of each other. Drenching seedlings with potassium nitrate solution prior to planting reduced final harvest yields compared to a drench with water only. Spraying fertiliser over the crop twice weekly for the first three weeks after planting increased yields in proportion to the rate of nitrogen supplied by the spray, with the best treatment being a mixture of potassium nitrate and low biuret LBU (S5). The mixed granular fertiliser, Nitrophoska Blue Special® gave the highest yields of the four fertiliser products tested when banded between the rows from 14 days after planting until row closure.

Not surprisingly, the highest yielding individual treatment (66.8 t/ha) was that without the preplant drench, with the combination potassium nitrate and LBU sprays (S5) followed by NPK Blue Special® top-dressing. This treatment, although amongst the most expensive treatments in terms of fertiliser cost, was only $100 more than the next best yielding treatments. This treatment also received significantly less potassium than many other treatments but slightly more phosphorus.

Adverse effects from drenching seedlings were never visible, but detectable only by analysing harvest weights. Sap nitrate levels were generally higher in drenched plants than undrenched, later in the crop's life, but the differences were small. There were no consistent trends in sap nitrate, phosphate or potassium levels at harvest related to the range of treatments.

Conclusion

The best treatment combination for cabbage grown in winter was undrenched seedlings, followed by six sprays of a mixture of 22.5 kg/ha LBU plus 20 kg/ha potassium nitrate applied in 1000 l/ha of water at 3-4 day intervals for the first 21 days after planting. Spray treatments should be followed by Nitrophoska Blue Special® banded between the rows at 550 kg/ha, commencing on day 16 after planting and continuing until row closure. After row closure, further fertigation treatments with nitrogen and potassium were required to a total of 600 kg/ha of potassium nitrate and 160 kg/ha of ammonium nitrate. It is likely that further yield increases could be achieved by further top-dressing beyond row closure and this aspect of winter cabbage production needs to be investigated further.

4. CAULIFLOWER

Introduction

Cauliflower is a crop that is widely transplanted in the field from ‘tray grown’ seedlings produced by specialist nurseries in Australia. In Western Australia it is almost exclusively grown this way in commercial practice. Cauliflower is grown on sandy soils of the Swan Coastal Plain, up to 200 km north and south of Perth during spring, winter and autumn. It is also grown on sandy loam soils throughout the year in the lower-south west of the State, in districts such as Manjimup.

Where cauliflower is grown on sandy soils, it is often in rotation with crops such as lettuce and celery. Traditional nutrition practice for these crops is to use poultry manure as a broadcast treatment before planting and/or banded between rows after planting. Mineral fertilisers are also routinely applied as topdressings on these crops also. Prior to this research, no work had been done to test the effectiveness of seedling drenches or fertiliser sprays as establishment treatments for cauliflower prior to the research reported on here. The potential benefits of the drench/spray technique are reduced leaching of fertiliser into groundwater from lower fertiliser application rates and better placement of fertiliser than achieved by current commercial practices.

Method

Site preparation and pre planting fertiliser applications were made according to standard practice as outlined in the ‘General Methods’.

Seedlings (cultivar ‘Liberty’) for the trial were bought in from a specialist nursery and planted on 25 May 2005. Half the seedling trays were drenched with 40 g/litre potassium nitrate at 500 mL/tray (100 cells) within one hour of planting for the drenched treatments and the other half were drenched with water.

Seedlings were planted by hand in the field at two rows per bed with 750 mm between rows and 450 mm between plants. Each plot had a buffer plant at both ends of each row (i.e. 4 buffer plants in total per plot). Plots were 5.85 m long (26 plants with 22 plants for harvest). The plots were un-buffered outside the rows, i.e. both rows were harvested and both had an unplanted pathway on one side. The experimental design comprised four replicates of a split-split plot design with banding as the main plot, drenching as the split plot and spray treatment as the split-split plot.

Immediately after transplanting, Dacthal® was applied by boom-spray for weed control at 6 kg/ha and this was followed with 3 mm irrigation.

A series of sprays were applied at weekly intervals according to the insecticide resistance management strategy for diamondback moth. Regent® (fipronil) was sprayed at 250 mL/ha and followed by two sprays of Success® (spinosad) at 400 mL /ha, one of Proclaim® (emamectin) at 300 g/ha, another two of Success® and a final spray of Proclaim®.

The cauliflowers were harvested from 24 August – 14 September in eight picks (97-118 days). Only curds deemed to be of marketable size were harvested. Curds were harvested as for export, i.e. trimmed of all leaves, in the field. Total plot weights were recorded, then plants assessed for marketability. Marketable and reject weights were recorded together with reasons for rejection, primarily the presence of rot and low head weight in some treatments.

Post-planting fertiliser treatments

Cauliflower was planted at the lowest plant density of all the crops tested in this series, consequently even though two bays were devoted to the trial, plot size constraints limited the trial to 128 plots in total compared to the 160 plots needed to test all forty treatments in trials with other closer spaced crops. This meant some rationalisation of treatments. The number of spray treatments was reduced from the five outlined in 'General Methods' to four – those being S1, S2, S4 and S5. This reduced the total number of treatments to 32. The number of replicates was increased to four.

A regime of spray treatments was commenced one day after planting which consisted of twice weekly applications of a range of the following spray treatments for a total of three weeks (six applications in total).

S1 No spray.

S2 40 kg/ha potassium nitrate (31.2 kg/ha nitrogen in total, 91.2 kg potassium in total).

S4 11.3 kg/ha LBU plus 40 kg/ha potassium nitrate (62.4 kg/ha nitrogen, 91.2 kg potassium in total).

S5 22.5 kg/ha LBU plus 20 kg/ha potassium nitrate (77.7 kg/ha nitrogen, 45.6 kg potassium in total).

This was followed by a series of one of four top-dressing treatments as detailed in Table 4.1. The prilled or granular fertilisers were banded into two shallow furrows between the pair of rows of cauliflower while Spurt-N® was simulation fertigated as outlined in 'General Methods', commencing 16 days after transplanting and ending at row closure.

Table 4.1 Schedule of top-dressing treatments (kg/ha of product) applied to the cauliflower crop

Days after planting	B1		B2	B3		B4	
	Potassium nitrate (kg/ha)	Ammonium nitrate kg/ha)	Nitrophoska Blue Special®	Potassium nitrate (kg/ha)	LBU (kg/ha)	Potassium nitrate (kg/ha)	Spurt-N® (kg/ha)
16	400		550	400		400	
22		200	550		150		200
30		200	550		150		200
35		200	550		150		200
44		200	550		150		200
49		200	550		150		200
53		200	550		150		200
59		200	550		150		200
63		200	550		150		200
71	500		550	500		500	
78		200	550		150		200
Total N:P:K	729N:0P:342K		726N:302.5P:847K	738N:0P:342K		693N:0P:342K	

This regime was followed by two applications each of 100 kg/ha of $MgSO_4$ in the week beginning 8/8/05 (75 days after sowing)

Figure 4.1 shows the placement of banded granular fertiliser in a double furrow between rows of cauliflower. The split-split plot design of the trial allowed eight consecutive plots in a bed to be mechanically banded at each date of top-dressing. Mechanical banding ensured more uniform application of top-dressing than could be achieved by hand.

Figure 4.1 Cauliflower plots showing granular fertiliser banded into a pair of furrows between rows of plants.

Sap and plant tissue tests

Tests for sap nitrate, phosphate and potassium were done using an RQflex® reflectometer and Merckoquant® indicator strips on samples from all plots collected on 24 August, prior to harvest (day 91). All plots were rated for two foliar symptoms separately, on a scale of 1-5 to correlate with sap nutrient levels. Figures. 7.11a-j show the rating system that was used for each of the symptoms. The two symptoms are labelled P and K in the figures with rating scores of 1-5, where 1 had no symptom and 5 was severe. Those labelled P are what we expected to be phosphorus toxicity and those labelled K, potassium deficiency.

Leaf blade and petiole samples were also taken from five plots for each symptom, representing the range of severity symptoms from score 1-5. These samples were tested for a range of elements on a dry weight basis by the Chemistry Centre of WA.

Results

The crop grew well with obvious visual differences between the unsprayed treatment (S1) and the other spray treatments by two weeks after planting. Over time, as the banding treatments were applied, these differences became less obvious but by the time of harvest, the unsprayed treatment was still visibly smaller than all other sprayed treatments. There were obvious visual differences in plant vigour between the S2 spray rate treatment and the two higher rate treatments, S4 and S5, for up to 60 days after planting, but there was little obvious difference between S4 and S5. Differences in maturity at harvest between spray treatments were more pronounced. Visible differences between drenched and undrenched treatments were not obvious at any stage of growth, nor were differences between banding treatments highly visible.

The photos which follow show differences between spray treatments over time.

Figure 4.2a Effect of spray S4 (left) sprayed vs S1 (right) unsprayed at 19 days.

Figure 4 2b Effect of spray S1 (left) unsprayed vs S5 (right) sprayed at 36 days.

Figure 4.2c-e. Effect of spray treatments S1 (left), S4 (middle) and S5 (right) still visible at 57 days after planting.

Harvest

Three of the four spray treatments commenced harvesting on August 24 (97 days), but the rate at which harvesting progressed was different for each of the treatments as shown in Figure 4.3. The rate at which cauliflower heads reached a marketable size and maturity was in direct proportion to the rate of nitrogen sprayed in the first three weeks after planting. Most of the unsprayed treatments did not reach a marketable size or maturity by the end of the harvesting period (September 13), and would not have matured if given more time.

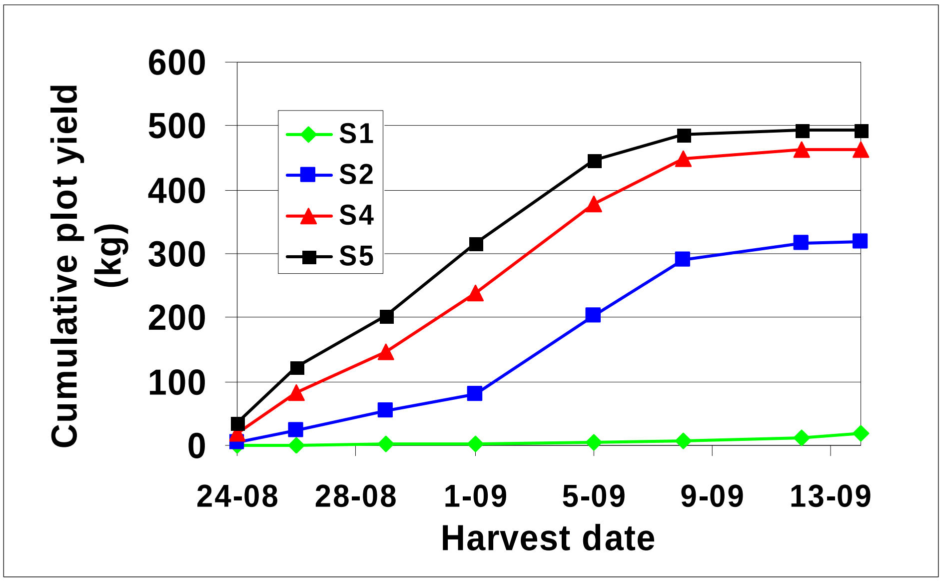


Figure 4.3 Cumulative yield of cauliflower by spray treatment.

A quadratic response function was fitted to the relationship between the rate of nitrogen sprayed and marketable yield at harvest. The function was highly significant and Figure 4.4 shows that the response to total nitrogen supplied as a spray in the first 21 days after planting had not peaked at 80 kg/ha N.

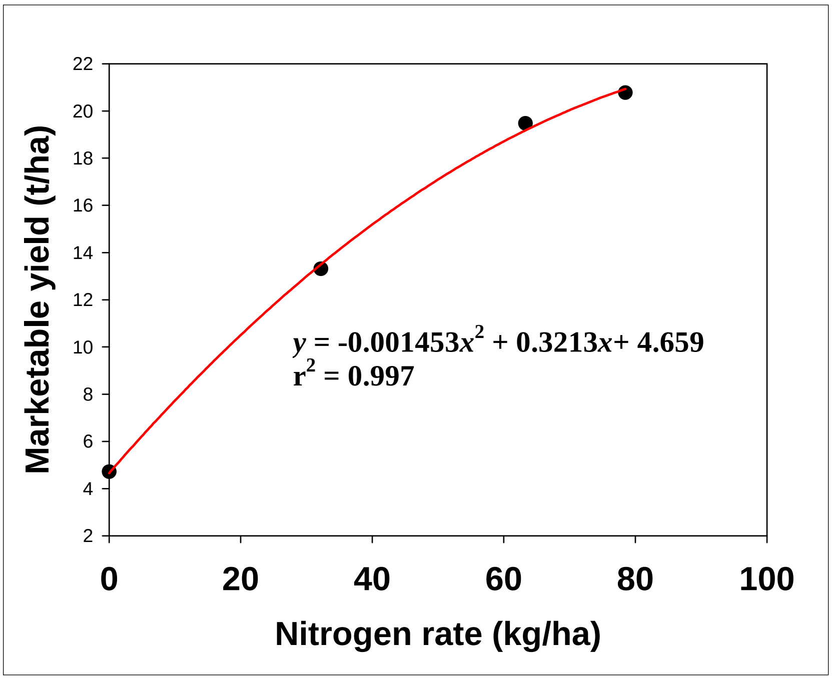


Figure 4.4 The effect on cauliflower curd yield of rate of nitrogen sprayed in the first 21 days after planting.

Analysis of the yield data showed an highly significant effect of spray treatment (Figure 4.5), with both S4 and S5 performing equally well. There was no difference between banding treatments and a slight adverse effect of the pre-planting drench (12.7 cf 14.3 t/ha).

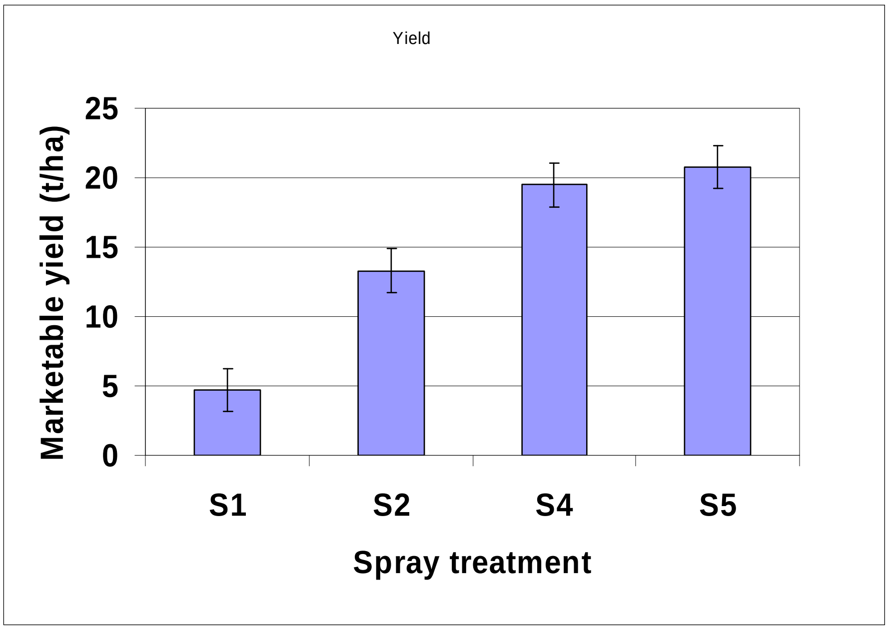


Figure 4.5 Marketable yield response of cauliflower to the four spray treatments.

Differences between the four top-dressing treatments were less than those between spray treatments as shown in Figure 4.6. The Nitrophoska Blue Special® treatment (B2) produced a higher proportion of marketable curds earlier than the other three treatments, while the rate of harvesting the other three treatments was very similar until September 5. After this date, the treatments diverged with B2 and B4 (Spurt-N®) falling behind the other two treatments.

Statistical analysis of data for marketable yields showed a significant interaction between top-dressing and spray treatments. There was no significant difference in yield between the four top-dressing products at the highest rate of spray (S5) and these were all the highest yielding treatments. At the S4 rate of spraying, Nitrophoska Blue Special® (B2) and LBU (B3) were also in the highest yielding group, but the other two top-dressing treatments yielded significantly less.

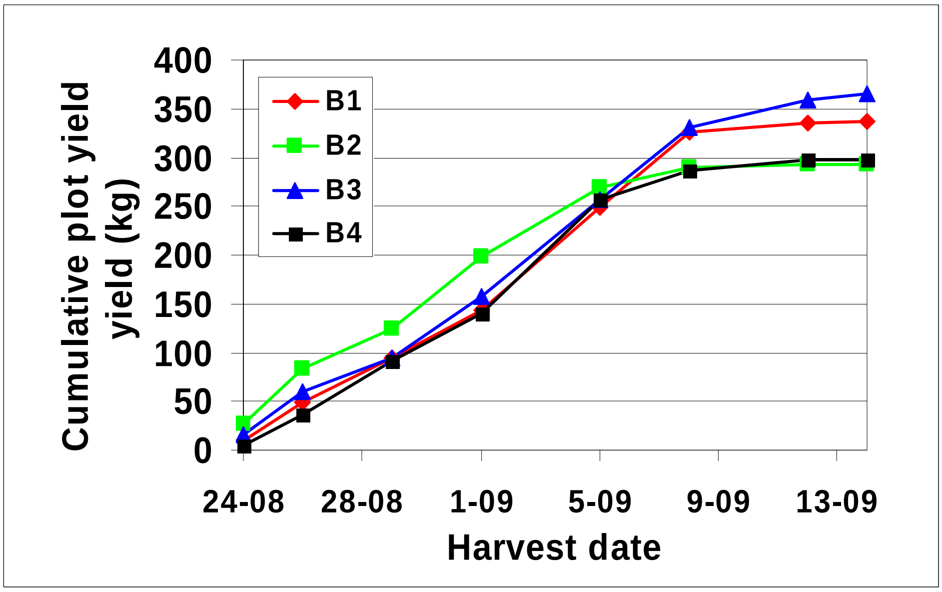


Figure 4.6 Cumulative yield of cauliflower crop by banding treatment.

Plant sap and tissue tests

All treatments maintained a healthy colour from 78 days until the early stages of heading around 90 days without further topdressing. After this time, the leaves of some treatments developed yellowing and marginal scorching of the old leaves, similar to the symptoms observed in broccoli. Other plots developed a marginal scorch on old leaves similar to what we expected from experience to be phosphorus toxicity. There was a difference in severity of these symptoms between treatments.

Relationships between symptom severity and treatments are shown in Figures 7.7 and 7.8. There was a clear association between treatments and symptom development. Treatments B3 and B4 showed few P toxicity symptoms, while the scores for this symptom were highest for Nitrophoska Blue Special® (B2). Symptoms increased with increasing spray rate, and consequently were most severe on larger plants.

Topdressing treatments B2 and B3 showed no K deficiency symptoms, while Spurt-N® (B4) had the most severe symptoms. Nitrophoska Blue Special® (B2) had the least severe K deficiency symptoms while the unsprayed (B1) and Spurt-N® (B4) treatments had the most severe symptoms (Figures 7.9 and 7.10).

The sap data for nitrate, phosphate and potassium is presented in Table 4.2. Ten petiole and leaf blade samples were tested for a full range of elements on a dry weight basis at the same time that sap tests were taken. The results of those tests are shown in Table 4.3 for P and Table 4.4 for K.

These results show a trend to increasing P symptom severity when P levels in blades exceed 1 per cent (dry basis). The K symptoms became more severe when K in blades fell below 0.86 per cent and 1.3 per cent in petioles.

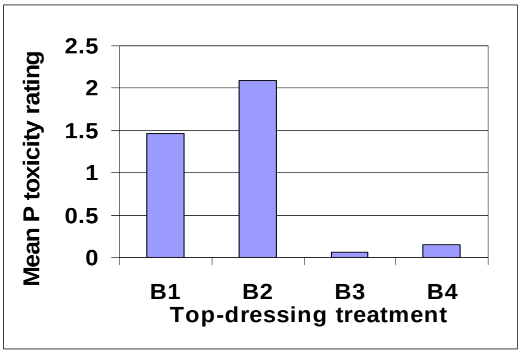


Figure 4.7 Effect of banding treatment on P severity score.

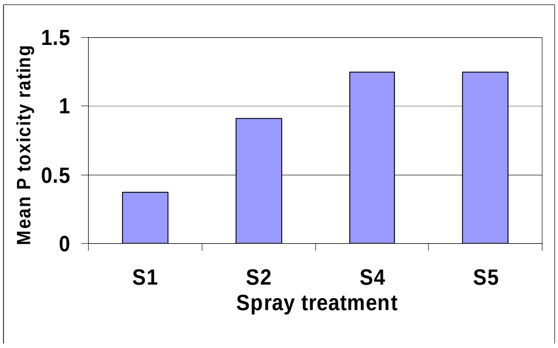


Figure 4.8 Effect of spray treatment on P severity score.

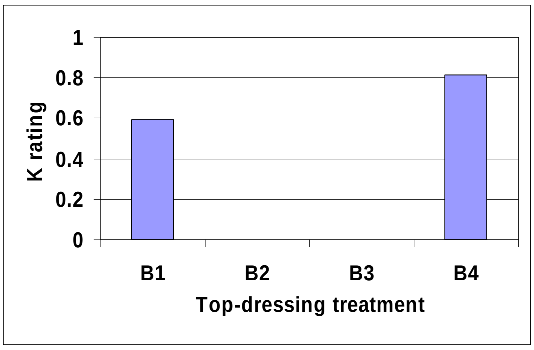


Figure 4.9 Effect of banding treatment on K severity score.

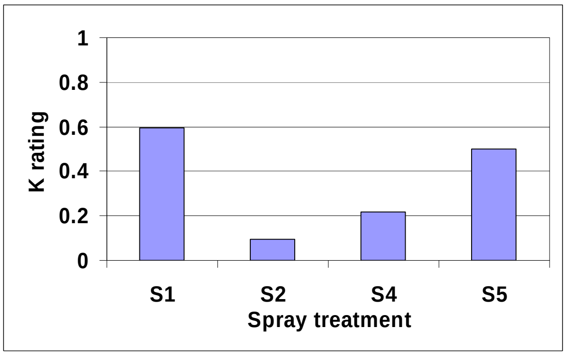


Figure 4.10 Effect of spray treatment on K severity severity score.

From the available sap data, no significant statistical relationship between sap N, P or K and marketable yield was apparent.

Table 4.2 Petiole sap test results for fertiliser treatments at 91 days after planting

	Sample	NO_3 (mg/L)	PO_4 (mg/L)	K^+ (g/L)
Undrenched	B1 S1	1620	480	1.04
	B1 S2	720	680	1.07
	B1 S4	700	600	0.98
	B1 S5	1280	520	1.04
	B2 S1	780	720	1.10
	B2 S2	2020	700	1.15
	B2 S4	700	760	1.12
	B2 S5	1380	820	1.14
	B3 S1	660	480	1.00
	B3 S2	680	640	1.01
	B3 S4	1280	440	1.18
	B3 S5	1560	340	0.82
	B4 S1	1500	520	1.27
	B4 S2	1220	480	1.06
	B4 S4	1360	540	1.13
	B4 S5	700	580	1.27
Drenched	B1 S1	500	640	1.11
	B1 S2	820	560	1.18
	B1 S4	1640	380	1.00
	B1 S5	920	340	0.71
	B2 S1	400	700	1.19
	B2 S2	900	640	1.24
	B2 S4	800	600	1.15
	B2 S5	980	740	1.24
	B3 S1	1120	520	1.10
	B3 S2	360	640	1.18
	B3 S4	2080	400	1.10
	B3 S5	1140	680	1.08
	B4 S1	400	540	1.14
	B4 S2	960	1040	1.11
	B4 S4	820	600	1.10
	B4 S5	1580	540	1.08
	B=Top-dressed			
	S=Spray			

Table 4.3 Complete nutrient analysis for selected treatments spanning the range of foliage symptoms for P toxicity

Sample type and plot	Treatment	K Score	N (tot) %db	N (NO_3) %db	P (ICP) %db	K (ICP) %db	Na (ICP) %db	Ca (ICP) %db	Mg (ICP) %db
Plot 2 Petioles	U B3 S2	1.58	1.58	0.03	0.42	2.65	0.68	0.62	0.13
Plot 87 Petioles	D B2 S1	0.98	0.98	< 0.01	0.4	3.22	0.73	0.76	0.15
Plot 82 Petioles	U B2 S1	1.31	1.31	0.02	0.51	5.13	0.73	1.01	0.18
Plot 15 Petioles	U B1 S1	1.39	1.39	0.06	0.42	1.64	2.19	1.29	0.15
Plot 33 Petioles	U B2 S5	1.73	1.73	0.1	0.6	5.94	1.08	1.37	0.25
Plot 2 Blades	U B3 S2	3.67	3.67	< 0.01	0.67	1.67	0.62	1.15	0.17
Plot 87 Blades	D B2 S1	3.1	3.1	< 0.01	0.75	1.84	0.71	1.51	0.18
Plot 82 Blades	U B2 S1	4.38	4.38	< 0.01	1.12	2.86	0.81	2.06	0.18
Plot 15 Blades	U B1 S1	4.52	4.52	0.01	1.1	1.07	1.59	2.67	0.2
Plot 33 Blades	U B2 S5	3.96	3.96	0.01	1.05	2.58	0.9	3.07	0.2

Sample type and plot	Treatment	K Score	S (ICP) %db	B (ICP) mg/kg	Cu (ICP) mg/kg	Fe (ICP) mg/kg	Mn (ICP) mg/kg	Mo (ICP) mg/kg	Zn (ICP) mg/kg
Plot 2 Petioles	U B3 S2	1	0.3	16	1.7	20	12	6	16
Plot 87 Petioles	D B2 S1	2	0.39	17	0.9	15	17	2	13
Plot 82 Petioles	U B2 S1	3	0.56	21	1.4	18	19	3	15
Plot 15 Petioles	U B1 S1	4	0.38	17	1.4	24	26	7	13
Plot 33 Petioles	U B2 S5	5	0.74	23	2	42	20	4	18
Plot 2 Blades	U B3 S2	1	0.59	24	3.8	79	37	23	39
Plot 87 Blades	D B2 S1	2	0.8	36	2.7	98	52	7	30
Plot 82 Blades	U B2 S1	3	1.14	49	3.4	97	55	10	35
Plot 15 Blades	U B1 S1	4	0.8	35	3.5	120	82	30	33
Plot 33 Blades	U B2 S5	5	1.47	49	3	110	56	12	26

Table 4.4 Complete nutrient analysis for selected treatments spanning the range of foliage symptoms for K deficiency

Sample type and plot	Treatment	K Score	N (tot) %db	N (NO_3) %db	P (ICP) %db	K (ICP) %db	Na (ICP) %db	Ca (ICP) %db	Mg (ICP) %db	N (tot) %db
Plot 2 Petioles	U B3 S2	1	1.55	0.04	0.42	2.68	0.62	0.61	0.13	0.27
Plot 97 Petioles	U B4 S1	2	0.62	< 0.01	0.33	1.31	1.71	1.26	0.13	0.30
Plot 9 Petioles	D B1 S1	3	1.06	< 0.01	0.39	1.06	2.1	0.94	0.11	0.38
Plot 22 Petioles	D B4 S1	4	0.71	< 0.01	0.34	0.92	2.19	1.27	0.13	0.31
Plot 104 Petioles	D B4 S1	5	0.76	< 0.01	0.34	1.04	1.80	0.99	0.12	0.29
Plot 2 Blades	U B3 S2	1	4.11	< 0.01	0.73	1.58	0.65	1.21	0.16	0.51
Plot 97 Blades	U B4 S1	2	2.47	< 0.01	0.67	0.86	1.68	2.91	0.22	0.83
Plot 9 Blades	D B1 S1	3	3.83	< 0.01	0.88	0.79	1.81	2.2	0.19	0.81
Plot 22 Blades	D B4 S1	4	2.71	< 0.01	0.72	0.71	1.87	3.35	0.25	0.88
Plot 104 Blades	D B4 S1	5	2.37	< 0.01	0.65	0.68	1.73	2.59	0.21	0.77

Sample type and plot	Treatment	K Score	S (ICP) %db	B (ICP) mg/kg	Cu (ICP) mg/kg	Fe (ICP) mg/kg	Mn (ICP) mg/kg	Mo (ICP) mg/kg	Zn (ICP) mg/kg
Plot 2 Petioles	U B3 S2	1	0.27	15	1.6	39	13	5	15
Plot 97 Petioles	U B4 S1	2	0.3	15	0.4	24	16	8	11
Plot 9 Petioles	D B1 S1	3	0.38	16	1	27	31	6	17
Plot 22 Petioles	D B4 S1	4	0.31	16	1.6	24	27	5	24
Plot 104 Petioles	D B4 S1	5	0.29	14	0.6	22	16	4	13
Plot 2 Blades	U B3 S2	1	0.51	22	3.6	89	42	21	38
Plot 97 Blades	U B4 S1	2	0.83	25	2.1	69	74	33	24
Plot 9 Blades	D B1 S1	3	0.81	27	2.7	85	98	23	38
Plot 22 Blades	D B4 S1	4	0.88	26	1.9	91	140	20	31
Plot 104 Blades	D B4 S1	5	0.77	26	2.1	76	66	17	27

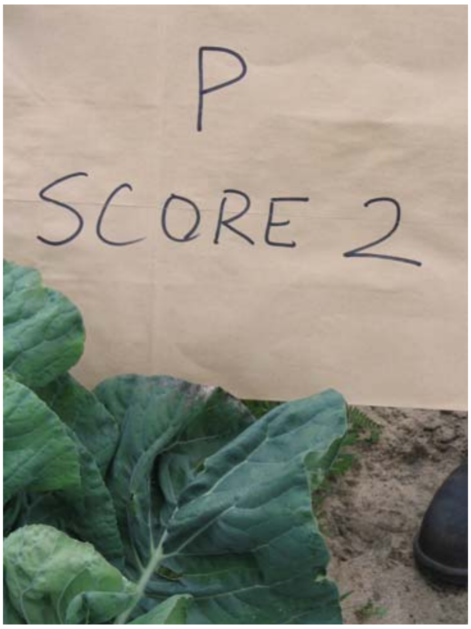


Figure 4.11a Close up of score 2 for P toxicity symptom severity.

Figure 4.11b Score 2 for P toxicity symptom severity.

Figure 4.11c Score 3 for P toxicity symptom severity.

Figure 4.11d Score 4 for P toxicity symptom severity.

Figure 4.11e Score 5 for P toxicity symptom severity.

Figure 4.11f Close up of Score 5 for P toxicity symptom severity.

Figure 4.11g Score 2 for K deficiency symptom severity.

Figure 4.11h Score 3 for K deficiency symptom severity.

Figure 4.11i Score 4 for K deficiency symptom severity.

Figure 4.11j Score 5 for K deficiency symptom severity.

Floret browning

During the later stages of growth, floret browning symptom began to appear on some of the curds. By harvest, this was responsible for rejection of a significant number of curds in some treatments. An analysis of variance was performed for this trait and it was found to be highly correlated to fertiliser treatment. The effects of banding and of spray were both highly significant and there was also a highly significant interaction between banding and spray treatment. Drenched plants also had higher levels of rejection from this condition (24 per cent vs 16.7 per cent) and the drench x spray x band interaction was also significant (Table 4.5)

Table 4.5 Per cent browning incidence in cauliflower nutrition trial at harvest by treatment

Top-dressing treatment	Spray treatment				
		S1	**S2**	**S4**	**S5**
B1	Drenched	25.0	5.7[a]	12.7[a]	6.8[a]
	Undrenched	0.0[a]	8.1[a]	6.3[a]	9.2[a]
B2	Drenched	100.0	54.5	20.5[a]	31.8
	Undrenched	75.0	33.3	25.6	4.5[a]
B3	Drenched	14.3[a]	10.6[a]	4.7[a]	5.7[a]
	Undrenched	0.0[a]	26.8	2.4[a]	3.4[a]
B4	Drenched	0.0[a]	63.6	34.1	20.5[a]
	Undrenched	0.0[a]	28.7	15.1[a]	19.3[a]

5 per cent LSD 22.06.

Figures 4.12 and 4.13 Floret browning symptom on cauliflowers.

Discussion

Key findings of this work are that winter cauliflower can be grown successfully by using a drench/spray/banding/fertigation technique for applying mineral fertiliser on infertile sandy soil with no previous vegetable cropping history. As for lettuce, on which the technique was first developed, the highly concentrated drench and spray solutions did not damage establishing seedlings, when left to dry on foliage without 'wash off'.

No advantage could be shown for a seedling drench with potassium nitrate for cauliflower planted in late May, but nitrogen based sprays applied 6 times in the first 21 days after planting gave marked increases in growth rate during the period of spraying. These early growth responses translated into a fourfold increase in marketable yield at harvest for both spray treatments compared to the unsprayed treatment. The latter treatment was not top-dressed for the first 16 days after planting and the effect on subsequent yield of such a practice was catastrophic for final yield at harvest, despite these plots having good nutrition for the last 80 days of their life.

As an example of the importance of early nitrogen application to final yield, very few of the unsprayed treatments produced marketable curds at harvest time, despite total applications of nitrogen exceeding 665 kg/ha of nitrogen for their life as top-dressings. Marketable yields were increased by up to 20.8 tonnes per hectare by spraying 78 kg per hectare of extra nitrogen in the first 21 days after planting. This yield increase could result in a gross return of around $20,000 for an extra fertiliser cost of $255 per hectare, and at the same time, no more than around 75 kg/ha of nitrogen could be leached into groundwater.

This example illustrates the importance of early nitrogen on final yield, but also the importance of accurate placement and constant availability of nitrogen during this sensitive stage of growth when seedlings have poorly developed root systems.

No differences in marketable yield could be found between the four top-dressing fertilisers at this time of year when used together with the highest rate of spraying. At the second highest spray rate, Nitrophoska Blue Special® and LBU top-dressing gave higher marketable yields than the other two top-dressing treatments. Nitrophoska Blue Special® was generally associated with higher levels of rejection due to floret browning than the other top-dressing treatments. There was, however, a substantial difference in the cost of applying some of these treatments. The cost of applying Nitrophoska Blue Special® was up to $2,200 more than equivalent yielding treatments. A combination of potassium nitrate and either LBU, ammonium nitrate or Spurt-N® topdressing would all produce acceptable yields for much less cost when combined high rates of early sprayed nitrogen.

Nitrophoska Blue Special® was included in the trial because it supplied phosphorus as well as nitrogen and potassium each time it was top-dressed. Both of these nutrients are known to leach from sandy soils and it was thought that regular topdressing of these as well as nitrogen may give an additional yield benefit. This did not prove to be the case.

The extra phosphorus in this fertiliser (327 kg/ha P) may have actually contributed to phosphorus toxicity symptoms in the foliage close to harvest. Nitrophoska Blue Special® gave the highest severity ratings for this symptom of all the treatments and symptom severity was associated with elevated P levels in leaf blades. The presence of this symptom did not however result in any yield loss. The additional phosphorus applied after planting this way produced no extra marketable yield and may have eventually been leached into the groundwater.

There was a trend for increasingly severe P symptoms when P levels in leaf blades exceeded 1 per cent (dry basis) and in petioles exceeded 0.5 per cent from a laboratory test at 91 days after harvest. These levels were associated with B2 and suggest the leaf scorching symptom was caused by the additional phosphorus (327 kg/ha) supplied in Nitrophoska Blue Special®. The sap results also reflect this trend.

Mild potassium deficiency symptoms appeared in the foliage of a number of treatments close to harvest. The symptoms were absent from the Nitrophoska Blue Special® and LBU top-dressing treatments and were less severe in the S2 and S3 spray treatments. All these treatments except for LBU supplied extra potassium. The two spray treatments supplied an extra 45.6 kg/ha K during the period of spraying and Nitrophoska Blue Special® supplied an extra 505 kg/ha during the top-dressing period. Despite this, there were no marketable yield differences between top-dressing treatments at the highest rate of spray application (S5). Although the foliage symptoms looked unsightly, the important determinate of yield by the stage of growth that the symptoms appeared was the size of the plant's frame and the reserves available to 'fill out' the developing head. Plant frame sizes were all determined much earlier in the life of the crop when fertiliser was being applied.

Foliage K symptom scores near harvest were not well correlated with the level of potassium in plant sap, and the levels of K in plant sap were only slightly higher on average in the Nitrophoska Blue Special® treatment, despite this treatment supplying 505 kg/ha more K than the other treatments during the top-dressing period and having no symptoms. Extrapolation from the sap potassium data suggested that a level of K in sap which would avoid the onset of this symptom may be around 1.4 g/L. Levels of potassium in dried petioles and blades were also variable, but the trend for lower levels of K in leaves exhibiting severe symptoms added weight to the conclusion that the symptoms observed were primarily caused by a deficiency of potassium. The K symptoms became more severe when K in blades fell below 0.86 per cent and 1.3 per cent in petioles on a dry weight basis. Onset of this symptom was partly mitigated by including potassium nitrate in the spray solution or by regular top-dressing of potassium as was the case where Nitrophoska Blue Special® was used.

Levels of nitrate in plant sap close to harvest were very variable and the differences could not obviously be attributed to drench, spray or top-dressing treatments. This was surprising given that fertiliser treatments had ceased only 13 days before the crop was sampled.

Future fertiliser strategies for cauliflower at this time of planting need to consider more frequent applications of potassium to avoid deficiency symptoms near harvest, as well as testing whether lower rates of nitrogen fertiliser could be used at each top-dressing without compromising marketable yield. The yield response to spray application in the first 21 days did not plateau and strategies such as higher N rates, more frequent application or application for periods longer than 21 days may give further yield increases.

Choice of top-dressing fertiliser may influence the level of floret browning. Results from this work suggest that LBU may be the safest fertiliser choice to minimise this condition. LBU also minimised potassium deficiency symptoms close to harvest.

Conclusions

Winter cauliflower responded positively to sprayed nitrogen for the first three weeks after transplanting, with a rate of 26 kg/ha (N) per week applied in two sprays per week being insufficient maximise marketable yield. No yield advantage could be demonstrated from drenching seedlings before planting.

Subsequent topdressing of N at 64 kg/ha per week to row closure was sufficient to produce a good marketable crop, but more than two topdressings with potassium fertiliser would be required to avoid potassium deficiency symptoms in foliage at harvest. LBU proved to be the cheapest and most effective form of nitrogen for top-dressing, and no additional positive yield effects could be shown from top-dressing phosphorus and potassium fertiliser throughout the life of the crop in the form of Nitrophoska Blue Special®. The practice of top-dressing with Nitrophoska Blue Special® throughout resulted in foliage symptoms thought to be phosphorus toxicity, but this did not cause yield loss.

5. CELERY

Introduction

Celery is a crop that is widely transplanted in the field from 'tray grown' seedlings produced by specialist nurseries in Australia. In Western Australia it is almost exclusively grown this way in commercial practice, and it is grown year round on sandy soils of the Swan Coastal Plain, up to 200 km north and south of Perth.

The crop is often in rotation with crops such as lettuce and broccoli. Traditional nutrition practice for these crops is to use poultry manure as a broadcast treatment before planting and/or banded between rows after planting. Mineral fertilisers are also routinely applied as topdressings on these crops, and fertigation is widely used. Prior to this, no research work had been done to test seedling drenches or fertiliser sprays as establishment treatments for celery on these sandy soils.

The potential benefits of the drench/spray technique are reduced leaching of fertiliser into groundwater from lower fertiliser application rates and better placement of fertiliser than achieved by current commercial practices. This is, particularly the case soon after transplanting when the plant has a poorly developed root system and low fertiliser demand.

Method

Site preparation and pre planting fertiliser applications were made according to standard practice as outlined in the 'General Methods'.

Seedlings (cultivar LV2459 'Big Ben') for the trial were bought in from a specialist nursery and planted on 18 March 2005. Half the seedling trays were drenched with 40 g/litre potassium nitrate at 500 mL/tray (100 cells) within one hour of planting. Seedlings were planted at 4 rows per bed with 300 mm between rows and 300 mm between plants. Each plot had a row of buffers at each end of the plot (eight buffer plants in total). Plots were 2.4 m long (32 plants in total with 24 plants for harvest). The plots were un-buffered outside the rows, i.e. all four rows were harvested and two rows had an unplanted pathway on one side. The experimental design was a split plot design with band x drench as the main plot and spray treatment as subplots.

Immediately after transplanting Gesagard® (prometryn 500 g/L) was applied at 2.2 kg/ha for weed control and followed with 3 mm irrigation. All plots were irrigated according to evaporation replacement as outlined in the 'General Introduction'.

Bravo Plus® (chlorothalonil 500 g/L) was sprayed at 2 L/ha four times and Benlate® (benomyl 500 g/kg) at 50 g/L twice as preventative measures for fungal diseases. Confidor® (imidacloprid 200 g/L) and Dimethoate® (dimethoate 400 g/L) were sprayed once each for aphid and sucking insect control.

The crop was harvested over two days, on 5-6 July (109, 110 days after planting). A maximum of 24 plants was harvested from each plot, excluding buffers. A total plant weight for each plot was recorded and then each plant was trimmed and a marketable weight recorded for each plot.

Post-planting fertiliser treatments

Celery was the first trial planted in the sequence of crops tested over the 18 months duration of this series. As for all other crops in this series, a seedling drench treatment was compared to un-drenched, but for celery, the full set of 5 spray treatments were compared as well as 4 banded top-dressing treatments. Two of the top-dressing treatments were different to those tested in all other trials. These were treatment B2 for which Nitrophoska Perfekt® (15N:2P:17K) was used and B4 was ammonium nitrate applied weekly at 150 kg/ha instead of the Spurt-N® treatment tested in all other trials.

The reasons for changing these treatments for crops grown after celery was to normalise the N and K crop life totals for all treatments and in the case of ammonium nitrate, to take account of the fact that ammonium nitrate was difficult to obtain and many growers began using Spurt-N® as a substitute during the period that these trials were conducted.

A regime of spray treatments was commenced one day after planting which consisted of twice weekly applications of a range of spray treatments as follows for a total of 14 days (four applications in total)

S1 No spray.

S2 40 kg/ha potassium nitrate (20.8 kg/ha nitrogen in total, 60.8 kg potassium in total).

S3 11.3 kg/ha LBU only (20.8 kg/ha N in total).

S4 11.3 kg/ha LBU plus 40 kg/ha potassium nitrate (41.6 kg/ha nitrogen, 60.8 kg potassium in total).

S5 22.5 kg/ha LBU plus 20 kg/ha potassium nitrate (51.8 kg/ha nitrogen, 30.4 kg potassium in total).

This was followed by a series of one of four banding treatments as detailed in Table 8.1. The prilled or granular fertilisers were banded into a shallow furrow equidistant between the pairs of rows of celery commencing at 14 days after planting.

Table 5.1. Schedule of top-dressing treatments (kg/ha of product) applied to the celery crop

Banding treatment	B1		B2	B3		B4	
Days after planting	Potassium nitrate (kg/ha)	High ammonium nitrate (kg/ha)	Nitrophoska Perfekt® (kg/ha)	Potassium nitrate (kg/ha)	LBU (kg/ha)	Potassium nitrate (kg/ha)	Medium ammonium nitrate (kg/ha)
14	400		550	400		400	
21		200	550		150		150
28		200	550		150		150
35		200	550		150		150
42	500		550	500		400	
49		200	550		150		150
Total N:P:K	N389:0P:342K		495N:66P:561K	393N:0P:342K		308N:0P:304K	

At day 56, all treatments received a top up spray of 300 kg/ha potassium nitrate plus 50 kg/ha ammonium nitrate boom-sprayed and immediately watered in over all plots as a simulated fertigation (56N:0P:114K).

A preventative spray of boron as Bortrak® 3 L/ha was applied over all plots 62 days after planting.

Sap tests

All plots were sampled for petiole sap testing 10 days after the last banded fertiliser application (16 May). The method was to collect 4 petioles from the most recently mature leaf from each plot, bulk them, extract the sap and combine sap from all three field reps to conduct the test. A representative sample was also collected from 4 sites in the buffer bed on one side of the trial approximately weekly after row closure. The latter was used as an indicator to decide whether further top-dressing was required between row closure and harvest. Tests for sap nitrate, phosphate and potassium were done using an RQflex® reflectometer and Merckoquant® indicator strips.

Results

The crop grew well with obvious visual differences between the unsprayed treatment and the other spray treatments as early as one week after planting (Figure 5.1a). Over time, as the banding treatments were applied, these differences became less obvious (Figures 8.1b,c; Figures 8.2a-i), but by the time of harvest, the unsprayed treatment was still visibly smaller than all other sprayed treatments. There were small obvious visual differences in plant vigour between the S2 spray rate treatment and the two higher rate treatments, S4 and S5, for up to 45 days after planting, but there was little obvious difference between S4 and S5 at any stage of growth. Differences in maturity at harvest between spray treatments were more pronounced. Visible differences between drenched and un-drenched treatments were not obvious at any stage of growth, nor were differences between banding treatments highly visible.

The photos which follow show treatment differences between spray treatments over time.

Figure 5.1a Spray applications had an effect on plant growth within one week after planting. S1 (foreground) has had no sprays, S4 (background) has had two applications of potassium nitrate plus LBU.

Figure 5.1b, c. Two weeks after planting the differences between spray treatments are even more apparent – unsprayed (left) S5 sprayed (right).

Figure 5.2a Overview of trial at 46 days after planting.

Figure 5.2b Spray S1 (left) vs S5 (right) in the middle ground at 46 days after planting.

Figure 5.2c S4 (left) vs S5 (right) in the middle ground.

Figure 5.2d Spray S2 (left) vs S5 (right) in the middle ground at 46 days after planting

Figure 5.2e Overview of trial at 56 days after planting.

Figure 5.2f Spray S4 (foreground) vs S1 (background between pegs) at 56 days.

Figure 5.2g Spray S1 (between pegs) at 56 days.

Figure 5.2h Spray S4 (between pegs) at 56 days.

Figure 5.2i Most treatment differences had almost disappeared by the time of harvest.

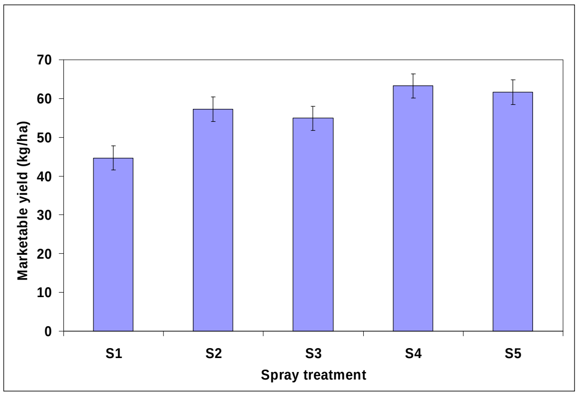
Analysis of variance showed there was a significant adverse effect of drenching on the final yield of celery (53.8 t/ha cf 58.9 t/ha).

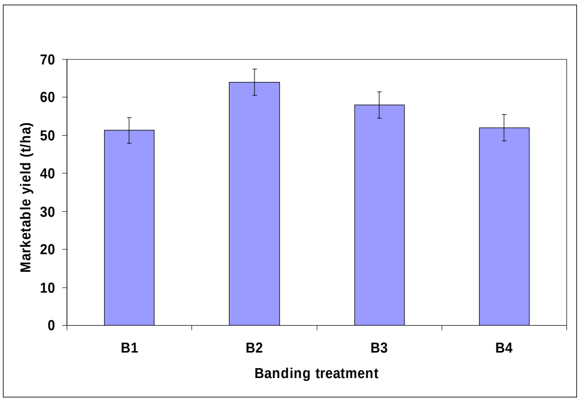
The effect of spray treatment was highly significant with both LBU plus potassium nitrate treatments (S4 and S5) out yielding the other sprayed and un-sprayed treatments ($p < 0.001$). The lower cost option of 22.5 kg LBU plus 20 kg potassium nitrate (S5) would be the logical choice on cost grounds alone, but the lower LBU treatment (S4) is potentially safer in all weather conditions. This is because LBU as a foliar spray tends to be relatively more phytotoxic than potassium nitrate.

There was no significant difference in yield from spraying nitrogen in the form of potassium nitrate (S2) and the same N rate as LBU (S3). This result suggests that the growth and yield response from spraying is a response to nitrogen only, not the form in which the nitrogen is supplied. LBU is widely reported in the literature to be a more effective foliar fertiliser than potassium nitrate, and the lack of any yield advantage from LBU compared to potassium nitrate, suggests that most, if not all of the effect of these fertiliser sprays is from root uptake after the spray is washed into the soil.

LBU plus potassium nitrate would also be the choice for post-plant banding. Banding with Nitrophoska Perfekt™ was not significantly different from LBU but much more expensive. The cost difference of applying fertiliser to the highest yielding treatments varied from $1752/ha to $3041/ha between the least and highest cost fertiliser options.

Notably there was no significant difference between the high (B1) and medium (B4) rates of banded ammonium nitrate, and these two treatments were not significantly different from banded LBU (B3). This suggests that there is scope for reducing banding rates of all fertilisers in future without compromising yield, and enhancing the environmental benefits of the fertiliser programs.





Figures 5.2a, b Comparison of yield differences between spraying (left) and banding (right) treatments.

The rate of nitrogen applied in spray treatments during the first two weeks of crop life was found to be highly correlated to marketable yield at harvest, ninety five days later (Figure 5.3). Yields were maximised at around 50 kg/ha N as a spray.

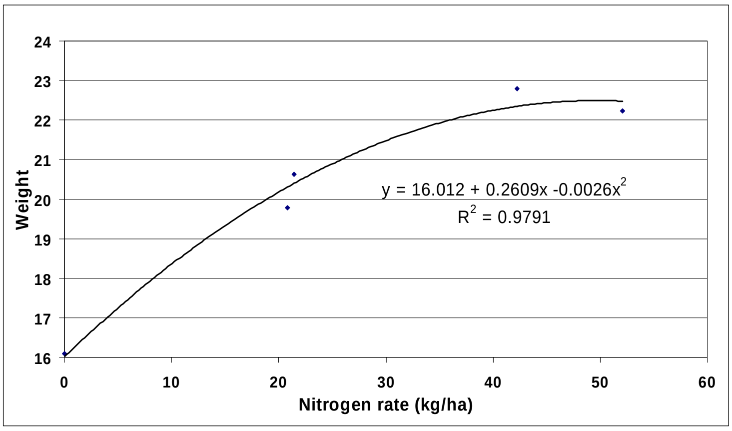


Figure 5.3 Relationship between the rate of nitrogen sprayed in the first 14 days after planting and final harvest yield of celery.

The highest marketable percentages were not necessarily associated with the highest yields. Marketable percentages varied from 52 per cent to 69 per cent. Typical marketable rates from the higher yielding treatments were in the range of 55- 63 per cent.

Plant sap tests

Sap testing was carried out in the latter growth stages of the crop to assist in determining the need for additional applications of fertiliser after the last scheduled banding. As a consequence, an extra banding (day 49) and a top-up spray were applied (day 56). Sap nitrate and potassium levels dropped dramatically to a low level soon after that, but were steady until harvest (Figure 5.4).

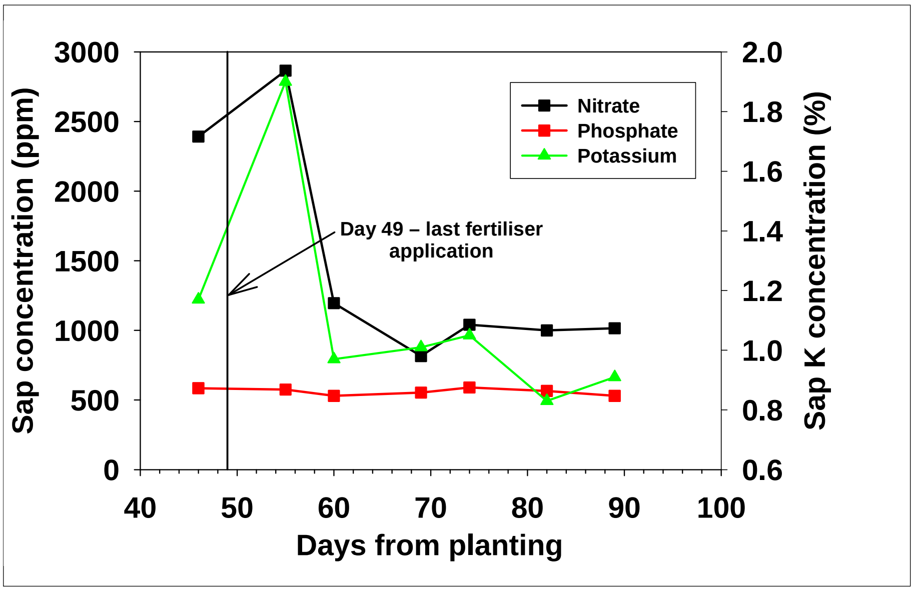


Figure 5.4 **Sap levels of nitrate, phosphate and potassium in the last stages of the crop. (Mean of four samples taken from buffer plots). Phosphate and nitrate results are in ppm and potassium in per cent (right hand axis).**

The value of sap testing for nitrate as a predictor of marketable yield was assessed by plotting the sap levels recorded on May 16th, 56 days after planting (about mid way through the crop's life) against marketable yields at harvest. A positive relationship between the two variables was found as shown in Figure 16, with an optimum around 1500 ppm (NO_3). The importance of timing of nitrogen applications, especially in the 14 days after planting compared to the rate of nitrogen supplied for the whole of the crop's life goes some way to explaining why the correlation shown in Figure 5.5 is not a highly significant one.

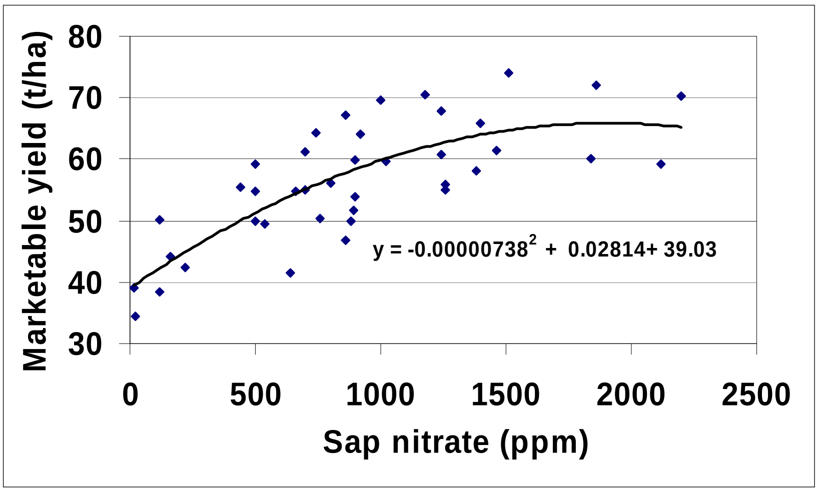


Figure 5.5 **Relationship between sap nitrate levels immediately prior to harvest and marketable yield in celery.**

Results from the sap testing conducted on 16 May 2005 (day 56) are shown in Table 8.2.

Table 5.2 Petiole sap test results for fertiliser treatments at 56 days after planting

Treatment		NO_3 (mg/L)	PO_4 (mg/L)	K (g/L)
Undrenched	B1 S1	2720	640	1.14
	B1 S2	2960	580	1.18
	B1 S3	2040	580	1.17
	B1 S4	2000	480	1.18
	B1 S5	2580	440	1.25
	B2 S1	2300	660	1.22
	B2 S2	3200	580	1.2
	B2 S3	2580	540	1.16
	B2 S4	3200	640	1.29
	B2 S5	2780	540	1.21
	B3 S1	2600	560	1.14
	B3 S2	2080	420	1.07
	B3 S3	1920	540	0.88
	B3 S4	2560	540	1.1
	B3 S5	1520	500	1.04
	B4 S1	3580	700	1.17
	B4 S2	2680	560	1.25
	B4 S3	3140	540	1.21
	B4 S4	3560	600	1.09
	B4 S5	2720	560	1.17
Drenched	B1 S1	2500	440	1.2
	B1 S2	3640	540	1.22
	B1 S3	2920	560	1.13
	B1 S4	3640	560	1.18
	B1 S5	2220	560	1.25
	B2 S1	3240	660	1.20
	B2 S2	2040	56	1.21
	B2 S3	2420	600	1.18
	B2 S4	2520	540	1.22
	B2 S5	2060	480	1.23
	B3 S1	2320	640	0.95
	B3 S2	1820	500	1.12
	B3 S3	2400	520	0.82
	B3 S4	2740	500	1.01
	B3 S5	1540	340	0.65
	B4 S1	1720	600	1.09
	B4 S2	1300	640	1.11
	B4 S3	2400	620	1.15
	B4 S4	1700	640	1.16
	B4 S5	2140	540	0.95
	B=Band			
	S=Spray			

Discussion

Key findings of this work are that winter harvested celery can be grown successfully by using a drench/spray/banding technique for applying mineral fertiliser on infertile sandy soil with no previous vegetable cropping history. As for lettuce, where the technique was first developed, the highly concentrated drench and spray solutions did not damage establishing seedlings, when left to dry on foliage without 'wash off'.

A small yield disadvantage was found from a seedling drench with potassium nitrate for celery planted in March, but nitrogen based sprays applied 4 times in the first 14 days after planting gave marked increases in growth rate during the period of spraying. These early growth responses translated into a forty per cent increase in marketable yield at harvest for the two spray treatments comprised of potassium nitrate mixed with LBU compared to the unsprayed treatment. The latter treatment was not supplied with nitrogen fertiliser for the first 14 days after planting and the effect on subsequent yield of this practice was very damaging for final yield at harvest, despite these plots having good nutrition for the last 95 days of their life.

Small but significant differences were found between the four banding treatments for marketable yield. The two ammonium nitrate treatments gave lower yields than Nitrophoska Perfekt® and LBU, but the latter were not different from each other despite having a 25 per cent difference in nitrogen rate applied.

It is significant that amongst the highest yielding treatments, were some of the lowest fertiliser application rates. Applied nitrogen ranged from 328 kg/ha – 605 kg/ha. One of the highest yielding treatments received only 369 kg/ha nitrogen. This demonstrates that the timing of nitrogen application and the form of that nitrogen can have a major impact on yield. Even though approximately 70 per cent more nitrogen was applied in the Nitrophoska Perfekt® banding treatment, through the life of the crop, the added nitrogen produced no more yield benefit than lower rates of potassium nitrate plus ammonium nitrate or LBU banding. Those treatments given Nitrophoska Perfekt® also had much higher rates of potassium and an additional 73 kg of phosphorus.

Work on celery in Israel (Feigin *et al.* 1976) on a light brown loessial soil indicated that about 360 kg N/ha is required for maximum yield (55-65 t/ha). Our results are in line with those results.

Sap testing proved to be useful for monitoring the nutritional status of the crop, but it was not a good predictor of final yield because high nitrate levels could be recorded in the sap of plants later in their growth cycle that had a low yield potential due to inadequate nutrition early in their life and vice versa.

Conclusions

Autumn grown celery responded positively to sprayed nitrogen for the first two weeks after transplanting, with a rate of 21 - 26 kg/ha (N) per week applied in two sprays per week being sufficient to maximise marketable yield. A small yield disadvantage was demonstrated from drenching seedlings before planting with concentrated potassium nitrate solution.

Subsequent topdressing of N at 68 kg/ha per week to row closure was sufficient to produce a good marketable crop but extra nitrogen applications after row closure were required to maximise yields, and the optimum rates and timing of these were not able to be determined in this trial.

Four applications of LBU at 150 kg/ha each time supplemented with two applications of potassium nitrate to a total of 900 kg/ha proved to be the cheapest and most effective top-dressing treatment. No additional positive yield effects could be shown from top-dressing phosphorus and potassium fertiliser in the period up to row closure, as measured by the lack of any additional yield response from the Nitrophoska Perfect® treatment.

6. CHINESE CABBAGE

Introduction

Heading Chinese cabbage (*Brassica campestris pekinensis*) is commonly direct sown in the field, but transplanting seedlings produced by specialist commercial nurseries has become popular in recent years. In Western Australia Chinese cabbage is grown year round on sandy soils of the Swan Coastal Plain by a small number of specialist producers, but it is more commonly planted seasonally from January to April. Chinese cabbage is also grown on sandy loam soils in summer in the lower-south west of the state in districts such as Manjimup.

Where Chinese cabbage is grown on sandy soils, it is often in rotation with crops such as lettuce and celery. Traditional nutrition practice for these crops is to use poultry manure as a broadcast treatment before planting and/or banded between rows after planting. Mineral fertilisers are also routinely applied as topdressings on these crops. Prior to this, no research work had been done to test seedling drenches or fertiliser sprays as establishment treatments for Chinese cabbage on these sandy soils. The potential benefits of the drench/spray technique are reduced leaching of fertiliser into groundwater from lower fertiliser application rates and better placement of fertiliser than achieved by current commercial practices.

Method

Site preparation and pre planting fertiliser applications were made according to standard practice as outlined in the ‘General Methods’.

Seedlings for the trial (cultivar ‘Blues’) were bought in from a specialist nursery and planted on 2 February, 2005. Half the seedling trays were drenched with 40 g/litre potassium nitrate at 500 mL/tray (100 cells) within one hour of planting for the drenched treatments and the other half were drenched with water. Seedlings were planted at four rows per bed with 300 mm between rows and 420 mm between plants. Each plot had a row of buffers at each end (eight buffer plants in total). Plots were 2.94 m long (28 plants, 20 plants for harvest). The plots were un-buffered outside the rows i.e. all four rows were harvested.

The experimental design comprised four replicates of a split plot design with top-dressing as the main plot, drenching as a split plot and spray treatment as a split-split plot.

Immediately after transplanting Dacthal® was applied at 6 L/ha and followed with 3 mm irrigation. All plots were irrigated three times per day for three days to a total of 9 mm per day depending on the weather.

Post-planting fertiliser treatments

A regime of spray treatments was commenced one day after planting (3 February) consisting of twice weekly applications of a range of spray treatments for a total of two weeks (four applications in total) as follows:

S1 = No spray.

S2 = 40 kg/ha potassium nitrate only (20.8 kg/ha nitrogen and 60.8 kg/ha potassium in total).

S4 = 11.3 kg/ha LBU plus 40 kg/ha potassium nitrate (41.6 kg/ha nitrogen and 60.8 kg/ha potassium in total).

S5 = 22.5 kg/ha LBU plus 20 kg/ha potassium nitrate (51.8 kg/ha nitrogen, 45.6 kg potassium in total).

This was followed by a series of one of four top-dressing treatments as detailed in Table 6.1. Top-dressings up to and including day 18 were banded between pairs of rows as described in the ‘General Methods’ section of this report or applied by ‘simulated fertigation’ for Spurt-N®. The first banded application for all treatments was split into two applications (days 12 and 14) because past experience had shown that in hot weather, the osmotic effect of this treatment could cause crop damage if applied in one application at the full weekly rate. The liquid fertiliser, Spurt-N® was mixed in one litre of water per square meter of bed area and spread over the foliage with a watering can in the treatment where it was used. This treatment was immediately washed from the foliage with two litres of water per square meter, using the same method.

Row closure was reached much earlier for Chinese cabbage than most other crops tested in this series of experiments (around 21 days after planting) and it was considered that ceasing top-dressing at row closure was unlikely to be successful. Three top-dressings beyond row closure were planned for all treatments and they were all supplied by the 'simulated fertigation' method described for Spurt-N®. Nitrophoska Blue Special® was not suitable for use by this method because it was not sufficiently soluble. For this treatment only, the fertiliser dressings beyond row closure were supplied as calcium nitrate and potassium nitrate, supplying approximately the same rate of nitrogen as a banded dressing with Nitrophoska Blue Special®, because these are soluble nitrogen fertilisers suitable for fertigation.

Table 6.1 Top-dressing treatments (B1-B4) applied to Chinese cabbage (kg/ha)

Top-dressing treatment	B1		B2	B3		B4	
Days after planting	Potassium nitrate (kg/ha)	Ammonium nitrate (kg/ha)	Nitrophoska Blue®	Potassium nitrate (kg/ha)	LBU	Potassium nitrate (kg/ha)	Spurt-N® (kg/ha)
12	200		275	200		200	
14	200		275	200		200	
18		200	550		150		200
25		200	445 CN		150		200
34		200	445 CN		150		200
39	500		500 KN	500		500	

CN – calcium nitrate
KN – potassium nitrate
Banded Fertiliser applications
Fertigated fertiliser applications

This program was supplemented with a foliar application of manganese sulphate at 5 grams per litre on day 40.

Pest and disease control

A treatment regime for control of diamondback moth was implemented using a rotation of Regent® (250 mL/ha), Success® (400 mL/ha) and Nitofol® (500 mL/ha).

Harvest and data recording

The trial was harvested on 20, 21 March, 46 days after planting. Total plot weights were recorded, then plants were trimmed and assessed for marketability. Marketable and reject weights were recorded together with reasons for rejection. These were primarily non-hearting and low head weight in some treatments and rot (the same rot as observed pre-harvest). The harvest data was analysed using the Analysis of Variance technique appropriate to the experimental design used in the trial.

Results

The crop grew well with obvious differences between S1 and the other spray treatments within the first two weeks. The rapid onset of row closure is illustrated in Figure 6.1 below showing the trial at 28 days after planting.

Figure 6.1 Overview of the summer Chinese cabbage trial twenty eight days after transplanting.

No obvious visual difference was noted between drenched and un-drenched seedlings in the weeks following planting, as shown in Figures 9.2a and b. Early plant vigour was directly proportional to the rate of nitrogen sprayed as shown in figures 9.3a-d.

Figure 6.2a Undrenched and unsprayed Chinese 20 days after planting.

Figure 6.2b Drenched and unsprayed Chinese cabbage cabbage 20 days after planting.

Figure 6.3a Chinese cabbage sprayed with the S2 treatment 20 days after planting.

Figure 6.3b Chinese cabbage sprayed with the S3 treatment 20 days after planting.

Figure 6.3c Chinese cabbage sprayed with the S5 treatment 20 days after planting.

Figure 6.3d Chinese cabbage sprayed with the S1 treatment (left foreground) vs S5 (right foreground) 28 days after planting.

In the latter stages of crop growth, some plants showed a marginal scorch and a small number of other plants collapsed from the base (see Fig. 9.4). This was thought not to be disease, but rather, to be related to the method used to apply 'simulated fertigation' applications. It was difficult to wash all the concentrated fertiliser from the leaves quickly or thoroughly enough after application to avoid some damage to foliage when using this method in hot weather. Some 'top-dressing' treatments were affected more than others.

Figure 6.4a, b Chinese cabbage showing scorched leaves (left) and basal soft rot (right), 46 days after planting.

At harvest, (46 days after planting), head sizes were large, though some treatments did not heart well. There was a high level of caterpillar infestation throughout the whole crop that onset within a few days of harvest, but this was not used as a reason for rejection because it was uniform across the trial and not a consequence of any of the treatments.

Analysis of the yield data showed there were no significant differences in total or marketable yield between the pre-plant drench treatments or between the top-dressing treatments for total or marketable yield. Differences between the spray treatments were highly significant ($p < 0.001$). There was no difference between spray treatments S2, S4 and S5 but they all yielded significantly better than S1 – the nil spray treatment. The yield response to spray treatment was highly correlated to applied nitrogen as shown by the fitted quadratic response curve (Figure 6.5).

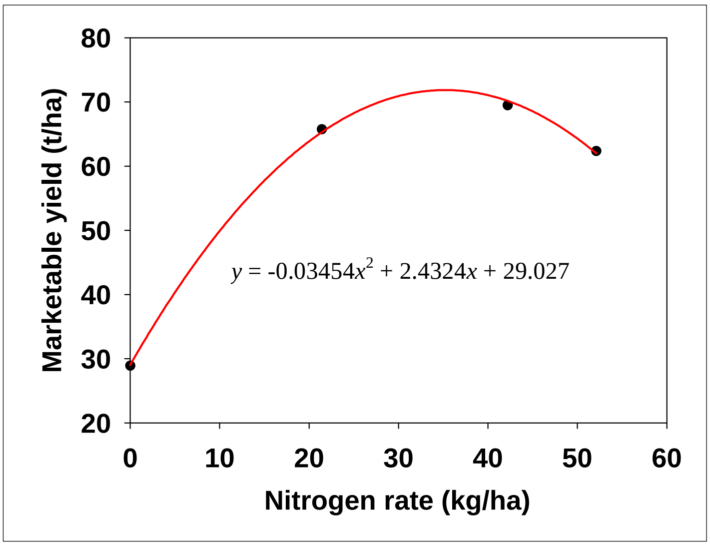


Figure 6.5 **The response of marketable yield in Chinese cabbage to total nitrogen applied as sprays in the first 14 days after planting.**

Although there were no significant differences between the main effect of top-dressing, the interaction between top-dressing and spray treatments was close to the 5% level of significance for both total and marketable yield. Figure 6.6 shows a strong trend for higher yields where top-dressed LBU (B3) was combined with the highest rate of spraying (S5).

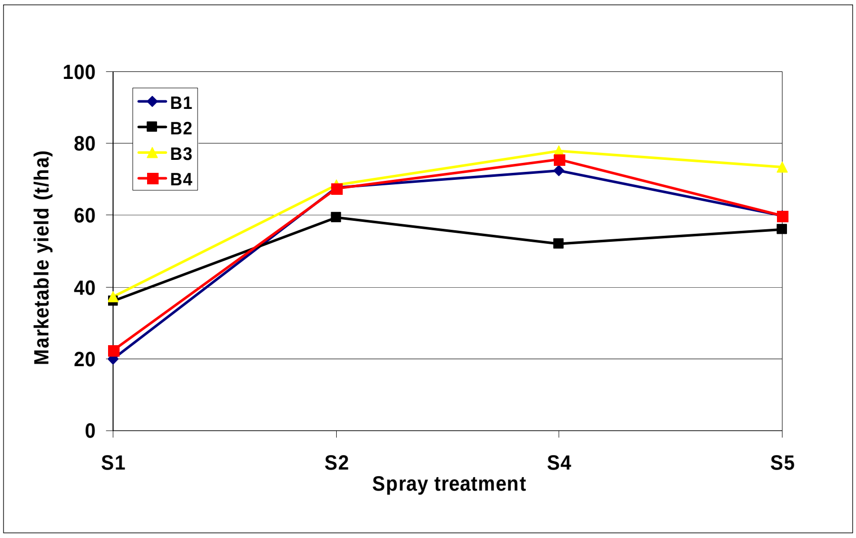


Figure 6.6 **The response of marketable yield in Chinese cabbage to sprayed nitrogen and top-dressing product.**

Discussion

There was no apparent yield benefit from drenching seedlings before planting.

Chinese cabbage proved to be highly responsive to sprayed nitrogen fertiliser in the first 14 days after transplanting, and no significant yield differences could be shown for rates greater than 20.8 kg/ha N supplied as potassium nitrate over the 14 day period immediately after transplanting for a summer crop. A quadratic fit to the response data showed that the yield maximising spray rate was 35.2 kg/ha N.

No differences between the four sources of nitrogen tested for top-dressing could be shown, but there was a strong trend for LBU to give slightly higher yields, particularly when combined with the high rate of sprayed nitrogen (51.8 kg/ha N).

Most of the higher yielding plots were also those with the cheaper fertiliser options. Nitrophoska Blue Special® followed by calcium nitrate generally performed poorly, and any of the other top-dressing options would be preferable, from a cost point of view in combination with any of the spray options supplying from 20.8 kg/ha N to 51.8 kg/ha N.

The extra phosphorus supplied by Nitrophoska Blue Special® seemed to confer no additional yield benefit, suggesting that neither phosphorus nor potassium were limiting the yield response in this trial.

Conclusion

Drenching seedlings with potassium nitrate solution before transplanting conferred no yield benefit to Chinese cabbage. Chinese cabbage was highly responsive to fertiliser sprays in the 14 days after planting. This practice is safe and a total rate of around 35 kg/ha N applied in the 14 day interval after transplanting maximised marketable yield.

All four top-dressing products and schedules gave equivalent yields, but there was a strong trend for LBU in combination with the highest rate of spraying (51.8 kg/ha N) to give highest yields. LBU was the most cost effective top-dressing treatment for Chinese cabbage.

The additional phosphorus and potassium in Nitrophoska Blue Special® conferred no yield benefit compared to the other fertiliser regimes tested.

7. COS LETTUCE

Introduction

Cos lettuce is a crop that is widely transplanted in the field from ‘tray grown’ seedlings produced by specialist nurseries in Australia. In Western Australia the crop is almost exclusively grown this way in commercial practice, and production is year round on sandy soils of the Swan Coastal Plain.

Cos lettuce is often grown alongside crops of iceberg lettuce and in rotation with crops such as cabbage, celery and broccoli in Western Australia. Traditional nutrition practice for these crops is to use poultry manure as a broadcast treatment before planting and/or banded between rows after planting. Mineral fertilisers are also routinely applied as topdressings on these crops. Cos lettuce can also be grown by specialist ‘leaf lettuce’ growers who supply processing and fresh markets. Some processors will not accept lettuce grown with animal manures for health and safety reasons. These growers are heavily reliant on mineral fertilisers for their production.

Prior to this, no replicated research work had been done to test seedling drenches or fertiliser sprays as establishment treatments for Cos lettuce on infertile sandy soils, but some unreplicated observations with leaf lettuces had been made on grower properties (Phillips 2004). The potential benefits of the drench/spray technique are reduced leaching of fertiliser into groundwater from lower fertiliser application rates and more uniform placement of fertiliser than achieved by current commercial practices.

Cos lettuce grown in winter can take as long as 100 days after planting to reach marketable maturity and fertiliser programs need to take account of a slow rate of crop establishment coupled with regular uncontrolled leaching events caused by heavy rainfall. However a summer crop of Cos lettuce often reaches marketable maturity in as little as 35 days after planting and as such, strategies to ensure maximum yield leave little margin for error. This is particularly the case in relation to tip burn, a disorder to which Cos lettuce is very sensitive.

Since rates and timing of nitrogen application for winter versus summer Cos lettuce may need to be quite different, we conducted separate trials for each, the details of which are presented below.

WINTER CROP

Method

Site preparation and pre planting fertiliser applications were made according to standard practice as outlined in the General Methods.

Seedlings for the trial (cultivar ‘Cosmic’) were bought in from a specialist nursery and planted on 4 August, 2005. Half the seedling trays were drenched with 40 g/litre potassium nitrate at 500 mL/tray (100 cells) within one hour of planting for the drenched treatments (D) and the other half were drenched with water (undrenched = U). Seedlings were planted at four rows per bed with 300 mm between rows and 300 mm between plants. Each plot had a buffer plant at both ends of each row (i.e. 8 buffer plants in total). Plots were 2.4 m long (32 plants in total with 24 plants for harvest). The plots were un-buffered outside the rows i.e. all four rows were harvested, but the trial block was buffered with two beds planted as buffers either side of the four replicate beds.

The experimental design comprised four replicates of a split-split plot design with banded fertiliser as the main plot (four fertiliser products), drenching as the split plot (drenched vs undrenched) and spray treatment (four spray rates) as the split-split plot.

Immediately after transplanting Kerb® was applied at 3 kg/ha and followed with 3 mm irrigation.

Post-planting fertiliser treatments

A regime of spray treatments was commenced one day after planting (5 August) consisting of twice weekly applications of a range of spray treatments for a total of 21 days (six applications in total).

S1 No spray.

S2 40 kg/ha potassium nitrate only (31.2 kg/ha nitrogen and 91.2 kg/ha potassium in total).

S3 11.3 kg/ha LBU only (31.2 kg/ha N in total).

S4 11.3 kg/ha LBU plus 40 kg/ha potassium nitrate (62.4 kg/ha nitrogen and 91.2 kg/ha potassium in total).

S5 22.5 kg/ha LBU plus 20 kg/ha potassium nitrate (77.7 kg/ha nitrogen, 45.6 kg potassium in total).

This was followed by a series of one of four top-dressing treatments as detailed in Table 7.1. The prilled fertiliser treatments were banded into a shallow furrow between pairs of rows of lettuce commencing 18 days after transplanting and ending at row closure. The liquid fertiliser, Spurt-N® was dissolved in one litre of water per square meter of bed area and spread over the foliage with a watering can. This treatment was immediately washed from the foliage with two litres of water per square meter, using the same method. The crop also received a foliar spray of borax at 10 g/L at mid growth as a preventive measure for boron deficiency.

Table 7.1 Top-dressing treatments (B1-B4) applied to winter Cos lettuce (kg/ha)

Top-dressing treatment	B1		B2	B3		B4	
Days after planting	Potassium nitrate (kg/ha)	Ammonium nitrate (kg/ha)	Nitrophoska Blue Special®	Potassium nitrate (kg/ha)	LBU (kg/ha)	Potassium nitrate (kg/ha)	Spurt-N® (kg/ha)
18	400		550	400		400	
28		200	550		150		200
33		200	550		150		200
39		200	550		150		200
48	500		550	500		500	

Figures 10.1a,b Banding Nitrophoska Blue Special® by machine to main plot treatments.

Results

All treatments grew slowly in the first four weeks after planting due to cool and wet weather. Differences between spray treatments were obvious by 14 days after planting, with plant vigour increasing in direct proportion to the rate of nitrogen applied. There were no consistent visual differences between the two spray treatments, S2 (potassium nitrate) and S3 (LBU) at any stage of growth. These two treatments applied the same rate of nitrogen each time they were sprayed but in two different forms, potassium nitrate and LBU.

Over time, as the top-dressing treatments were applied, these differences became less obvious but by the time of harvest, the unsprayed treatment was still visibly smaller than all other sprayed treatments. Visible differences between drenched and un-drenched treatments were not obvious at any stage of growth, but most plots top-dressed with LBU (B3) were visibly smaller than the other topdressing treatments in most plots.

Figures 7.2a-f show treatment differences between spray treatments over time.

Figure 7.2a, b Twenty eight days after planting showing unsprayed Cos lettuce (left) compared to Cos lettuce sprayed six times with S5 spray rate (right) – both plots were undrenched at planting.

Figures 10.2c, d **Twenty eight days after planting showing Cos lettuce sprayed with potassium nitrate (left) compared to lettuce sprayed with LBU at the same rate of nitrogen (right) - both plots were undrenched at planting.**

Figure 7.2e, f **Twenty eight days after planting showing Cos lettuce drenched (left) compared to Cos lettuce undrenched (right) – both plots were unsprayed for the first 21 days after planting.**

Despite good early growth in the better sprayed treatments, none of the treatments hearted well, consequently marketable yields were low. The crop was harvested on 14, 17 October (71, 74 days after planting). Heads were trimmed in the field. Whole plots were weighed and then sorted into reject and marketable heads to obtain separate weights for each category. Reasons for rejection were mostly low head weights or non-hearting but there was some Tomato Spotted Wilt Virus, tip burn and rots. Tip burn in particular was more visible in bigger heads, and these were more likely to be rejected when marketable yields were assessed. Many plots also included plants with leaf distortion which was thought to be caused by an infestation of leafhoppers towards harvest. These symptoms caused many heads to be rejected for marketable yield, distorting the interpretation of marketable yield data (Figures 7.3a,b).

Figure 7.3a,b Distorted foliage thought to be caused by leafhoppers (left) and tomato spotted wilt virus (right).

Figure 7.4c,d Unsprayed Cos lettuce (right) and Cos lettuce sprayed with treatment S5 (left) at harvest on day 71.

Despite the high levels of rejection, crop yields for both marketable and total weight yield were directly proportional to the rate of nitrogen sprayed in the first 21 days after planting. This response to spraying is shown in Figures 10.4a and b and graphically in Figures 10.5a, b.

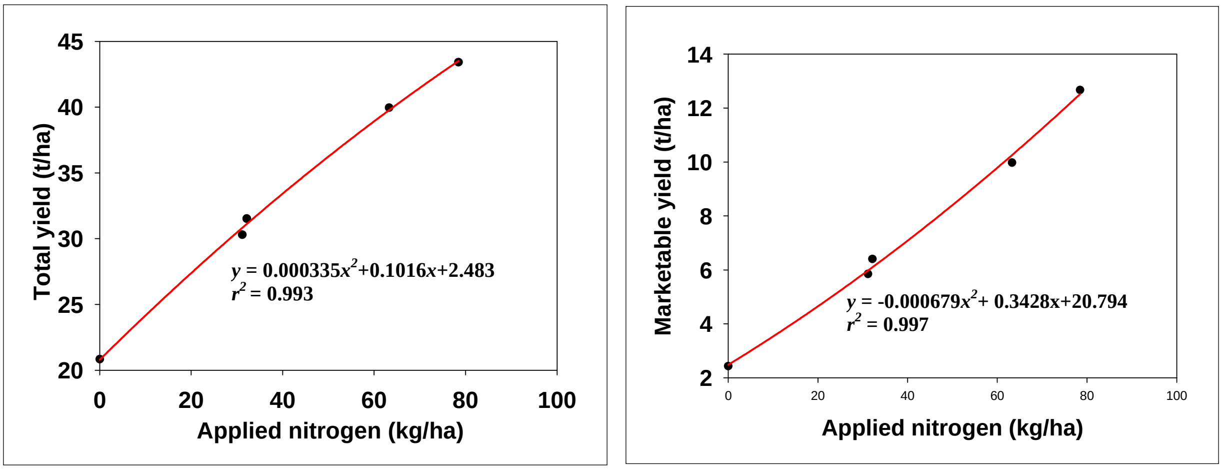


Figure 7.5a,b **Response to the cumulative rate of nitrogen sprayed in the first 21 days after planting for total weight yield (left) and marketable weight yield (right).**

There was a significant interaction between band + drench + spray for both total ($p < 0.044$) and marketable yield ($p < 0.006$).

Table 7.2 **Significance table for the band x drench x spray interactions, showing final total yields that were not significantly different from the highest yielding treatment (in grey)**

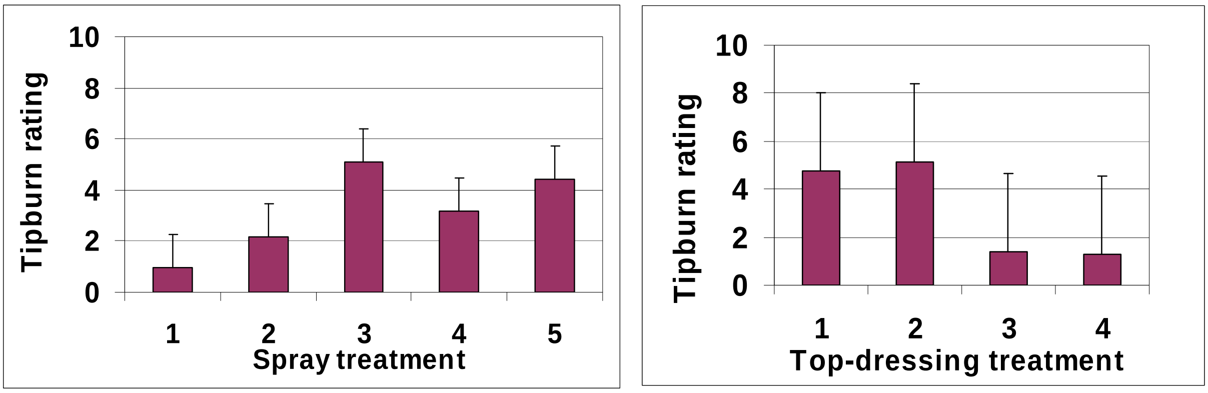
Band	Spray	Nil spray	Potassium nitrate	LBU	High potassium nitrate, low LBU	Low potassium nitrate, high LBU
High ammonium nitrate	Drenched	21.48	34.90	28.24	44.94	51.98
	Undrenched	20.43	26.31	28.92	37.49	39.90
Nitrophoska Blue Special®	Drenched	34.02	38.98	36.69	41.05	37.91
	Undrenched	21.34	29.63	29.27	37.87	41.94
Low biuret LBU	Drenched	14.73	19.28	27.99	35.75	38.12
	Undrenched	15.72	24.51	24.20	35.06	40.82
Spurt-N®	Drenched	18.16	31.87	39.27	42.74	51.03
	Undrenched	20.82	36.93	37.58	44.68	45.55

The table of interactions for total yield (Table 7.2) is presented as it is felt that this gives a clearer picture of treatment response given many of the reasons for rejection were felt to be independent of treatment.

The use of potassium nitrate and LBU sprays combined with Spurt-N® or ammonium nitrate topdressing treatments and drenching appears to be the best treatment combination in terms of yield alone. It could be argued that given the yield response to increasing nitrogen given as spray treatments, the low potassium nitrate/high LBU spray would be preferable.

Tip burn/bolting

There was a highly significant effect of spray treatment on the incidence of tip burn and bolting and a significant effect of top-dressing treatment.



Figures 7.6a,b Effect of spray treatment (left) and top-dressing treatment (right) on incidence of tip burn in the winter Cos lettuce crop.

The incidence of tip burn appeared correlated to the rate of LBU used in the spray treatments, with S3 (LBU only) showing the highest rate of tip burn. Amongst the banding treatments, ammonium nitrate and Nitrophoska Blue Special® both produced more tip burn. Whilst the band + drench + spray interaction was not significant there did appear to be a clear relationship with the two sprays containing the highest rates of LBU in combination with either ammonium nitrate or Nitrophoska Blue Special® banding being associated with more tip burn.

Discussion

This crop had a high level of rejection due to non hearting and undersize heads. It was probably harvested too early but that was prompted by the high incidence of tip burn in some of the treatments. A reasonably high level of tomato spotted wilt infection also meant that marketable yields were low. These factors led to a lack of precision in the data from the trial, making interpretations of results difficult.

There was no clear yield advantage in winter Cos lettuce from applying the pre-plant potassium nitrate drench to seedlings, but there were significant interactions between drench, spray and banded treatments.

The winter Cos crop grew slowly at the start due to cool weather, yet still showed obvious differences between spray treatments by 14 days after planting. As with iceberg lettuce, a combination of LBU and potassium nitrate sprays gave a yield advantage, but the top of the response curve was not reached with the highest rate of nitrogen spraying of 13 kg/ha N sprayed 6 times over the first 21 days after planting (77.7 kg/ha N in total).

Spurt-N® top-dressing gave consistently high yields when applied to drenched or undrenched seedlings while ammonium nitrate only performed as well on drenched seedlings. LBU and Nitrophoska Blue Special® both gave lower yields. Whilst total yields were equal to Spurt-N®, topdressing with ammonium nitrate gave higher levels of tip burn and is not recommended. The use of Nitrophoska Blue Special® was also related to a higher level of tip burn and cost about $900 per hectare more than the lowest cost yield maximising treatment, and therefore cannot be recommended for late winter planted Cos lettuce.

Conclusion

Interpretation of the results of this trial needs to be treated with some caution because there were significant yield losses caused by factors unrelated to the treatments and others such as tip burn that probably were influenced by the treatments.

Overall trends were similar to trials on other crops in this series, with clear positive responses to sprayed nitrogen in the first 21 days after planting. Interactions between drenching, spraying and banding treatments may have been recorded because the trial lacked uniformity.

Yields appeared to be increasing even at the highest rate of spraying and maximum yields were recorded from total spray rates of at least 62.4 kg/ha N over the first 21 days after planting in combination with Spurt-N® top-dressing. Ammonium nitrate top-dressing in combination with high rates of spraying yielded equally well but only in the presence of the potassium nitrate drench.

The impact of fertiliser treatments on the incidence of tip burn was conflicting, with LBU based sprays being associated with higher levels, but LBU top-dressing not so.

Good yields of winter Cos lettuce with a minimal incidence of tip burn were grown in this trial with no pre-plant drench followed by a spray treatment consisting of 11.3 kg/ha LBU plus 40 kg/ha potassium nitrate, six times in the first three weeks after planting and then followed by three top-dressings with Spurt-N® at 200 kg/ha and two top-dressings of potassium nitrate to a total of 900 kg/ha until row closure.

SUMMER CROP

Method

Site preparation and pre planting fertiliser applications were made according to standard practice as outlined in the 'General Methods'.

Seedlings for the trial (cultivar Cosmic) were bought in from a specialist nursery and planted on 15 December. Half the seedling trays were drenched with 40 g/litre potassium nitrate at 500 mL/tray (100 cells) within one hour of planting for the drenched treatments (D) and the other half were drenched with water (Undrenched = U). Seedlings were planted at four rows per bed with 300 mm between rows and 300 mm between plants. Each plot had a buffer plant at both ends of each row (i.e. 8 buffer plants in total). Plots were 2.4 m long (32 plants in total with 24 plants for harvest). The plots were un-buffered outside the rows i.e. all four rows were harvested, but the trial block was buffered with two beds planted as buffers either side of the four replicate beds.

The experimental design comprised four replicates of a split-split plot design with banded fertiliser as the main plot (four fertiliser products), drenching as the split plot (drenched vs undrenched) and spray treatment (four spray rates) as the split-split plot.

Immediately after transplanting, Kerb® was applied at 3 kg/ha and followed with 3 mm irrigation.

(a)

(b)

Figures 7.7a, b Planting Cos lettuce trial at Medina Research Station, 15 December 2005.

Post-plant fertiliser

A regime of spray treatments was commenced one day after planting on December 16 which consisted of twice weekly applications of a range of spray treatments for two weeks (four applications in total) as follows:

S1 No spray.

S2 40 kg/ha potassium nitrate only (31.2 kg/ha nitrogen and 91.2 kg/ha potassium in total).

S3 11.3 kg/ha LBU only (31.2 kg/ha N in total).

S4 11.3 kg/ha LBU plus 40 kg/ha potassium nitrate (62.4 kg/ha nitrogen and 91.2 kg/ha potassium in total).

S5 22.5 kg/ha LBU plus 20 kg/ha potassium nitrate (77.7 kg/ha nitrogen, 45.6 kg potassium in total).

This was followed by a series of one of four top-dressing treatments as detailed in Table 7.3. The prilled fertiliser treatments were banded into a shallow furrow between pairs of rows of lettuce commencing 15 days after transplanting and ending at row closure. The liquid fertiliser, Spurt-N® was dissolved in one litre of water per square meter of bed area and spread over the foliage with a watering can. This treatment was immediately washed from the foliage with two litres of water per square meter, using the same method.

Table 7.3 Top-dressing treatments (B1-B4) applied to winter Cos lettuce (kg/ha)

Top-dressing treatment	**B1**		**B2**	**B3**		**B4**	
Day No.	**KN**	**AN**	**Nitrophoska Blue Special®**	**KN**	**LBU**	**KN**	**Spurt-N® (kg/ha)**
14	400		550	400		400	
21		200	550		150		200
26	500		550	500		500	

Pest and disease control

A regime of sprays was applied for sucking and chewing insects. These consisted of Confidor® (imidacloprid) at 300 mL/ha, Pirimor® (pirimicarb) at 550 mL/ha), Sumisclex® (procymidone) at 80 mL/100L, Supracide® (methidathion) at 1.4 L/ha, Malathion® at 200 mL/100 L, and Nitofol® (methamidophos) at 500 mL/ha). Bavistin® (carbendazim) at 2 L/ha) was also applied for *Sclerotinia* control.

Results

All treatments established and grew rapidly in the first two weeks after planting due to warm weather. Differences between spray treatments were obvious by 7 days after planting, with plant vigour increasing in direct proportion to the rate of nitrogen applied. There were no obvious visual differences between the two spray treatments, S2 and S3 at any stage of growth. These two treatments applied the same rate of nitrogen each time they were sprayed but in two different forms, potassium nitrate and LBU. Over time, as the top-dressing treatments were applied, these differences became less obvious but by the time of harvest, the unsprayed treatment was still visibly smaller than all other sprayed treatments. There were no visible differences between drenched and un-drenched treatments in the days after planting. Differences between top dressed products were not obvious at any stage of growth.

The crop was harvested on 30, 31 January (46, 47 days after planting). This was almost a week longer than expected for this time of year and probably the result of the abnormally cool summer. Compared to the year before, December was especially cool with maximum temperatures at Medina Research Station about 6 degrees cooler on average (Table 7.4). In addition, both December and in particular, January were wetter than average leading to increased disease risk.

Table 7.4 Comparison of temperature records from Medina Research Station, 2004 and 2005

Year	Month	Mean min temp	Mean max temp	Mean min soil temp	Mean max soil temp	Total rain (mm)
2004	December	15.9	29.1	24	39.2	4.8
2005	December	12.8	22.6	20.8	33.7	12
2005	January	16.2	29.3	24.8	43.2	0.2
2006	January	16.3	28.2	23.1	35.9	55.6

At the time of harvest the crop had started to bolt even though head development was not necessarily advanced. Seed stems were well developed in some treatments, though not yet protruding through the top of the plants. Bolting also tended to be associated with tip burn. Much of this we believe was the product of the cool December weather although the data suggests there was a treatment component as well. For that reason we are inclined to put more weight on the data for total head weight as opposed to marketable head weight.

At harvest, heads were trimmed in the field and whole plot weights (marketable and reject) recorded. Heads less than 300 g were deemed unmarketable. Reasons for rejection included Tomato Spotted Wilt Virus, tip burn and caterpillar damage as well as some problems with non heading in some treatments and over-maturity in others.

There was a highly significant effect of spray treatment on total head weight (Figure 7.8). There were no other significant treatment differences.

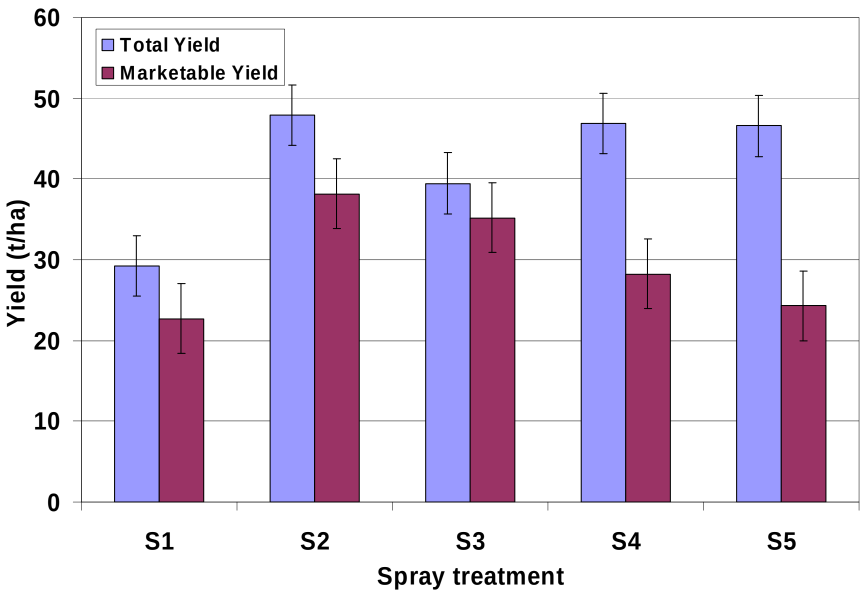


Figure 7.8 The effect of fertiliser spray treatment on total and marketable yield of Cos lettuce in summer

Whilst the potassium nitrate only spray treatment (S2) gave the highest total and marketable yield, it was not significantly different to the LBU only spray treatment (S3) in respect of marketable yield, or to both of the LBU and potassium nitrate sprays (S4 and S5) for total yield. Treatment S1, the nil spray gave significantly lower total yields compared to all other treatments but was not significantly different to S5 for marketable yield.

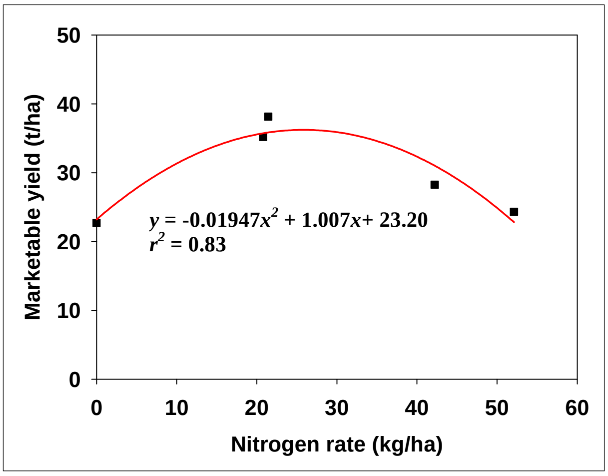


Figure7.9a Regression of marketable yield and nitrogen rate for Cos lettuce planted December 2005.

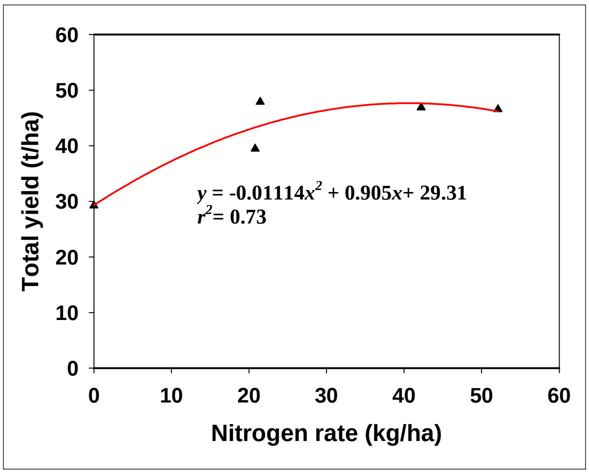


Figure 7.9b Regression of total yield and nitrogen rate for Cos lettuce planted December 2005.

There was a significant correlation between nitrogen rate and both total and marketable yield. Figures 7.9a,b illustrate that relationship.

The effect of spray treatment on the incidence of tip burn and bolting proved to be highly significant. There was no significant effect of drench although drenched plants had a slightly higher incidence of tip burn and bolting (5.93 cf 4.75) but there was a highly significant interaction between drench and spray treatments ($p < 0.004$). Spray treatments 4 (11.3 kg LBU plus 40 kg/ha potassium nitrate) and 5 (22.5 kg LBU plus 20 kg/ha potassium nitrate) were both associated with high levels of bolting and tip burn, possibly because these heads were bigger and the seed stems had advanced further to be more visible in these treatments.

Discussion

The unseasonally cool weather during this trial slowed the growth of this crop and seemed to promote bolting and tip burn even when head development was lacking. Rejections for visible tip burn at harvest tended to mask the growth promoting effects of fertiliser sprays and for this reason data for total yield (ignoring market rejects) as well as marketable yield were considered when interpreting yield data. There were strong indications that certain treatments were associated with higher levels of bolting and tip burn. Therefore, while there was no significant yield difference between spray treatments S2, S4 and S5, the latter two treatments cannot be recommended due to their association with high levels of rejection for tip burn. It is uncertain whether more rejections for tip burn in S4 and S5 treatments may have been because they were generally larger heads on the day chosen for harvest, and seed stems with associated tip burn were more visible on these than smaller heads from other treatments.

When the data for total yield was considered alone, ignoring rejections for tip burn and bolting, there was a positive yield response to increasing rates of nitrogen up to S4 (62.4 kg/ha N in 21 days). No yield benefit could be shown from drenching seedlings and there were no yield differences between the four top-dressing treatments. Even though there was no significant difference between top-dressing treatments, a recommendation of ammonium nitrate would also be safer with regard to the likelihood of tip burn.

The fertiliser cost difference between the highest yielding treatments was minimal – about $250 (in fact identical to the iceberg). There was no benefit in applying additional postplant phosphorus (as in the NPK Blue treatments). Application of only 20-40 kg N in the first two weeks produced a yield difference of around 35 t/ha at harvest. At a price of 65c/kg this represents a benefit of at least $20,000 for an investment of only $40 for the LBU only treatment, or up to $200 for the other spray treatments.

Conclusion

Summer Cos lettuce may be grown successfully without the need for a pre-plant seedling drench. A spray treatment consisting of 40 kg/ha potassium nitrate applied four times in the first two weeks and followed by ammonium nitrate banding at 200 kg/ha until row closure will give good yields and minimise the incidence of tip burn. The apparent adverse effects of LBU based sprays on tip burn incidence and severity needs to be investigated further in future research to determine if it could be avoided by earlier harvesting. There was an inconsistency in the effects of top-dressed LBU on tip burn severity between summer and winter Cos lettuce and this also needs further investigation.

8. ICEBERG LETTUCE

Introduction

Iceberg lettuce is a crop that is widely transplanted in the field from 'tray grown' seedlings produced by specialist nurseries in Australia. In Western Australia the crop is almost exclusively grown this way in commercial practice, and production is year round on sandy soils of the Swan Coastal Plain.

Where iceberg lettuce is grown on sandy soils, it is often in rotation with crops such as cabbage, celery and broccoli. Traditional nutrition practice for these crops is to use poultry manure as a broadcast treatment before planting and/or banded between rows after planting. Mineral fertilisers are routinely applied as topdressings on these crops also. No replicated research work had been done to test seedling drenches or fertiliser sprays as establishment treatments for iceberg lettuce on these sandy soils prior to the research reported on here, but extensive unreplicated observations had been made on grower properties (Phillips 2004). The potential benefits of the drench/spray technique are reduced leaching of fertiliser into groundwater from lower fertiliser application rates and more uniform placement of fertiliser than achieved by current commercial practices.

Iceberg lettuce grown in winter can take as long as 100 days after planting to reach marketable maturity and fertiliser programs need to take account of a slow rate of crop establishment coupled with regular uncontrolled leaching events caused by heavy rainfall. Iceberg lettuce grown in summer, however, often reaches marketable maturity in as little as 35 days after planting and as such, strategies to ensure maximum yield leave little margin for error.

Since rates and timing of nitrogen application for winter versus summer lettuce may need to be quite different we conducted separate trials for each, the details of which are presented below.

WINTER CROP

Method

Site preparation and pre planting fertiliser applications were made according to standard practice as outlined in the 'General Methods'.

Seedlings for the trial (cultivar 'Patagonia') were bought in from a specialist nursery and planted on 4 August 2005. Half the seedling trays were drenched with 40 g/litre potassium nitrate at 500 mL/tray (100 cells) within one hour of planting for the drenched treatments (D) and the other half were drenched with water (un-drenched = U). Seedlings were planted at four rows per bed with 300 mm between rows and 300 mm between plants. Each plot had a buffer row at each ends (eight buffer plants in total). Plots were 2.4 m long (32 plants in total with 24 plants for harvest). The plots were un-buffered outside the rows, i.e. all four rows were harvested, but the trial block was buffered with two beds planted as buffers either side of the four replicate beds.

The experimental design comprised four replicates of a split-split plot design with banded fertiliser as the main plot (four fertiliser products), drenching as the split plot (drenched vs un-drenched) and spray treatment (four spray rates) as the split-split plot.

Immediately after transplanting Kerb® was applied at 3 kg/ha and followed with 3 mm irrigation.

Post-planting fertiliser treatments

A regime of spray treatments was commenced one day after planting (5 August) consisting of twice weekly applications of a range of spray treatments for a total of 21 days (six applications in total) as follows:

S1 No spray.

S2 40 kg/ha potassium nitrate only (31.2 kg/ha nitrogen and 91.2 kg/ha potassium in total).

S3 11.3 kg/ha LBU only (31.2 kg/ha N in total).

S4 11.3 kg/ha LBU plus 40 kg/ha potassium nitrate (62.4 kg/ha nitrogen and 91.2 kg/ha potassium in total).

S5 22.5 kg/ha LBU plus 20 kg/ha potassium nitrate (77.7 kg/ha nitrogen, 45.6 kg potassium in total).

This was followed by a series of one of four top-dressing treatments as detailed in Table 8.1. The prilled fertiliser treatments were banded into a shallow furrow between pairs of rows of lettuce commencing 18 days after transplanting and ending at row closure. The liquid fertiliser, Spurt-N® was dissolved in one litre of water per square meter of bed area and spread over the foliage with a watering can. This treatment was immediately washed from the foliage with two litres of water per square meter, using the same method.

Table 8.1 Top-dressing treatments (B1-B4) applied to iceberg lettuce (kg/ha)

Banding treatment	B1		B2	B3		B4	
Days from planting	Potassium nitrate (kg/ha)	Ammonium nitrate (kg/ha)	Nitrophoska Blue Special®	Potassium nitrate (kg/ha)	LBU (kg/ha)	Potassium nitrate (kg/ha)	Spurt-N® (kg/ha)
18	400		550	400		400	
28		200	550		150		200
33		200	550		150		200
39		200	550		150		200
48	500		550	500		500	

A foliar spray of Borax (10 g/L) was applied midway through the growth cycle.

Pest and disease control

Bavistin® (carbendazim) at 2 L/ha was sprayed twice two weeks apart for *Sclerotinia* control. Five days later Pirimor® (pirimicarb) at 500 g/ha, Permasect® (permethrin) at 20 mL/100 L and Mancozeb® at 2 kg/ha were sprayed as a preventive for sucking insects and caterpillars. These were repeated 10 days later.

Results

All treatments grew slowly in the first four weeks after planting due to cool and wet weather. Differences between spray treatments were obvious by 14 days after planting, with plant vigour increasing in direct proportion to the rate of nitrogen applied. . There were no obvious visual differences between the two spray treatments, S2 and S3 at any stage of growth. These two treatments applied the same rate of nitrogen each time they were sprayed but in two different forms, potassium nitrate and LBU. Over time, as the top-dressing treatments were applied, these differences became less obvious but by the time of harvest, the unsprayed treatment was still visibly smaller than all other sprayed treatments. Visible differences between drenched and un-drenched treatments were not obvious at any stage of growth, but differences between top-dressing treatments were obvious from mid growth to harvest with the LBU plots noticeably less vigorous than the other top dressing products.

The photos which follow (Figures 8.1a-f) show treatment differences between spray treatments over time.

(a)

(b)

Figures 8.1a, b **Twenty eight days after planting showing unsprayed lettuce (left) compared to lettuce sprayed 6 times with S5 spray rate (right) – both plots were drenched at planting.**

(c)

(d)

Figures 8.1c, d **Twenty eight days after planting showing lettuce sprayed with potassium nitrate (left) compared to lettuce sprayed with LBU at the same rate of nitrogen (right) – both plots were drenched at planting.**

(e)

(f)

Figures 8.1e, f **Twenty eight days after planting showing lettuce drenched (left) compared to lettuce undrenched (right) – both plots were unsprayed for the first 21 days after planting.**

Despite the obvious differences between spraying treatments early in the crop's life, many plots were of poor quality with a great range in size and maturity by harvest time. For this reason it was picked in replicates over a range of dates (7, 12, 14 October, 2005). This uneven maturity effect is illustrated in Figure 8.2.

Figure 8.2. Fifty five days after planting showing uneven maturity typical of most plots at harvest.

The reasons for this lack of uniformity at harvest are uncertain, but possibilities include an uneven uptake of early banded treatments, an unsuitable cultivar for the time of planting, nutrients other than nitrogen limiting growth or an unsatisfied requirement for nitrogen beyond row closure.

At harvest, there was a significant interaction between the three treatment factors, drenching, spraying and banding. Table 8.2 shows that the majority of high yielding treatments were associated with the two spray rates which supplied the highest rates of nitrogen to the crop (S4 and S5). The exception was all plots that had LBU as the banding treatment, drenched plots with Spurt -N® (B4) and the treatment where S4 was combined with Nitrophoska® as the banded treatment.

Some other anomalies were also found for other treatment combinations. The relatively imprecise nature of the marketable yield response for this trial may have been the result of the uneven plots at harvest noted earlier.

Table 8.2 Significance table for the band x drench x spray interactions, showing final total yields that were not significantly different from the highest yielding treatment (in grey)

Band	Spray	Nil spray (S1)	Potassium nitrate only (S2)	LBU (S3)	Low LBU plus high potassium nitrate, (S4)	High LBU plus low potassium nitrate, (S5)
B1	Drenched	9.39	34.46	29.41	43.68	33.80
	Undrenched	3.42	18.63	19.66	36.39	38.71
B2	Drenched	15.64	30.81	40.92	43.18	40.05
	Undrenched	8.17	38.87	26.17	30.57	34.36
B3	Drenched	3.19	23.47	21.19	22.70	16.61
	Undrenched	0.00	11.59	8.93	28.08	17.49
B4	Drenched	5.62	31.92	20.11	25.37	36.65
	Undrenched	1.58	18.63	25.44	45.71	42.11

Notwithstanding the significant interactions, marketable yield was positively correlated with increasing rates of sprayed nitrogen as shown in Figure 8.3.

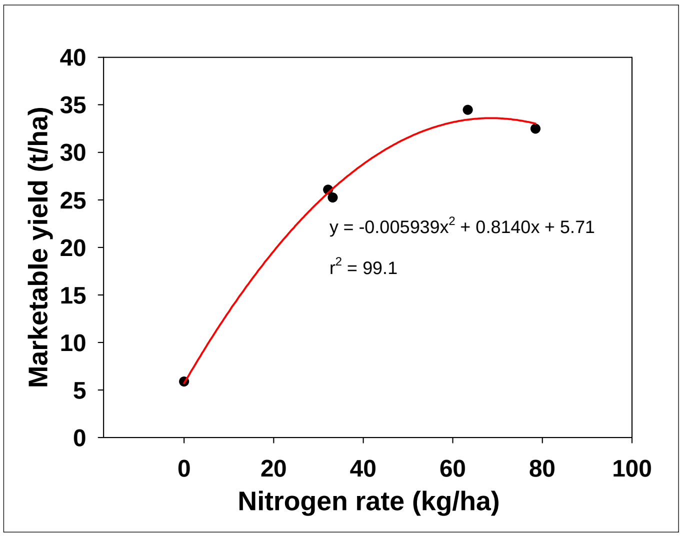


Figure 8.3 Response to the cumulative rate of nitrogen sprayed in the first 21 days after planting for marketable weight yield.

The trend for treatments top dressed with LBU was to perform poorly compared to other top dressing products is illustrated in Figure 8.4.

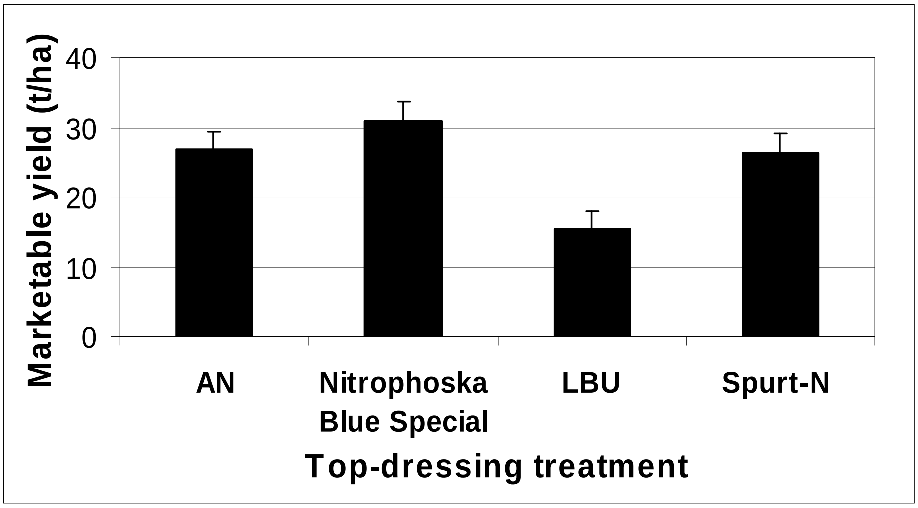


Figure 8.4 The effect of the four top dressing products tested on final marketable yield of winter iceberg lettuce.

Discussion

Winter lettuce responded positively to nitrogen sprays applied for the first 21 days after transplanting, but there were no differences between drenched and un-drenched plants apparent at harvest.

Again, the treatments that were not sprayed with nitrogen in the first 21 days yielded almost no marketable crop whereas those sprayed during that period yielded from 35-45 t/ha. The two spray treatments that supplied 21 – 26 kg/ha N per week (S4 and S5) gave the highest marketable yields. Nitrogen was supplied in the form of a mixture of potassium nitrate and LBU for these two treatments.

The use of Nitrophoska Blue Special® as opposed to either ammonium nitrate, LBU or Spurt-N® for top-dressing added about $900 per hectare to the cost of fertiliser for no clear yield benefit, but it could be more convenient to use and reduce labour costs for application in some situations.

At this stage spraying with potassium nitrate and LBU mixtures and topdressing with Spurt-N®, LBU or ammonium nitrate are recommended treatments for winter lettuce from the results of this work. The use of a pre-plant drench had variable results in this trial and further clarification is needed before it can be recommended for use in winter.

This trial was not very uniform and there may have been factors operating that mitigated against optimum yields being achieved. One of these unknown factors was the possibility that yields could have been improved by continuing to top-dress the crop beyond row closure. Further research is required to clarify this unknown for winter grown lettuce.

Conclusions

Good yields of winter iceberg lettuce can be achieved without a preplant drench using a spray treatment consisting of 11.3 kg/ha LBU plus 40 kg/ha potassium nitrate applied six times in the first 21 days after planting and followed by top-dressing with either ammonium nitrate or Spurt-N®, both at 200 kg/ha. Nitrophoska Blue Special® combined with a seedling drench also produced equivalent yields, but cost more than the other banding treatments.

Additional work is needed to clarify whether further yield increases would be possible by top-dressing beyond row closure.

SUMMER CROP

Method

Site preparation and pre planting fertiliser applications were made according to standard practice as outlined in the 'General Methods'.

Seedlings for the trial (cultivar 'Raider') were bought in from a specialist nursery and planted on 8 December 2005. Half the seedling trays were drenched with 40 g/litre potassium nitrate at 500 mL/tray (100 cells) within one hour of planting for the drenched treatments (D) and the other half were drenched with water (undrenched = U). Seedlings were planted at four rows per bed with 300 mm between rows and 300 mm between plants. Each plot had a buffer row at each end (eight buffer plants in total). Plots were 2.4 m long (32 plants in total with 24 plants for harvest). The plots were un-buffered outside the rows i.e. all four rows were harvested, but the trial block was buffered with two beds planted as buffers either side of the four replicate beds.

The experimental design comprised four replicates of a split-split plot design with banded fertiliser as the main plot (four fertiliser products), drenching as the split plot (drenched vs undrenched) and spray treatment (four spray rates) as the split-split plot.

Immediately after transplanting Kerb™ was applied at 3 kg/ha and followed with 3 mm irrigation.

Post-plant fertiliser

A regime of spray treatments was commenced one day after planting (9 December) consisting of twice weekly applications of a range of spray treatments for a total of 14 days (four applications in total) as follows:

S1 No spray.

S2 40 kg/ha potassium nitrate only (20.8 kg/ha nitrogen and 60.8 kg/ha potassium in total).

S3 11.3 kg/ha LBU only (20.8 kg/ha N in total).

S4 11.3 kg/ha LBU plus 40 kg/ha potassium nitrate (41.6 kg/ha nitrogen and 60.8 kg/ha potassium in total).

S5 22.5 kg/ha LBU plus 20 kg/ha potassium nitrate (51.8 kg/ha nitrogen, 30.4 kg potassium in total).

This was followed by a series of one of four top-dressing treatments as detailed in Table 8.3. The prilled fertiliser treatments were banded into a shallow furrow between pairs of rows of lettuce commencing 15 days after transplanting and ending at row closure. The liquid fertiliser, Spurt-N® was mixed in one litre of water per square meter of bed area and spread over the foliage with a watering can. This treatment was immediately washed from the foliage with two litres of water per square meter, using the same method.

Table 8.3 Top-dressing treatments (B1-B4) applied to iceberg lettuce (kg/ha)

Banding treatment	B1		B2	B3		B4	
Days after planting	**Potassium nitrate (kg/ha)**	**Ammonium nitrate (kg/ha)**	**Nitrophoska Blue Special®**	**Potassiu m nitrate (kg/ha)**	**LBU (kg/ha)**	**Potassium nitrate (kg/ha)**	**Spurt-N® (kg/ha)**
15	400		550	400		400	
21		200	550		150		200
26	500		550	500		500	

Pest and disease control

A regime of sprays were applied for sucking and chewing insects. Confidor® (imidacloprid) at 300 mL/ha, Pirimor® (pirimicarb) at 550 mL/ha), Sumisclex® (procymidone) at 80 mL/100L, Supracide® (methidathion) at 1.4 L/ha, Malathion® at 200 mL/100 L and Nitofol® (methamidophos) at 500 mL/ha).

Bavistin®(carbendazim) at 2 L/ha) was also applied for *Sclerotinia* control.

Results

All treatments established and grew rapidly in the first two weeks after planting due to warm weather. Differences between spray treatments were obvious by 14 days after planting, with plant vigour increasing in direct proportion to the rate of nitrogen applied. There were no obvious visual differences between the two spray treatments, S2 and S3 at any stage of growth. These two treatments applied the same rate of nitrogen each time they were sprayed but in two different forms, potassium nitrate and LBU. Over time, as the top-dressing treatments were applied, these differences became less obvious but by the time of harvest, the unsprayed treatment was still visibly smaller than all other sprayed treatments. There were visible differences between drenched and un-drenched treatments in the days after planting, with drenched treatments appearing greener and a little bigger. Differences between top dressed products were not obvious at any stage of growth (Figures 8.5, 8.6a,b).

Figure 8.5 Overview of the summer iceberg lettuce trial forty days after transplanting.

(a)

(b)

Figures 8.6a,b Forty days after planting showing unsprayed lettuce (left) compared to lettuce sprayed 4 times with S5 spray rate (right) – both plots were un-drenched at planting.

The crop was harvested on 17 January (40 days). Heads were trimmed in the field as for processing and whole plot weights (marketable and reject) recorded. Heads less than 300 g were deemed unmarketable. Reasons for rejection included Tomato Spotted Wilt Virus, tip burn and caterpillar damage as well as some problems with non heading in some treatments and over-maturity in others.

The nil spray treatment (S1) was significantly lower yielding than all other spray treatments. The response to spray treatments was highly correlated to the rate of applied nitrogen in that first two weeks. Marketable yield was maximised at 37.45 kg/ha of sprayed nitrogen using the quadratic fit to the data shown in Figure 8.7.

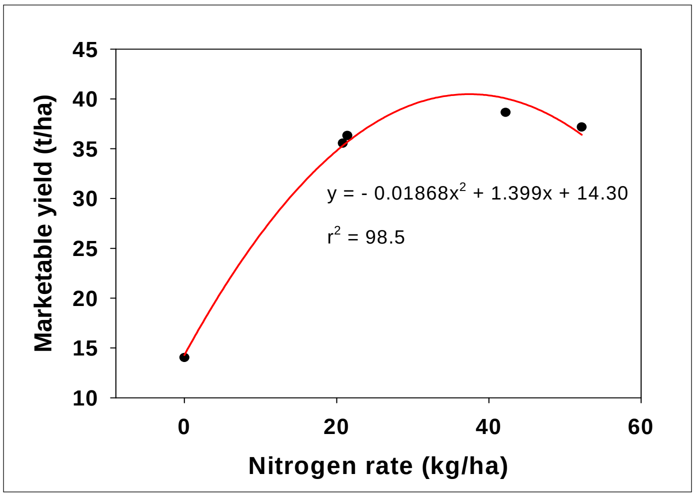


Figure 8.7 Response to the cumulative rate of nitrogen sprayed in the first 14 days after planting for marketable weight yield.

The response to spraying had a similar effect on lettuce head weight as shown in Figure 8.8 with mean head weight maximised at 47.88 kg/ha of sprayed nitrogen in the first 14 days.

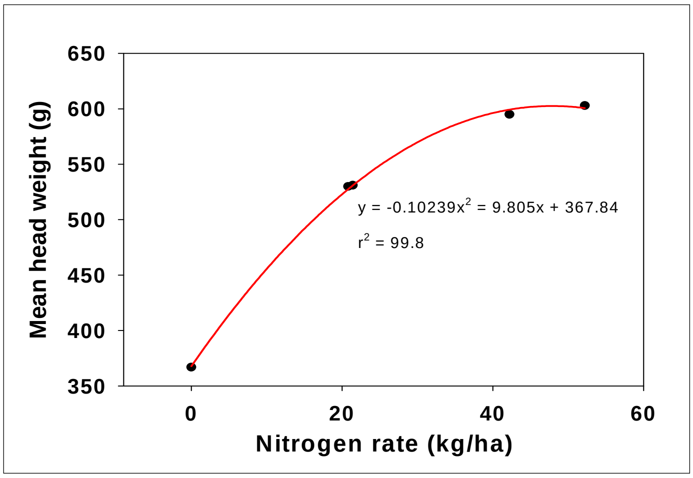


Figure 8.8 Response to the cumulative rate of nitrogen sprayed in the first 14 days after planting for mean marketable head weight.

Whilst there was no significant difference between any of the top-dressing treatments there was an interaction between drenching and top-dressing (See Figure 8.9) with drenched plants responding more to both B1(ammonium nitrate) and B4 (Spurt-N®). The yield advantage from the seedling drench when combined with Spurt-N® was 9 t/ha.

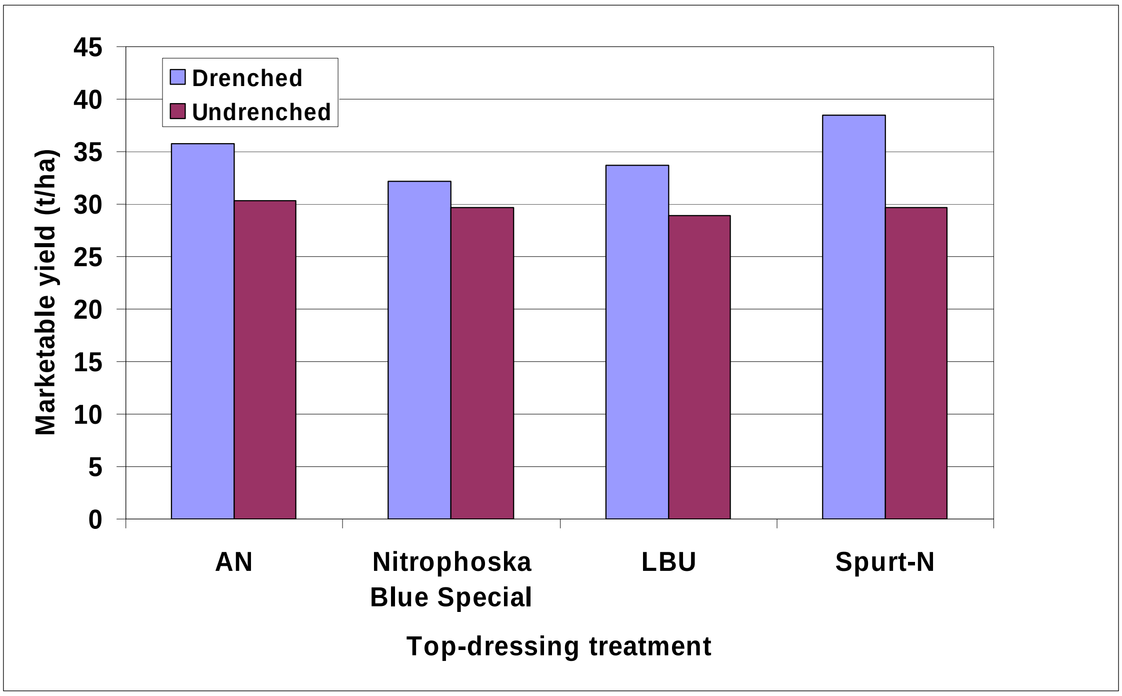


Figure 8.9 The effect of the four top dressing products and a seedling drench tested on final marketable yield of summer iceberg lettuce.

Discussion

Summer lettuce proved to be highly responsive to nitrogen sprays for the first 14 days after transplanting, as well as to the seedling drench with potassium nitrate prior to planting. The two effects appeared to operate independently of each other, both adding to the marketable yield potential of the crop. The drench proved to be a particularly cost effective way to gain extra yield when followed by topdressing with ammonium sources of nitrogen, ammonium nitrate or Spurt-N®. For a cost of around $14 per hectare this treatment could give a gross return of $6000 at processing lettuce prices.

The fertiliser cost difference between the highest yielding treatments was minimal at around $250. There was no benefit in applying additional post plant phosphorus (as in the Nitrophoska Blue Special® treatments), but this treatment offered the benefit of convenience in that there was no need to switch between nitrogen and potassium containing fertilisers from week to week.

The lowest yielding treatments tended to be those that were not sprayed with nitrogen for the first 14 days. This shows the importance of early nutrition. Spray applications as low as 20.8 kg/ha N in the first two weeks produced a yield difference of around 35 t/ha at harvest compared to not spraying. At a price of 65c/kg this represents as benefit of at least $20,000 for an investment of only $40 for the ‘LBU only’ (S3) treatment.

Conclusion

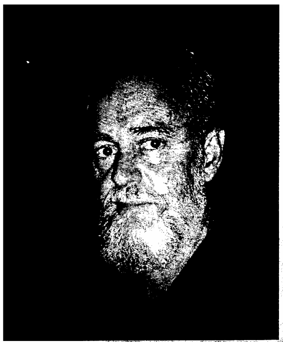
Optimal yields of summer grown iceberg lettuce with minimal tip burn may be achieved by using a pre-plant seedling drench with potassium nitrate, followed by spraying with 11.3 kg/ha LBU plus 40 kg/ha potassium nitrate four times in the first two weeks after planting then topdressing with Spurt-N® or ammonium nitrate at 200 kg/ha per week to row closure.

9. EXTENSION AND TECHNOLOGY TRANSFER

Seminar for growers

A grower meeting to present the results of nutrition work carried out in project VG99014 and to introduce the aims and objectives of project VG04018 was held for Perth leafy crop growers on 1 April 2004. This meeting was held in advance of approval being given for project VG04018, to take advantage of a visiting road show on lettuce IPM run by Sandra McDougall and Andrew Creek from Agriculture NSW. Combining the two events allowed for a more diverse programme to be offered to growers which attracted a larger audience.

There was considerable interest among growers and fertiliser suppliers in the project at the meeting. The outcome of the meeting was reported to the wider industry in a story published in the WA Grower magazine, June 2004 (reprinted hereunder).



Lettuce update

meeting at the Wanneroo Tavern

Text and photos Linda Manning

David Gatter, Department of Agriculture WA, gave an overview of the Department's lettuce research over the last five years.

The results presented were some of the findings of two consecutive projects funded by Horticulture Australia commencing in 1997 and terminating in 2003. The final report of both projects is now available from Horticulture Australia. The second project entitled 'A model for lettuce industry development' was completed in December 2003, and has recently been accepted by Horticulture Australia.

Replacing raw poultry manure with chemical fertilizers

The aim of this work was to develop fertiliser programmes for iceberg and leaf lettuce that minimise health and environmental risks associated with growing lettuce using raw animal manures.

This was part of a broader strategy to re-invigorate lettuce exports and to maximise marketable yields while heading off any objections that the market may have to the use of manures for production. Agriculture WA identified a market for shredded lettuce in South-east Asia and it was really important that strict food safety requirements are met to supply this market.

The ban on the use of raw poultry manure between the 1 September and 30 April was the catalyst for this research. Growers used to incorporate into the soil and/ or sideband raw poultry manure anywhere between 8 and 80 cubic metres per hectare (equivalent to 3 to 32 tonnes ha).

The Department of Agriculture WA team of Dennis Phillips, Dave Gatter and Aileen Reid, evaluated one chemical fertilizer regime after another on one commercial property. As soon as the team got one level right, they worked on the next chemical, rate or method. Their final recommendations are outlined in the table below.

They have been able to successfully grow high yielding, high quality lettuce under this fertilizer regime. Dave Gatter pointed out that this method may not work precisely the same for all growers in all situations and it may require 'customising' to fit different situations.

The team from Agriculture will work through the 'customising' process with interested growers over the next two years, by conducting on farm demonstrations.

These methods may also have application to other leafy and Brassica vegetable crops, and Horticulture Australia have funded another project to explore these possibilities. The new project will commence in July 2004. Dennis and his team will be seeking grower volunteers to help develop these new techniques.

TIMING	FERTILISER	RATE	COMMENTS
Step 1. Broadcast application before planting	Phosphorus (P) e.g. Double Phos or other.	Up to 2500 Kg/ha	Based on soil test and crop history
	Potassium and Magnesium e.g. K-Mag® or other.	Up to 200 Kg/ha	Based on soil test and crop history
	Trace Elements.	Recommended rate	Once annually.
Step 2. Seedling Drench in trays on the day of transplanting.	Potassium nitrate (KNO_3) greenhouse grade.	40 grams/litre (500 ml per 100 seedlings)	***ALERT!*** Critical Step which must not be missed!.
Step 3. Boomspray in field one day after planting and twice per week for 2 to 3 weeks.	KNO_3 + Urea (low biuret) **OR** KNO_3	20 kg/ha + 22.5 kg/ha 40 kg/ha	***ALERT!*** Low biuret urea is much safer than ordinary urea..
Step 4. Banding high rate at 7 day intervals, commencing at 10-14 days after transplanting, up to row closure.	**1st** Potassium nitrate (KNO_3). **2nd** Ammonium nitrate **or** Calcium ammonium nitrate **or** NPK mixed fertiliser.	500 kg/ha. 200 kg/ha **or** 250 kg/ha **or** 600 kg/ha.	***ALERT!***. Critical Step, first banding must not be missed.

30 WA Grower

Field Day for growers

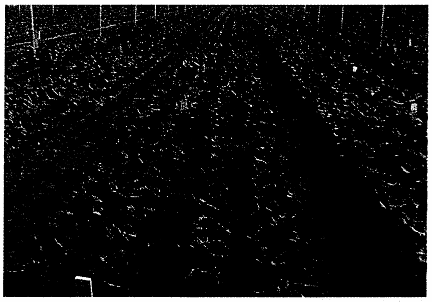
A seminar and field day was held at Medina Research Station on Friday, 17 June and was attended by 22 growers and trade representatives. The programme for the day was developed in conjunction with David Ellement, the WA IDO. David did the advertising for the field day and was an invited speaker. Other current HAL funded projects were topics also covered at the field day. A Powerpoint slide presentation was presented on the day and is available on request.

Grower magazine articles

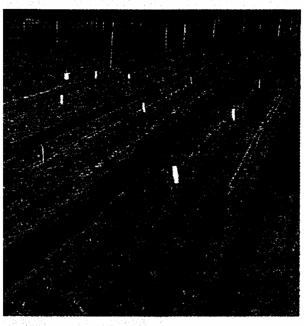
As well as the story described on the outcome of the grower seminar (above), an update on the project was published in the 'Vegelink" insert in the December 2004 edition of WA Grower (reprinted hereunder).

VEGE

New Horticulture Australia project on improving fertiliser use efficiency gets underway in WA



A new Horticulture Australia Ltd (HAL) funded project has been approved and is underway in WA to increase the efficiency of utilisation of fertilisers applied to vegetable crops. Most of the work will be done with leafy crops grown on sandy soils of the Swan Coastal Plain where fertiliser losses through leaching are often unacceptably high.



The project will build on successes from a recently completed HAL project that ran from 2000 – 2003 and examined alternative approaches to growing lettuce in these soils without poultry manure. This project showed that nitrogen losses and consequent ground water pollution could be greatly reduced by better timing of mineral nitrogen applications and methods of delivering this fertiliser.

The lettuce project came up with workable and practical solutions to the problem which growers could easily adopt. It was found that drenching seedlings immediately before planting with highly concentrated solutions of nitrate fertiliser gave significant growth responses in the first week after planting. This enhanced early growth translated directly into shorter maturity times and yield increases of the order of 15 – 20% at harvest. Spraying highly concentrated solutions of nitrogen fertilisers onto the crop in the two weeks after planting enhanced yields further.

This work showed that returns from the crop could be increased by thousands of dollars per hectare for the expenditure of less than $100 of nitrogen fertiliser as long as other management practices were good. Far lower rates of fertiliser were required to establish the crop than those used in traditional practice with pre planting or banded poultry manure. Consequently only relatively small quantities of nitrogen were left to be leached away after the crop had established.

Seedling drenching gave worthwhile yield increases even where poultry manure was used as well. Results have also been encouraging on heavy soils in Manjimup where nitrogen availability for crop establishment has traditionally considered to not be a problem.

The new project aims to test the suitability of these methods for other transplanted leafy crops, including cauliflower, broccoli, celery, cabbage and Chinese cabbage. The research will measure the scale of yield increase and its cost/benefit and tailor techniques to maximise growth responses and safety for these new crops.

The work is important, not only because it will save fertiliser and reduce production costs, but also because it will demonstrate to the wider community that the industry is serious about reducing groundwater pollution and that big gains can be made without loss of yield or quality of products.

For Further Information contact: Dennis Phillips 93683319 or Aileen Reid 93683393.

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The project was reported nationally in the January 2005 edition of Good Fruit and Vegetables magazine (reprinted hereunder) and the June 2005 edition of Vegetables Australia magazine, Volume 1.6, pages 36-37(reprinted hereunder).

YOUR VEGETABLE LEVY @ WORK

Fertiliser trials start in WA

Vegetable Platter
Collated by VEGETABLE IDOs

A new Horticulture Australia Ltd (HAL) funded project has been approved and is under way in WA to increase the efficiency of use of fertilisers applied to vegetable crops. Most of the work will be done with leafy crops grown on sandy soils of the Swan coastal plain, where fertiliser losses through leaching are often unacceptably high.

The project will build on successes from a recently completed HAL project that ran from 2000-2003 and examined alternative approaches to growing lettuce in these soils without poultry manure. This project showed that nitrogen losses and consequent ground water pollution could be greatly reduced by better timing of mineral nitrogen applications and methods of delivering this fertiliser.

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Contact: Dennis Phillips, phone (08) 9368 3319, or Aileen Reid, phone (08) 9368 3393.

Trial plantings in lettuce.

The trial site after growth.

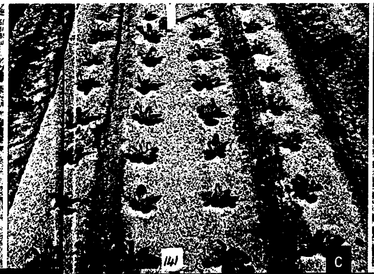
Computer user group in Vic

A number of Victorian growers have shown interest in the use of computers for farm management. As their businesses continue to grow, these farmers have found that computers can help manage the increased complexity of their operations.

Following a visit to Queensland, the Victorian industry development officer (IDO) identified a program that had been successfully adopted in Bundaberg. The developer of the computer program was invited to visit Victoria to demonstrate the features and benefits of his program. After the demonstration, a group of growers formed a group to modify the program and make it even more useful to Victorian growers. It is expected that this original group will set the trend for many more growers in the future as they take advantage of electronic technology to manage their farms.

Contact: Patrick Ulloa, Victorian vegetable IDO, phone (03) 9800 4631; fax (03) 9800 4632; mobile 0429 990 553; email <pulloa@vgavic.org.au>.

Good Fruit and Vegetables January, 2005 17



Boosting fertiliser efficiency for transplanted vegetables

Australia's environment is set to benefit from a project to allow growers to use less fertiliser when transplanting vegetables. By Carolyn Walker.

Australian vegetable growers may soon be able to grow transplanted vegetables with less fertiliser, thereby reducing the impact of fertilisers on the environment.

Researchers at Western Australia's Department of Agriculture have been working on a project to establish achievable targets for good nutrition practice for transplanted crops grown under sprinkler irrigation. The methods should have application wherever these crops are grown throughout Australia.

All crops responded positively to nitrogen sprays in the first 2-3 weeks after planting.

Researcher Dennis Phillips said the project addressed increasing scrutiny on the irrigation and nutrition practices of Australian vegetable growers by environmentalists, and the perception that they were polluters of the environment – particularly water quality.

"Growers are also faced with the restricted supply of ammonium nitrate, one of the cheapest and most effective nitrogen fertilisers. Access to this granular fertiliser will be regulated in the future, adding extra costs to vegetable production. Consequently, we decided to test alternative nitrogen based fertilisers as possible substitutes," Dennis said.

The third factor motivating the research was the widespread use of poultry manure as a pre-planting fertiliser for vegetables growing on the Swan Coastal Plain's sandy soils. Raw poultry manure is banned for much of the year in most production districts in WA.

The project aimed to repeat results achieved in another project in 2003 in WA, which showed that for iceberg lettuce, high rates of pre-planting poultry manure could be replaced by low rates of mineral nitrogen placed in the field with no yield loss and vastly reduced nitrate leaching to groundwater. The aim was to apply this to other transplanted leafy and heading crops, including celery, broccoli, cauliflower, cabbage, Cos lettuce and Chinese cabbage.

Field trials on virgin field sites compared between 24 and 40 combinations of seedling drench, early spraying and banding/fertigating with four nitrogen fertiliser products (Ammonium nitrate, Urea, Nitrophoska Blue Special and Spurt-N).

The four fertiliser products were compared at the same rate of nitrogen and applied weekly to the crop from 14 days after transplanting until 'row closure'. Treatments were repeated three of four times, with around 160 individual plots totalling around 5,000 plants each time – all hand sprayed with fertiliser.

Eight trials have been completed, including two Iceberg lettuce (winter and summer), two Cos lettuce (winter and summer), one celery, broccoli, cauliflower and cabbage. The final trial involves Chinese cabbage, which is still growing.

Dennis said that final results were expected towards the middle of 2006.

A Petiole sap tests were done on all crops at harvest. This one is a cauliflower petiole with the blade removed from which sap will be extracted in the lab.

B Cabbage plots on August 19 (36 days after planting) – The only difference between the plants in the foreground and the bigger ones in the background is that the bigger ones were sprayed with Urea and potassium nitrate for the first 21 days and the small ones were not.

C Granular Nitrophoska was banded between the rows on most trials by machine. This shows cos lettuce 28 days after planting on September 1.

D Broccoli trial on June 13 (19 days after planting) – up to 128 plots were sprayed with fertiliser solutions twice a week for 3 weeks in winter.

Source for all images: Dennis Phillips.

The bottom line:

- No crops were visibly damaged by a seedling drench with potassium nitrate (greenhouse grade) at 40 grams per litre immediately before planting. Iceberg lettuce and cabbage gave marketable yield increases of up to 20 per cent at final harvest from drenching (equivalent to 2kg/ha of N) – the 20 per cent could be worth $5,000 of extra return for $14 worth of fertiliser for Iceberg lettuce.
- All crops responded positively to nitrogen sprays in the first 2-3 weeks after planting, with increasing vigour as the nitrogen rate increased. Marketable yields increased by 300–500 per cent between plots that had no nitrogen applied for the first two weeks and the optimum spray rate. This resulted from as little as 10 kg/ha of nitrogen per week for two weeks for summer lettuce and would have returned an extra $14,000 of marketable product for an extra $70 worth of fertiliser. Broccoli, cauliflower and celery had their optimum yields at higher rates of spraying (20 kg/ha per week) while cabbage needed 26 kg/ha per week in winter.
- The four fertiliser products applied from 14 days to row closure gave similar results to ammonium nitrate in summer crops. Nitrophoska Blue Special was better for winter iceberg lettuce and cabbage, and seemed more resistant to leaching under regular rainfall. Urea did not perform well for winter iceberg lettuce, and Urea and Spurt-N were poorer for winter cabbage. March planted celery yielded best with Nitrophoska and Urea.
- There were problems with three trials. Chinese cabbage was severely damaged by the herbicide s-metolachlor (Dual Gold) on light sandy soils at below the recommended rate on the permit for leafy brassicas; broccoli produced an excellent marketable crop, but the late appearance of potassium deficiency symptoms allowed threshold sap and leaf tissue levels for this disorder to be identified; cauliflower showed symptoms of phosphorus toxicity symptoms close to harvest that did not affect crop marketability.

i For more information: Visit www.ausveg.com.au/levy-payers/login.cfm
Project number: **VG04018**
Keywords: **Fertiliser**

National Conference Poster

A poster on the project was accepted and submitted to the 3rd National Lettuce Industry Conference in Werribee in May 2005. A copy of the poster is reprinted below.

Government of Western Australia
Department of Agriculture

Fertiliser programmes for processing lettuce

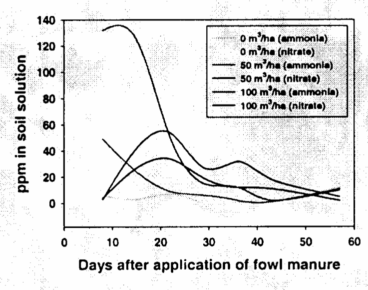
Dennis Phillips, Aileen Reid - South Perth. Shane Trainer - Manjimup.
Department of Agriculture, Western Australia,

HAL
Know-how for Horticulture™

Traditional fertiliser programmes for growing lettuce on sandy soils are based on broadcast and banded applications of deep litter poultry manure (PM). Release of nitrogen is unpredictable and rapid from PM leading to fertiliser wastage, and ultimately, unacceptable levels of groundwater pollution.

Trials over the last 4 years have developed programmes for growing lettuce based on mineral fertilisers for both sandy and sandy loam soils.

The system developed is a three stage process, at and after planting which we call drench/spray/band



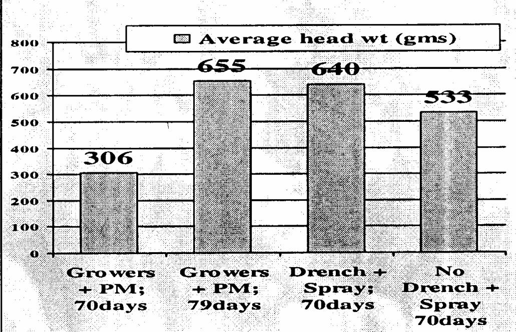
The Drench/Spray/Band Method for container grown seedlings

Rapid early growth is vital for high yields. Drench seedlings with 40 g/L potassium nitrate in the seedling trays immediately before planting.

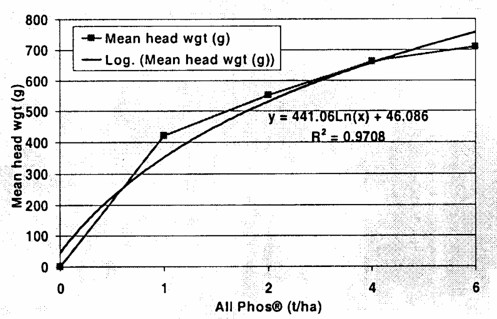
Spray early nitrogen and potassium with a boom spray (20 kg/ha potassium nitrate plus 22.5 kg/ha low biuret urea/1000 L/ha) without wash-off, twice weekly for 2 weeks in summer and 3 weeks in winter from planting.

Fourteen days after planting, band either ammonium nitrate (200 kg/ha – sandy loams) or potassium nitrate (400 kg/ha - sands) followed by ammonium nitrate (200 kg/ha) at 7 day intervals until row closure .

Seedling size/quality does not have the impact we thought if nutrition management is good. These seedlings eventually harvested at virtually identical weights.



Early nitrogen was important on sandy soils. Seedling drenches and sprays advanced maturity and increased head weights compared to traditional programmes.



Phosphorus had the biggest impact on lettuce yield on sandy loam soils with a high fixing capacity. Our trials showed that at least 5 t/ha of triple super (AllPhos) was needed on soils testing at around 100 mg/kg P (Colwell).

These methods are now being tested on other leafy and heading crops grown from container seedlings in a new HAL project (VG04018).

On-farm demonstrations

Five on-farm demonstrations of the drenching and spraying techniques for lettuce were conducted on two commercial vegetable farms at Bullsbrook and Gin Gin, to facilitate transfer of the technology. Details of the treatments tested and results are presented in the following three case studies.

CASE STUDY 1: FERTILISER STRATEGIES FOR ICEBERG LETTUCE VARIETIES AT BULLSBROOK, SEPTEMBER TO NOVEMBER

D.R. Phillips, A. Reid and D.G. Gatter

Summary

This work was an investigation into the suitability of several iceberg lettuce cultivars for the production of export and processing quality lettuce. A series of three consecutive plantings was undertaken at the property of a commercial vegetable grower in the Bullsbrook district of Western Australia, during the spring.

Several strategies using mineral fertilisers including combinations of pre-plant fertiliser drenches, fertiliser sprays and top-dressed applications were overlaid on the three plantings in order to manipulate crop yield, maturity and quality outcomes.

In all three trials, a fertiliser drench at transplanting provided a clear advantage to all varieties tested. It produced a significant yield improvement at harvest. The other fertiliser treatments (sprays and banding) produced variable results. They were superimposed on top of the grower's schedule and may have been beyond crop needs.

Most varieties produced adequate crops in the three trials. Across all trials, the varieties Toronto, Silverado, Jefferson and Brisbane performed best. Marksman and Magnum produced highly variable crops and lower yields. The variety Lindy performed poorly in every case.

The incidence of plant bacterial diseases was unacceptably high during the all three trials and believed to be related to crop management and other factors beyond our control. The level of disease incidence would have impacted adversely on percentage recovery at the processor.

Background

Lettuce grown for processing must meet several rigorous quality parameters. For example, processing lettuce heads must have an optimum density that is neither too loose nor too firm for the processing equipment to handle efficiently. Lettuce heads need to have good internal colour (not too white or too yellow) and need to be free, or nearly free, of internal blemishes such as tip burn and bacterial problems.

Careful selection of varieties matched to correct time of planting is essential. Timing of harvest is also critical to achieve optimum head density. Many potential problems such as bolting and uneven head size can be reduced in this way.

Lettuce grown for fresh market sale is often sold by volume, not weight. Processing lettuce, however, is trimmed of all excess outer leaves (the frame) and sold by weight. Therefore, crop yields in tonnes per hectare and percentage recovery are more critical for processing lettuce crops.

There is much scope to influence crop yield and quality outcomes in lettuce crops with well managed fertilizer application. High yielding crops are only achieved when adequate levels of plant nutrition are readily available early in plant life. In particular, lettuce plants require high levels of available nitrogen and phosphorus in the first two weeks after transplanting.

Lettuce crops that receive inadequate levels of nutrition or poorly applied fertiliser will often have one or more yield and quality disadvantages. They may grow more slowly and unevenly, produce smaller heads, have poorer colour and be more prone to stress related disorders such as tip burn. Well managed fertiliser regimes have the potential to promote vigorous growth. They also produce larger head sizes with smaller frames and more even crops. As a result higher yields and recovery rates are obtained.

Aims

1. To evaluate a range of commercially available lettuce cultivars for suitability in producing export and processing standard crops.
2. To investigate the potential of new fertiliser practices specifically developed to ensure rapid crop establishment and early growth in a commercial crop environment.
3. To provide a set of recommendations in variety selection and fertiliser application for growers considering the production of lettuce crops for export or processing markets.

Treatments

The work was conducted over three trials (or plantings) on one commercial property. Lettuce seed of several varieties was supplied to the grower in July. The grower produced sufficient seedlings of each variety in his own seedling nursery and allocated trial sites for three plantings.

All trial sites were prepared by the grower, using his customary fertiliser program, for that time of year. In each trial, small plots of between 450 to 1800 plants of seven varieties were transplanted into a site within the growers own commercial crop at the same time as his own commercial planting. This provided an opportunity for direct comparison of the trial planting with the commercial crop.

Table 9.1 contains details of lettuce variety and transplant dates.

Immediately prior to transplanting each trial, a soluble fertiliser drench in water was applied to batches of approximately half the available seedlings of each variety. All other experimental fertiliser applications made to the trial plots commenced after transplanting and were in addition to the grower's normal commercial application for that time of year.

Post transplanting fertilizer applications were made as either sprays or as side banded application or a combination of both, and were divided so that half of the applications were made to un-drenched seedlings and half made to drenched seedlings. In this way a matrix of eight fertiliser treatments were applied over each trial (Table 9.2.). Plots were marked out in each site so that individual treatment areas were clearly identifiable.

Table 9.1 Lettuce variety and transplant date.

Trial 1. 5 September planted		Trial 2. 24 September planted		Trial 3. 13 October planted	
Lettuce cultivar (seed company)	Plant no.	Lettuce cultivar	Plant no.	Lettuce cultivar	Plant no.
Jefferson (Lefroy Valley)	1750	Jefferson	450	Jefferson	900
Kingsway (Lefroy Valley)	1800	Kingsway	450	Kingsway	940
Toronto (Rijk Zwaan)	1650	Toronto	450	Toronto	800
Brisbane (Rijk Zwaan)	1650	Brisbane	450	Brisbane	900
Silverado (South Pacific)	720	Silverado	450	Silverado	800
Lindy (South Pacific)	1650	Lindy	450	Lindy	800
Marksman (Terra-Nova)	1220	Marksman	450	Pistol (Terra-Nova)	540
Magnum (Terra-Nova) (growers own crop)		Magnum (growers own crop)		Magnum (growers own crop)	

Table 9.2 Pre and post transplant fertiliser treatments

Treatment	Comment
1. Un-drenched (nil)	Control treatment. Plants received grower fertiliser application only.
2. Un-drenched plus sprays	Applications of one or more sprays of soluble fertiliser commencing after transplanting.
3. Un-drenched plus banding	Application of a single side dressing of mineral fertiliser 14 days after transplanting.
4. Un-drenched plus sprays plus banding	Applications of one or more sprays plus one side dressing 14 days after transplant.
5. Drench only	Seedlings received soluble fertiliser drench just prior to transplanting.
6. Drench plus sprays	Seedling drench plus one or more sprays of soluble fertiliser applied after transplanting.
7. Drench plus banding	Seedling drench plus single side dressing of mineral fertiliser 14 days after transplanting.
8. Drench plus sprays plus banding.	Seedling drench plus one or more sprays plus one side dressing 14 days after transplanting.

Table 9.3 (below) details the dates on which each fertiliser treatment was applied.

Table 9.3 Fertiliser treatment schedule

Fertiliser treatments and application dates	Trial 1. (transplanted 5 Sept.)	Trial 2. (transplanted 24 Sept.)	Trial 3. (transplanted 13 Oct.)
Seedling drench	5 September	24 September	13 October
Fertiliser spray application 1	5 September	25 September	16 October
Fertiliser spray application 2	8 September	1 October	20 October
Fertiliser spray application 3	10 September	3 October	24 October
Fertiliser spray application 4	12 September	8 October	
Fertiliser spray application 5	15 September		
Fertiliser spray application 6	17 September		
Fertiliser side banding	19 September	8 October	27 October

Materials and methods

Seedling drenches

A solution of technical grade potassium nitrate (KNO_3) in irrigation water (40 g/L) was prepared on site and applied by watering can to trays of lettuce seedlings (500 mL per 100 seedlings) just prior to transplanting. At each time of planting about half of the available seedlings were treated with the drench.

Fertiliser sprays

Fertiliser solutions were made up on site with pre weighed fertiliser and the same irrigation water used by the grower and applied to marked plots. Sprays were KNO_3 at 20 kg/ha plus LBU at 22.5 kg/ha. Spray volumes were 1000 L/ha which required two passes over a plot with a single fan jet knapsack sprayer at 200-300 kPa pressure. Spray applications were made to plots every two to four days and solutions were not washed off the foliage until the next scheduled irrigation.

Fertiliser top-dressing

Fertiliser top-dressing by banding was applied 14 days after transplanting of each crop. Applications were of prilled KNO_3 at 500 kg/ha banded by hand between pairs of rows of plants on a 4 row bed.

Crop Management

The site soil type was Bassendean sand.

Trials were transplanted by hand with seedlings from trays into prepared 1.6 m wide four row beds. In row plant spacing was 35 cm. A bay of lettuce (between sprinkler lines) contained seven beds. Irrigation was applied with overhead impact sprinklers spaced at 12 m by 12 m. The grower followed typical commercial fertiliser practice at the site with pre-plant preparation and post plant applications. The trial fertiliser applications were applied over the top of the growers program. The grower's program included a broadcast application of around 70 cubic meters per hectare of deep litter poultry manure applied within one week before planting. This treatment probably limited the magnitude of the response to treatments that we tested.

Weather data was not specifically recorded but was typical spring weather for this region with cool nights and warm to hot fine, clear days.

Data Recording

Visual assessment

All plots were inspected regularly from 8 September. Assessments and observations for growth response, adverse or phytotoxic effects were made on the same day as the spray fertiliser application. An assessment of disease problems and other quality factors was also made at harvest time.

Fertiliser application

All application amounts, dilutions and dates were recorded for all plots.

Leaf sampling

Plant sampling was not undertaken on this work.

Harvest

At harvest, mature heads were cut, trimmed of frame leaves, weighed individually and counts per plot taken. The number and weight of heads required to fill a crate was also recorded and any additional lettuce were weighed and recorded separately. In some cases, there were not enough marketable heads to fill a crate.

Results

The harvest period for each trial extended over several days because of the differing maturity times of the varieties. The first harvest (Trial 1) commenced on 27 October and the last harvest (Trial 3) was completed on 28 November. The crop life for each trial was therefore: Trial 1, 53-60 days, Trial 2, 48-52 days and Trial 3, 45-47 days.

Selected samples of each variety were sent to the processor for appraisal soon after each harvest.

First trial

At the time of the second spray on 8 September some spotting and staining was noted on about 80 Brisbane plants (one tray only) at the eastern end of the site. On 10 September, the drenched plants appeared to be slightly greener and bigger than the un-drenched plants. A slight marginal scorch was noted on the sprayed Magnum plants on 12 September. By the time of the last spray, those plants were bigger, greener and more leathery looking compared to the unsprayed plants. At the final inspection prior to harvest (8 October), the drenched plants were still slightly bigger in all cases than the un-drenched and the sprayed plants were slightly greener and bigger than the unsprayed and also noticeably prostrate.

The plants were harvested between 27 October and 3 November. Jefferson matured first, Lindy performed poorly and was harvested last. Table 9.4 summarises the mean head weights for each variety and treatment. Magnum and Marksman had the highest mean head weights but they also had a large percentage of unmarketable heads (< 300 g) and hence a poor percentage cut, reducing the total yield. Jefferson, Kingsway and Silverado had slightly lower head weights but were much more consistent and therefore yields were good (see Table 9.14). Both Toronto and Brisbane were lighter but there were differences in plant maturity since it was not possible to harvest all varieties at their optimum time. For this reason, the analyses concentrate on treatment differences rather than variety.

Table 9.4 Mean head weights (g) variety x fertiliser treatment for Trial 1. (5 September)

Variety	Fertiliser treatment							
	Drench	Drench + band	Drench + spray	Drench + spray + band	No drench	No drench + band	No drench + spray	No drench + spray + band
Brisbane	642.2	710.2	785.2	794.3	669.5	720.9	759.3	728.0
Jefferson	821.1	856.9	858.8	835.5	712.5	694.0	785.3	802.8
Kingsway	802.2	797.2	846.8	919.8	704.3	719.1	831.4	822.0
Lindy	587.6	573.6	679.5	599.0	540.0	655.2	612.0	705.2
Magnum	802.7	919.1	908.1	936.1	725.4	865.6	937.7	846.5
Marksman	904.1	811.1	867.9	1052.7	710.6	778.4	729.6	866.5
Silverado	739.5	883.0	858.1	877.2	664.3	744.3	851.9	855.3
Toronto	682.7	743.8	735.3	781.3	647.2	720.7	748.6	775.3

Statistical analysis

Two statistical analyses were done. The first included all data, the second excluded the poorly performing varieties (Magnum, Marksman and Lindy). REML was used because of the uneven reps.

1. All data

This was given a log transformation as the data was not normally distributed. Highly significant effects were found for all main effects (variety, spray, drench and band). Also for variety x spray x band. The variety x drench interaction was close to significance.

2. Restricted data

With three varieties that performed poorly and were highly variable, excluded from the analysis, the data proved to have a normal distribution so no transformation was needed. This time there was no effect of variety but there were main effects of spray, band and drench ($p<0.001$). The interaction between spray and band approached significance as did that between spray and drench (both $p<0.01$).

Table 9.5 Mean head weights (g) for selected treatments (poor performing varieties excluded) (Trial 1)

Treatment contrast	Treated	Untreated
Drench versus not drenched	799.4	747.3
Banded versus unbanded	788.6	758.1
Spray versus unsprayed	812.8	734.0

Note: Treated = Drenched or Banded or Sprayed

Table 9.6 Mean head weights (g) for spray x drench treatments (Trial 1)

	Drench	Undrench
Spray	830.1	795.4
Unsprayed	768.7	699.2

Table 9.7 Mean head weights (g) for spray x band treatments (Trial 1)

	Band	Unbanded
Spray	817.5	808.1
Unsprayed	759.8	708.2

Second trial

At each spray, the drenched plants appeared to be slightly greener and bigger than those not drenched. Two weeks after transplanting, all sprayed plants were slightly bigger and greener than unsprayed plants and noticeably prostrate.

At the time of harvest, Kingsway was the heaviest variety, recording the highest mean head weights in seven out of the eight treatments. Magnum was unavailable for harvest in the trial plots, however sample heads were harvested from the grower's own crop for quality evaluation and assessment by the processor. Table 9.14 displays yields in t/ha for each variety and harvest.

Table 9.8 Mean head weights (g) variety x fertiliser treatment (Trial 2)

Variety	Fertiliser treatment							
	Drench	Drench + band	Drench + spray	Drench + spray + band	No drench	No drench + band	No drench + spray	No drench + spray + band
Brisbane	802.9	914.8	883.0	916.5	765.9	760.0	834.5	816.4
Jefferson	793.5	872.8	786.2	807.7	754.1	770.0	768.3	736.7
Kingsway	997.4	1034.0	916.1	868.3	900.0	890.0	975.6	923.0
Lindy	767.9	801.4	752.7	797.3	732.5	714.5	721.4	766.0
Marksman	888.2	894.2	858.6	895.2	801.7	778.4	714.5	778.0
Silverado	941.9	940.4	896.4	915.7	745.2	850.5	806.5	812.9
Toronto	674.1	695.5	744.8	673.3	600.4	603.0	653.7	637.5

Statistical analysis

There was only one rep for this harvest. The data followed a normal distribution. REML was used due to the uneven numbers of reps. The only significant effects were the main effects of variety and drench (Table 9.9).

Table 9.9 Mean head weights (g) for selected treatments (Trial 2)

Treatment contrast	Treated	Untreated
Drench versus not drenched ($p<0.001$)	847.2	771.8
Banded versus unbanded (n.s.)	816.5	802.5
Spray versus unsprayed (n.s.)	808.6	810.4

Third trial

At each spray, the drenched plants appeared to be slightly bigger and greener than undrenched plants. Sprayed plants also appeared to have a slight size advantage over unsprayed plants. At harvest, Lindy was again the worst performer.

Table 9.10 Mean head weights (g) (variety x fertiliser treatment) for trial 3. (13 October)

Variety	Fertiliser treatment							
	Drench	Drench + band	Drench + spray	Drench + spray + band	No drench	No drench + band	No drench + spray	No drench + spray + band
Brisbane	788.8	808.1	752.6	787.0	683.1	703.8	711.9	739.6
Jefferson	956.8	934.0	901.2	819.3	905.5	913.1	895.9	765.2
Kingsway	940.2	919.8	920.0	976.0	848.3	854.0	863.3	879.3
Lindy	706.7	694.7	661.6	608.3	556.0	553.3	619.1	524.1
Magnum	747.9	819.8	879.4	825.8	683.5	731.8	786.2	834.4
Pistol	682.9	717.2	719.2	745.2	627.8	657.4	668.9	701.4
Silverado	867.2	844.1	858.7	814.4	845.1	777.0	741.2	726.2
Toronto	842.2	769.4	829.1	790.4	733.3	655.2	836.8	731.3

Statistical analysis

Again there was only one rep but plots were twice the size of previous plantings. The data was normally distributed. REML was used due to the uneven rep sizes. Head counts were all roughly the same so no second analysis was done to eliminate poorly performing varieties. Again Kingsway was the heaviest variety, closely followed by Jefferson.

There were highly significant main effects of variety and drench. There were also highly significant interactions between variety x spray and variety x band. Spray x drench and variety x spray x band approached significance ($p < 0.008$ and $p < 0.005$ respectively).

Table 9.11 Mean head weights (g) for selected treatments (Trial 3)

Treatment contrast	Treated	Untreated
Drenched versus not drenched	810.3	742.3
Banded versus unbanded	769.4	783.1
Sprayed versus unsprayed	778.5	774.0

Table 9.12 Mean head weights (g) for variety x spray treatments (Trial 3)

Variety	Spray	Unsprayed
Brisbane	747.8	746.0
Jefferson	845.4	927.3
Kingsway	909.7	890.6
Lindy	603.3	627.7
Magnum	831.4	745.7
Pistol	708.7	671.4
Silverado	785.1	833.4
Toronto	796.9	750.0

Table 9.13 Mean head weights (g) for variety x band treatments (Trial 3)

Variety	Banded	Unbanded
Brisbane	759.6	734.1
Jefferson	857.9	914.9
Kingsway	907.3	892.9
Lindy	595.1	635.8
Magnum	803.0	774.2
Pistol	705.3	674.7
Silverado	790.4	828.1
Toronto	736.6	810.3

Table 9.14 Total plot weights converted to yield (t/ha) for each harvest x variety

Variety	Trial Number		
	1	2	3
Brisbane	40.92^{d}	52.58^{a}	46.35^{c}
Jefferson	48.80^{a}	49.32^{a}	52.77^{ab}
Kingsway	46.90^{abc}	48.03^{ab}	55.79^{a}
Lindy	17.23^{f}	43.75^{bc}	36.48^{d}
Magnum	34.48^{e}		51.83^{ab}
Marksman	34.51^{e}	47.01^{ab}	
Silverado	47.00^{ab}	51.82^{a}	48.42^{bc}
Toronto	45.76^{abc}	40.61^{c}	48.19^{bc}
Pistol			40.23^{d}

Note: Numbers followed by the same letter are not significantly different from each other ($p<0.05$).

Discussion

Quality issues

The disease issues discussed below were believed unrelated to the fertiliser treatments used in the trials. It is our belief that the crop was watered to excess and this, in combination with warm to hot weather conditions, resulted in an environment that was highly conducive to the development of disease problems. However, the relative incidence of disease problems indicated that there were differences in susceptibility between varieties.

First trial

The first harvest was notable for the high level of bacterial problems and other quality issues that were observed in the field and at the processor. Lettuce heads that have high levels of blemishes require much more grading on the production line and throughput slows considerably as a result. Good crop management combined with precise fertiliser application and careful variety selection can minimise these problems.

Marksman and Magnum were the worst varieties in terms of quality issues. They both tended to be misshapen (lopsided) and had high incidence of bacterial rot, jelly butt and varnish spot. They produced uneven crops with large percentages of small and un-hearted heads.

Lindy produced a very poor crop with most heads unmarketable (small) or un-hearted. Lindy also was badly affected by bacterial rots, varnish spot and leaf mid-rib staining.

Toronto, Silverado, Brisbane and Jefferson all produced reasonable quality crops with only small numbers of unmarketable heads and lower levels of bacterial problems and varnish spot.

Kingsway produced a reasonable crop with a few small and unhearted lettuce but was downgraded because of an unacceptably high incidence of mid-rib browning or brown vein.

Second trial

Lindy again produced a very poor crop with a lot of unmarketable heads and high incidence of brown vein and tip burn.

The quality of Marksman and Magnum had improved somewhat over trial one with lower levels of bacterial rots and brown vein. Marksman was still a bit lopsided and was large, leafy and thick stemmed.

Toronto, Brisbane and Jefferson produced good lettuce with lower levels of brown vein and varnish spot. Silverado was to some extent downgraded because it was slightly lopsided and had some brown vein.

Kingsway was again affected with high levels of brown vein.

Third trial

The third harvest produced the best result in terms of lettuce quality. There was generally less bacterial problems and fewer blemishes overall.

The variety Pistol replaced Marksman in this trial. Pistol produced reasonable quality lettuce but head weights and harvest yields were a bit low. Magnum produced good quality but was downgraded a little because of mild incidence of tip burn.

Lindy was the worst performer, producing a very uneven crop with lots of brown vein.

Toronto, Brisbane and Silverado all produced good lettuce with lower levels of varnish spot and bacterial problems. Jefferson also produced good lettuce but was downgraded a little because it had just started to bolt.

Maturity and harvest spread

In this set of trials, harvest periods had to be timed to minimise disruption to the grower. It was not always possible to harvest varieties at their optimum maturity. The number of varieties and the spread of maturities meant that, on occasion, some varieties were harvested beyond their optimum maturity.

Apart from this constraint, it was also apparent that some varieties were extremely variable in terms of their individual spread of maturity. Table 15 shows the percent marketable for each variety and trial. Generally, the varieties that produced good percentage picks were less variable in their maturity times and coincidentally produced more even crops. It should be noted however, that some varieties that have poor recovery (low marketable percentages) do not "improve" with time. That is, if a variety has poor crop uniformity near harvest time, the smaller plants do not catch-up and un-hearted plants do not fill out.

This phenomenon can have acute implications for the production of lettuce for processing. Low marketable percentages result in poor yields per hectare and therefore reduced profitability. Over all three trials, Lindy and Marksman performed the worst, producing only 72-74% marketable overall. Brisbane, Jefferson, Silverado and Toronto all had around 90% marketable. These results are reflected in the yield per hectare data (Table 9.14).

Table 9.15 Percent pick for each variety x trial and mean for all trials

	Trial 1	Trial 2	Trial 3	Mean
Brisbane	88.0	94.0	93.0	91.7
Jefferson	96.1	94.0	89.5	93.2
Kingsway	89.7	77.0	93.0	86.6
Lindy	43.2	86.5	89.0	72.9
Magnum	61.7		98.8	80.2
Marksman	64.3	85.5		74.9
Silverado	90.6	90.0	89.8	90.1
Toronto	94.1	92.5	93.5	93.4
Pistol			87.0	87.0

Fertiliser treatments

In all three trials the seedling fertiliser drench treatment produced a clear benefit in yield (see Figure 9.1).
A potassium nitrate drench at transplanting will provide at least an extra 50g of head weight at harvest time. This translates into a yield improvement of about 3 t/ha.

The benefits of sprays or band treatment (or both) are not as clear. For the first trial, both main effects of spray and of band were significant, but not for trials two and three. Interestingly, also for the first trial, the effect of sprays (whether drenched or un-drenched) significantly increased head weights. This was not the case for the subsequent two trials, where spraying did not significantly increase head weights in either case. It should be noted that trial one was slower growing and received more sprays than the other two trials

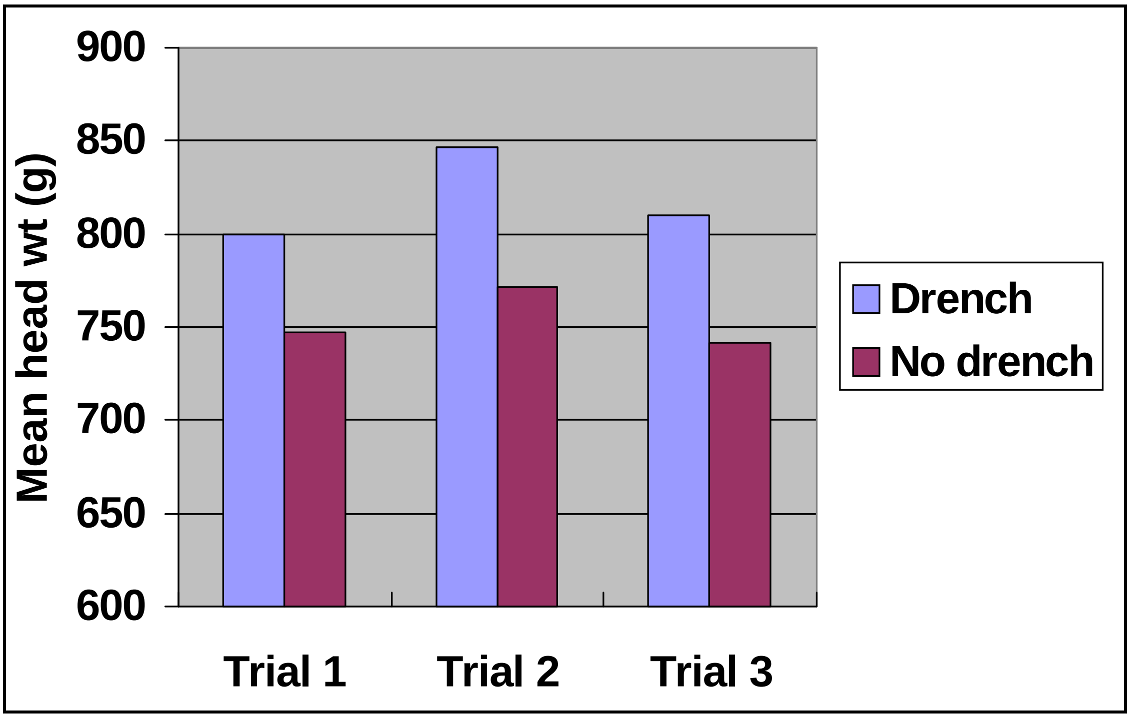


Figure 9.1 **Comparison of lettuce head weights with or without preplant drench over three monthly plantings (average of all varieties).**

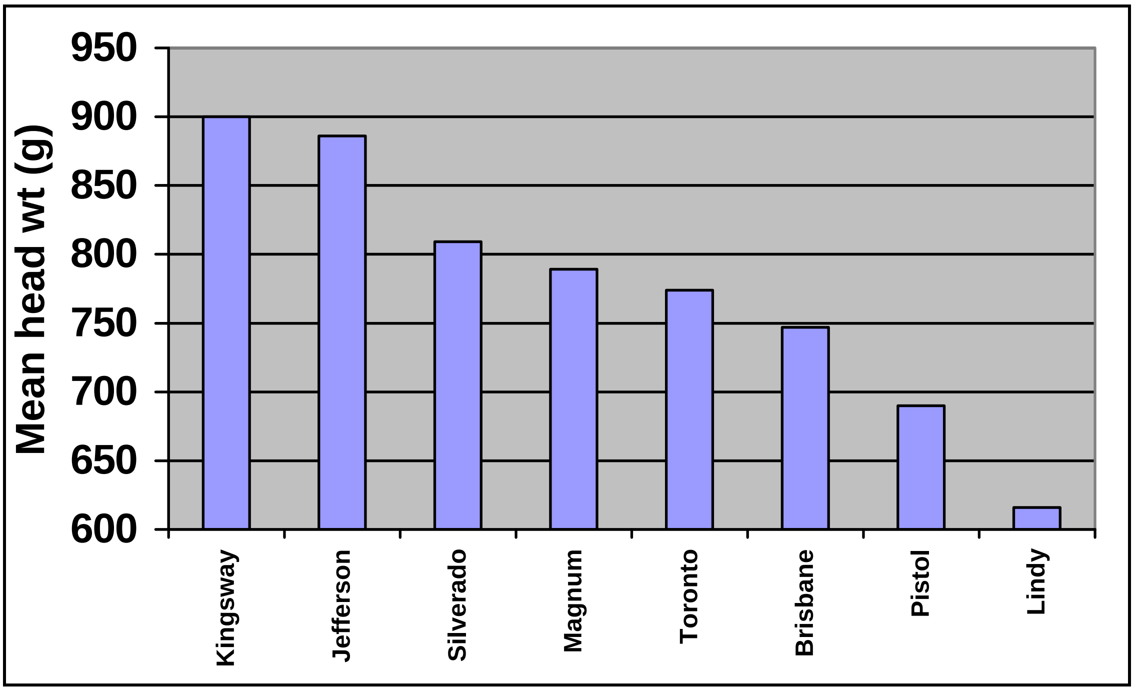


Figure 9.2 **Comparison of average lettuce head weight for the third trial.**

Conclusions

The varieties Kingsway, Jefferson, Brisbane, Toronto and Silverado all proved suitable for transplanting in the Perth region from early September to mid October. The variety Pistol was satisfactory if planted in mid October.

Consistent yield increases of the order of 3 tonnes per hectare of processing quality lettuce were achieved for all varieties by drenching seedlings at planting time with a solution of potassium nitrate at 40 grams per litre and 5 mL per seedling. This equates to only 12 kg/ha of potassium nitrate or 1.56 kg/ha of nitrogen (N).

This practice compares very favourably with traditional practice of applying poultry manure pre planting on economic and environmental grounds. For a cost of approximately $12 of fertiliser and possibly $40 in labour, this treatment will return more than $2000 in extra return from marketable lettuce. The nitrogen loss to the environment is estimated to be no more than 1 kg/ha (N).

By contrast, 70 cubic metres per hectare of poultry manure applied to the trial crops before planting was not able to produce this yield increase for a cost of around $1000 per hectare and a potential nitrogen loss of around 500 kg/ha (N) to the environment and 150 kg/ha of phosphorus (P).

CASE STUDY 2: FERTILISER STRATEGIES FOR ICEBERG LETTUCE AT GIN GIN, MAY TO AUGUST

Summary

Four fertilizer treatments were compared with a grower control on a commercial property at Gin Gin from a late May planting. The results showed that the drench/spray/band treatments using the standard rate of spraying were equally as good as the grower control, and there was no advantage from banding potassium nitrate at day 22 compared to DAP at the same date. Spraying LBU at double the standard rate and half the frequency combined with DAP banding to row closure gave lower yields than the standard spray treatment combined with ammonium nitrate banding to row closure. The grower could not be convinced to change his fertilizer practice thereafter because no yield benefit could be demonstrated from drench/spray/band at this time of year. More work needs to be done to refine the technique for growing winter lettuce.

Background

The drench/spray/band technique developed for iceberg lettuce was found to be a suitable substitute for fertilizer programs based on poultry manure pre-planting and post-planting applications. Poultry manure is banned for use in Gin Gin Shire because it breeds stable flies which are injurious to livestock, and grazing is a major enterprise in the Shire. There was a need to demonstrate that the drench/spray/band technique could be a suitable substitute for fertilizer based programs used by growers. These programs are often wasteful of fertiliser because placement, rate and timing of granular applications can be inappropriate in the crop establishment phase in winter when rainfall is frequent and unpredictable.

Aims

To demonstrate that the drench/spray/band technique can be as effective or better than traditional fertilizer practices for iceberg lettuce planted in winter in Gin Gin.

Treatments

There were two demonstrations of fertilizer treatments at the Gin Gin site, with plantings on May 27 and July 27. The cultivar Oxley was planted in May. The May 27 planting is reported hereunder.

Treatments for the May planting were as follows:

T1 = Grower control

Pre-plant: Muriate of potash at 120 kg/ha two weeks pre-plant (No poultry manure.)

Fertigation:	Ammonium nitrate	26 kg/ha weekly from planting to harvest
	LBU	25 kg/ha weekly from planting to harvest
	MAP	14 kg/ha weekly from week six
	$MgSO_4$	20 kg/ha weekly from planting to harvest
	K_2SO_4	50 kg/ha at weeks 6 and 7
	Trace element mix	every 2 weeks
Banding:	Potato E®	200 kg/ha just after planting.
	Nitrophoska Blue Special®	200 kg/ha at week 4.
Spreading:	Sulphate of Potash	50 kg/ha at weeks 1, 2 and 3.

T2 = Drench/spray plus banding potassium nitrate and Ammonium nitrate

Pre plant as for grower control.

All seedlings drenched with potassium nitrate at 40 grams/litre potassium nitrate at 500ml per 100 seedlings.

Spraying with LBU 22.5 g/l plus 20 g/l of potassium nitrate at days 1,4,8,12,15,18 and 22 after transplanting.

Banded application of potassium nitrate at 300 kg/ha on day 22 after transplanting followed by ammonium nitrate at 120:20:120 kg/ha on days 29, 36 and 43 after transplanting respectively.

T3 = Drench/spray plus banding DAP and ammonium nitrate

Pre plant as for grower control.

All seedlings drenched with potassium nitrate at 40 grams/litre potassium nitrate at 500ml per 100 seedlings.

Spraying with LBU 22.5 g/l plus 20 g/l of potassium nitrate at days 1,4,8,12,15,18 and 22 after transplanting.

Banded application of DAP at 223 kg/ha on day 22 after transplanting followed by ammonium nitrate at 120:20:120 kg/ha on days 29, 36 and 43 after transplanting respectively.

T4 = Drench/double rate spray plus banding potassium nitrate and DAP

Pre plant as for grower control.

All seedlings drenched with potassium nitrate at 40 grams/litre potassium nitrate at 500ml per 100 seedlings.

Spraying with LBU 50 g/L on days 1, 8 and 15 after transplanting.

Banded application of potassium nitrate at 300 kg/ha on day 22 after transplanting followed by DAP at 230:40:230 kg/ha on days 29, 36 and 43 after transplanting respectively.

T5 = Drench/double rate spray plus banding DAP

Pre plant as for grower control.

All seedlings drenched with potassium nitrate at 40 grams/litre potassium nitrate at 500 mL per 100 seedlings.

Spraying with LBU 50 g/L on days 1, 8 and 15 after transplanting.

Banded application of DAP at 223 kg/ha on day 22 after transplanting followed by DAP at 230:40:230 kg/ha on days 29, 36 and 43 after transplanting respectively.

Materials and methods

All plots consisted of 100 plants sited within a commercial crop with plants spaced at 35cm x 38cm. Fertiliser sprays were applied to the plots by knapsack and bandings were applied between pairs of rows in 4 row beds by hand.

Yields were assessed by harvesting and individually weighing 50 heads from each plot at a once over harvest on August 18.

Results

Mean head weight yields for the four treatments are shown in Table 9.16.

Table 9.16 Mean head weight yields for four fertilizer strategies compared to the grower control treatment (T1)

Fertiliser treatment	T1	T2	T3	T4	T5
Mean head weight (grams)	**509.4**	**520.6**	**517.0**	**489.6**	**426.2**

The demonstration was not replicated and therefore, no statistical treatments could be applied to the data. However the results suggested that both sprayed treatments, T2 and T3 gave at least equivalent yields to the grower treatment. Yields from T4 and T5 were relatively poorer than the others. The reason for this is unknown, but the yield depression may have been the result of double rate LBU spraying for the first 21 days of the crop's life or that the response to late bandings of DAP was not as good as ammonium nitrate in this growth phase.

Conclusions

The drench/spray/band treatments using the standard rate of spraying were equally as good as the grower control, and there was no advantage from banding potassium nitrate at day 22 compared to DAP at the same date. Spraying LBU at double the standard rate and half the frequency combined with DAP banding to row closure gave lower yields than the standard spray treatment combined with ammonium nitrate banding to row closure. The potential of the drench/spray/band treatment is limited in winter by the long maturity times of crops and weather factors often limiting yield, despite improved fertilizer practice.

CASE STUDY 3: FERTILISER STRATEGIES FOR ICEBERG LETTUCE AT GIN GIN, JULY TO OCTOBER

Summary

Three fertilizer treatments were compared with a grower control on a commercial property at Gin Gin from a late July planting. The results showed that a drench/spray/band treatment using a modified spray concentration was equally as good as the grower control. There was no yield loss associated with not applying a banded top-dressing at day 27, compared to ammonium nitrate or DAP at this date. The grower could not be convinced to change his fertilizer practice thereafter because no yield benefit could be demonstrated from drench/spray/band at this time of year. . More work needs to be done to refine the technique for growing winter lettuce.

Background

The drench/spray/band technique developed for iceberg lettuce was found to be a suitable substitute for fertilizer programs based on poultry manure pre-planting and post-planting applications. Poultry manure is banned for use in Gin Gin Shire because it breeds stable flies which are injurious to livestock, and grazing is a major enterprise in the Shire. There was a need to demonstrate that the drench/spray/band technique could be a suitable substitute for fertilizer based programs used by growers. These programs are often wasteful of fertiliser because placement, rate and timing of granular applications can be inappropriate in the crop establishment phase in winter when rainfall is frequent and unpredictable.

Aims

To demonstrate that the drench/spray/band technique can be as effective or better than traditional fertilizer practices for iceberg lettuce planted in winter in Gin Gin.

Treatments

There were two demonstrations of fertilizer treatments at the Gin Gin site, with plantings on 27 May and 27 July. The cultivar Oxley was planted in May and Marksman in July. The 27 July planting is reported hereunder.

Treatments for the July planting were as follows:

T1 = Grower control

Pre-plant: Muriate of potash at 120 kg/ha two weeks pre-plant (no poultry manure.).

Fertigation:	Ammonium nitrate	26 kg/ha weekly from planting to harvest
	LBU	25 kg/ha weekly from planting to harvest
	MAP	14 kg/ha weekly from week six
	$MgSO_4$	20 kg/ha weekly from planting to harvest
	Potassium sulphate	50 kg/ha at weeks 6 and 7
	Trace element mix	every 2 weeks
Banding:	Potato E®	200 kg/ha just after planting.
	Nitrophoska Blue Special®	200 kg/ha at week 4.
Spreading:	K_2SO_4	50 kg/ha at weeks 1, 2 and 3.

T2 = Drench plus modified spray regime plus potassium nitrate banding at day 26 (1st banding date)

Pre plant as for grower control.

All seedlings drenched with potassium nitrate at 40 grams/litre potassium nitrate at 500ml per 100 seedlings.

Spraying with LBU 15 g/L plus 40 g/L of potassium nitrate at days 1, 3, 6, 10, 13, 17, 20 and 24 after transplanting.

Banded application of potassium nitrate at 300 kg/ha on day 27 after transplanting followed by ammonium nitrate at 200:200:200 kg/ha on days 27, 34, 41 and 48 after transplanting respectively.

T3 = Drench plus modified spray regime plus DAP banding at day 27 (1st banding date)

Pre plant as for grower control.

All seedlings drenched with potassium nitrate at 40 grams/litre potassium nitrate at 500 mL per 100 seedlings.

Spraying with LBU 15 g/L plus 40 g/L of potassium nitrate at days 1, 3, 6, 10, 13, 17, 20 and 24 after transplanting.

Banded application of DAP at 217 kg/ha on day 27 after transplanting followed by ammonium nitrate at 200 kg/ha on days 27, 34, 41 and 48 after transplanting respectively.

T4 = Drench plus modified spray regime plus no banding at day 27 (1st banding date).

Pre plant as for grower control.

All seedlings drenched with potassium nitrate at 40 g/L potassium nitrate at 500 mL per 100 seedlings.

Spraying with LBU 15 g/L plus 40 g/L of potassium nitrate at days 1, 3, 6, 10, 13, 17, 20 and 24 after transplanting.

No top-dressing on day 27 after transplanting followed by ammonium nitrate banded at 200 kg/ha on days 27, 34, 41 and 48 after transplanting respectively.

Materials and methods

All plots consisted of 80 plants sited within a commercial crop with plants spaced at 35 cm x 38 cm. Fertiliser sprays were applied to the plots by knapsack and bandings were applied between pairs of rows in 4 row beds by hand.

Yields were assessed by harvesting and individually weighing 40 heads from each plot at a once over harvest on October 13.

Results

Mean head weight yields for the four treatments are shown in Table 9.17.

Table 9.17 Mean head weight yields for three fertilizer strategies compared to the grower control treatment (T1)

Fertiliser treatment	T1	T2	T3	T4
Mean head weight (grams)	**1014.5**	**1114.8**	**1183.5**	**1091.5**

The demonstration was not replicated and therefore, no statistical treatments could be applied to the data. However the results suggested that all treatments gave at least equivalent yields to the grower treatment. All treatments were damaged by wind about 14 days after planting and this is expected to have had a leveling effect on the yield potential of all treatments. At this stage of growth, the sprayed treatments were visibly greener than the grower control, but plants had a more prostrate growth habit.

Conclusions

The drench/spray/band treatments using a reduced concentration of LBU and double the concentration of potassium nitrate yielded as well as the grower control. There was no yield loss associated with not applying a banded top-dressing at day 27, compared to ammonium nitrate or DAP at this date. The potential of the drench/spray/band treatment is limited in winter by the long maturity times of crops and weather factors often limiting yield, despite improved fertilizer practice.

10. Recommendations

Seedling drenches

The seedling drench treatment, potassium nitrate at 40 g/L drenched over seedlings immediately before transplanting at a rate of 500 mL per 100 seedlings was tested in every trial in this sequence. Yield responses to this treatment varied from crop to crop and at different times of year for the same crop.

The drench proved most effective for summer iceberg lettuce where it enhanced yields when used in combination with banded top-dressings of ammonium nitrate and Spurt-N®. There may have been some benefit from this treatment in combination with some other spray and drench combinations for winter iceberg lettuce, but crop uniformity in this crop was poor and responses would need to be re-checked by further trial work.

No significant yield response could be shown from drenching for winter and summer Cos lettuce, winter broccoli, winter cauliflower or summer Chinese cabbage.

The seedling drench depressed yields slightly in both winter cabbage and autumn celery.

Sprays

Nitrogen based sprays applied for between 14 and 21 days after transplanting increased marketable and total yields of all crops tested, but the magnitude of the response differed from crop to crop. Sprays tested were selected from a set of five spray formulas for the series of crops tested but not all five treatments were tested in every crop.

The strongest responses to sprayed nitrogen were noted in winter cabbage and winter Cos lettuce with rates in excess of 6 sprays at 13 kg/ha of nitrogen per time required in the first 21 days after planting to maximize yield.

Yields were maximized for winter iceberg lettuce, winter broccoli and winter cauliflower with 6 sprays at between 10.4 and 13 kg/ha of nitrogen per time in the first 21 days after planting. Small increases in yield may have been possible beyond these levels for cauliflower and broccoli but higher rates were not tested.

Highest yields for autumn celery and summer Cos lettuce were achieved with 6 sprays at between 10.4 and 13 kg/ha of nitrogen per time in the first 14 days after planting. However, these high spray rates were associated with higher levels of tip burn in Cos lettuce.

Spray rates as low as 5.2 kg/ha of nitrogen per time applied 4 times in 14 days was sufficient to maximize yield for summer Chinese cabbage, but a theoretical optimum of 8.8 kg/ha per time was calculated for this crop. Summer iceberg lettuce yields were maximized at the 5.2 kg/ha rate for summer iceberg lettuce, but a theoretical optimum of 9.4 kg/ha of nitrogen per time was calculated for this crop.

Sprayed nitrogen was supplied in two different forms, potassium nitrate (S2) vs LBU (S3) at the same rate of nitrogen (5.2 kg/ha N per time) in six of the trials. There was no difference in yield between the two of these for winter cabbage, autumn celery, winter Cos, summer Cos and winter iceberg. In the only other crop where this comparison was made, winter iceberg, there were some small differences between these two spray sources in combination with particular drench and banding combinations. The inference from this finding is that the yield response from spraying is not affected by the form that the nitrogen is supplied in. LBU is generally believed to have better foliar absorption than potassium nitrate, so the other conclusion that could be drawn is that most of the plant response from spraying was derived from soil uptake not foliar.

Banded top-dressing to 'row closure'

Four banded top-dressing treatments were compared in most of the trials, these being ammonium nitrate, LBU, Nitrophoska Blue Special® and Spurt-N®. The exceptions were autumn celery where Nitrophoska Perfekt® was used instead of Nitrophoska Blue Special® and a reduced rate of ammonium nitrate was used instead of Spurt-N® and Chinese cabbage where additional top-dressings with calcium nitrate were applied beyond row closure on the Nitrophoska Blue Special® plots. All top-dressing products that supplied nitrogen only were supplemented by additional top-dressings with potassium nitrate at pre determined intervals.

No yield differences could be shown between the four top-dressing treatments for winter broccoli, summer Chinese cabbage, summer Cos lettuce and winter cauliflower in combination with the highest rate of sprayed nitrogen. Of these, ammonium nitrate was associated with lower levels of tip burn in Cos lettuce. LBU was always the most cost effective treatment where yields were not different, but Nitrophoska Blue Special® though more expensive to buy, offered the potential for time and labour savings from only having to spread one product throughout the life of the crop.

Summer and winter iceberg lettuce both gave highest yields with ammonium nitrate and Spurt-N®. These products yielded best in combination with the seedling drench for summer iceberg, and at the two highest spray rates. Winter Cos lettuce yielded best when top-dressed with Spurt-N® in combination with the two highest spray rates.

Winter cabbage gave highest yields when top-dressed with Nitrophoska Blue Special® but there was a clear need in this crop for further top-dressing beyond row closure.

Autumn celery gave highest yields when top-dressed with Nitrophoska Perfekt® or LBU but there was possibly a need in this crop for further top-dressing beyond row closure.

Other factors

Potassium deficiency symptoms were noted in some treatments in the winter broccoli trial close to harvest. These symptoms did not reduce marketable yields, but tissue tests showed that the critical level for potassium in leaf blades is probably around 1.2% and 2.5% in petioles on a dry weight basis. In fresh petiole sap the critical level is around 1400 mg/L of K. The reason for the potassium deficiency is that only one top-dressing application of potassium nitrate was given to this crop up to row closure.

Winter cauliflower exhibited symptoms of mild potassium deficiency, phosphorus toxicity and an unknown floret browning symptom in some plots. Tissue tests determined that the P toxicity symptoms usually occurred when the P level in leaf blades exceeded 1% on a dry weight basis and 0.5% in the petioles. The critical level for K in cauliflower was around 0.86% in leaf blades and 1.3% in petioles on a dry weight basis. The cause of floret browning could not be determined, but it was minimized where LBU was used as the top-dressing fertilizer.

Further research work on fertilizer requirements beyond row closure is required for all the winter crops as well as autumn celery and summer Chinese cabbage. More work also needs to be done on relationships between fertilizer treatments, timing of harvest and tip burn in Cos lettuce in both winter and summer.

11. Acknowledgments

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Appendix 1. Temperature, rainfall and evaporation records for Medina research station for the duration of the trial

Date	Minimum temp (degrees C)	Maximum temp (degrees C)	Rainfall (mm)	Evaporation (mm)
01-May-05	17.4	22.2	1.6	1.5
02-May-05	17.9	27.3	41	3.6
03-May-05	17.5	23.3	4.6	2
04-May-05	12.6	21.7	0.2	2.4
05-May-05	11.8	21.2	1	2.4
06-May-05	9.2	21.2	0.2	3.6
07-May-05	12.9	22.1	0	3.7
08-May-05	14.1	22.7	0	3.3
09-May-05	18.4	27.6	0	4.4
10-May-05	20.0	28.6	0	4.8
11-May-05	17.2	29.4	0	3.0
12-May-05	17.5	22.0	6.0	1.1
13-May-05	13.5	22.4	11.4	2.2
14-May-05	13.9	21.5	7.2	2.2
15-May-05	15.1	23.7	0.2	3.1
16-May-05	17.2	20.3	36.4	0.6
17-May-05	12.9	20.5	0	2.8
18-May-05	11.3	22.4	0	3.2
19-May-05	14.7	19.3	63.4	0.4
20-May-05	13.1	21.7	0.4	3.5
21-May-05	15.9	22.9	0.2	2.8
22-May-05	13.0	21.3	9.4	1.0
23-May-05	110	23.2	0.2	2.9
24-May-05	8.3	19.0	0	1.6
25-May-05	9.3	18.8	0	3.2
26-May-05	15.6	22.6	0	3.9
27-May-05	15.0	25.4	0	3.7
28-May-05	14.4	25.6	0	3.9
29-May-05	13.1	23.6	0	2.4
30-May-05	13.0	28.4	0	3.8
31-May-05	15.1	22.5	0	2.7
01-Jun-05	14.2	19.4	0	2.4
02-Jun-05	15.4	21.7	0	3.1
03-Jun-05	14.0	20.6	5.2	1.5
04-Jun-05	14.8	20.9	2.4	1.2
05-Jun-05	10.6	20.7	0	1.5

Date	Minimum temp (degrees C)	Maximum temp (degrees C)	Rainfall (mm)	Evaporation (mm)
06-Jun-05	10.8	21.8	0	1.9
07-Jun-05	11.3	20.2	33.2	1.1
08-Jun-05	14.8	19.0	6.8	2.5
09-Jun-05	13.3	20.7	12.2	2.6
10-Jun-05	9.1	15.2	35.6	1.4
11-Jun-05	12.0	16.4	9.4	2.0
12-Jun-05	8.6	14.8	9.4	2.4
13-Jun-05	4.7	10.7	14.6	0.5
14-Jun-05	4.8	14.8	0	1.6
15-Jun-05	7.7	17.7	0	1.3
16-Jun-05	11.2	17.2	1.4	1.2
17-Jun-05	9.1	12.2	22.0	0.2
18-Jun-05	6.4	17.0	7.4	1.1
19-Jun-05	6.5	15.5	3.0	2.4
20-Jun-05	3.3	15.5	0.2	2.2
21-Jun-05	2.4	15.3	0	1.3
22-Jun-05	7.5	17.0	0	2.6
23-Jun-05	9.9	19.0	27.2	3.1
24-Jun-05	10.7	17.0	6.8	1.6
25-Jun-05	11.3	17.3	7.8	1.1
26-Jun-05	10.0	16.7	1.6	1.1
27-Jun-05	5.7	20.6	0	2.7
28-Jun-05	6.6	21.1	0	2.9
29-Jun-05	9.9	20.7	0	3.3
30-Jun-05	12.2	17.1	10.4	1.1
01-Jul-05	5.1	17.1	2.8	2.1
02-Jul-05	7.3	17.6	0	1.4
03-Jul-05	9.4	19.2	0	2.7
04-Jul-05	12.3	19.2	4.4	2.3
05-Jul-05	7.3	15.3	6.0	1.9
06-Jul-05	0.7	14.5	0	1.7
07-Jul-05	0.6	14.1	0.2	2.2
08-Jul-05	0.6	15.2	0	2.6
09-Jul-05	5.5	16.1	0	2.8
10-Jul-05	8.3	17.6	0	3.6
11-Jul-05	5.0	17.9	0	3.3
12-Jul-05	0	16.8	0	2.7
13-Jul-05	9.9	17.3	16.2	3.1

Date	Minimum temp (degrees C)	Maximum temp (degrees C)	Rainfall (mm)	Evaporation (mm)
14-Jul-05	9.1	17.2	4.6	2.4
15-Jul-05	11.3	18.0	7.4	1.3
16-Jul-05	8.0	18.3	1.6	1.7
17-Jul-05	2.3	16.7	0	2.1
18-Jul-05	2.3	18.2	0	2.6
19-Jul-05	6.9	21.2	0	3.1
20-Jul-05	9.7	23.0	0	3.6
21-Jul-05	12.1	21.7	21.6	3.2
22-Jul-05	7.8	16.3	0	2.1
23-Jul-05	9.5	17.6	3.6	2.5
24-Jul-05	10.3	17.4	0.4	1.4
25-Jul-05	12.9	17.5	2.0	1.2
26-Jul-05	10.3	20.2	0	2.0
27-Jul-05	7.4	20.9	0	2.9
28-Jul-05	12.9	21	0.4	3.1
29-Jul-05	9.8	18.7	0	2.0
30-Jul-05	7.4	18.1	0	1.6
31-Jul-05	4.3	18.9	0.2	2.9
01-Aug-05	4.0	18.7	0	3.0
02-Aug-05	10.4	24.3	10.6	3.3
03-Aug-05	5.9	15.9	10.0	2.3
04-Aug-05	9.3	16.2	0	2.2
05-Aug-05	8.9	17.5	1.2	1.8
06-Aug-05	8.3	17.7	0.8	1.8
07-Aug-05	7.7	18.4	0	2.0
08-Aug-05	5.8	19.9	0	3.1
09-Aug-05	5.4	19.6	0	3.2
10-Aug-05	8.9	21.2	4.0	3.3
11-Aug-05	5.7	17.8	0.6	2.3
12-Aug-05	7.9	21.1	0	3.5
13-Aug-05	12.9	17.5	15.2	1.2
14-Aug-05	9.6	16.7	6.8	2.7
15-Aug-05	11.2	15.7	0	2.3
16-Aug-05	9.9	17.6	7.0	2.5
17-Aug-05	8.6	14.6	27.4	1.4
18-Aug-05	5.2	12.0	24.8	0.7
19-Aug-05	1.1	14.6	0	3.3
20-Aug-05	5.4	16.6	0	3.1
21-Aug-05	4.3	17.8	0	3.5

Date	Minimum temp (degrees C)	Maximum temp (degrees C)	Rainfall (mm)	Evaporation (mm)
22-Aug-05	6.8	18.9	0	3.3
23-Aug-05	11.1	20.1	0	4.4
24-Aug-05	12.5	20.3	0	3.4
25-Aug-05	12.2	17.5	0	1.3
26-Aug-05	8.8	18.5	0	2.0
27-Aug-05	5.0	18.4	0	1.9
28-Aug-05	13.5	19.8	3.6	2.2
29-Aug-05	11.7	17.7	0.6	2.7
30-Aug-05	9.3	17.2	1.8	3.6
31-Aug-05	7.6	14.5	0.2	3.2
01-Sep-05	1.2	17.2	0	3.9
02-Sep-05	4.2	17.3	0	4.1
03-Sep-05	4.3	18.9	0	3.5
04-Sep-05	10.9	19.5	0	3.7
05-Sep-05	12.9	19.9	1.2	3.1
06-Sep-05	12.6	19.1	9.0	3.0
07-Sep-05	14.2	18.0	7.0	2.8
08-Sep-05	12.2	17	6.8	2.4
09-Sep-05	10.9	17.8	3.8	4.2
10-Sep-05	1.6	14.9	0.2	3.2
11-Sep-05	7.1	16.8	0	4.1
12-Sep-05	9.8	21.4	4.2	4.2
13-Sep-05	5.0	16.0	1.4	3.0
14-Sep-05	8.1	19.2	10.8	3.6
15-Sep-05	4.6	17.4	0.2	4.7
16-Sep-05	5.5	17.7	0	4.8
17-Sep-05	12	24.6	18.2	5.7
18-Sep-05	10.7	17.2	1.4	3.8
19-Sep-05	8.1	18.7	0.2	4.3
20-Sep-05	11.7	23.6	9.4	4.7
21-Sep-05	11.9	19.4	4	3.5
22-Sep-05	12.4	16.7	0	2.3
23-Sep-05	9.5	19.7	0.2	3.1
24-Sep-05	7.6	19.2	0	4.3
25-Sep-05	6.4	17.1	0	5.0
26-Sep-05	5.3	18.8	0	5.2
27-Sep-05	11.4	19.0.	1.8	5.4
28-Sep-05	10.8	15.4	1.8	3.9
29-Sep-05	12.3	16.9	2.6	3.6

Date	Minimum temp (degrees C)	Maximum temp (degrees C)	Rainfall (mm)	Evaporation (mm)
30-Sep-05	13.3	17.1	8.4	2.9
01-Oct-05	14.5	18.4	6.2	2.7
02-Oct-05	14.5	18.8	1.4	2.4
03-Oct-05	7.9	18.8	0	4.1
04-Oct-05	13.0	20.6	6.4	4.8
05-Oct-05	9.0	17.0	2.4	4.6
06-Oct-05	9.8	18.1	19.2	2.2
07-Oct-05	7.3	19.7	0.6	3.8
08-Oct-05	6.4	16.9	0.2	3.7
09-Oct-05	13.2	18.7	2.6	4.2
10-Oct-05	2.1	15.2	0	3.4
11-Oct-05	2.9	16.5	0	4.5
12-Oct-05	10.5	17.4	0	4.9
13-Oct-05	2.9	16.8	0	5.7
14-Oct-05	6.6	18.4	0	5.4
15-Oct-05	4.2	19.8	0	6.1
16-Oct-05	9.7	23.9	0	6.1
17-Oct-05	11.3	19.5	0	5.6
18-Oct-05	10.4	20.4	0	3.3
19-Oct-05	3.8	18.3	0	3.5
20-Oct-05	5.5	20.5	0	6.2
21-Oct-05	7.5	22.1	0	5.6
22-Oct-05	14.8	20.0	11.0	2.8
23-Oct-05	8.1	20.1	0	5.1
24-Oct-05	12.0	24.3	0	6.7
25-Oct-05	12.4	21.6	4.0	3.2
26-Oct-05	10.6	18.6	0.6	5.3
27-Oct-05	10.6	18.8	0	3.7
28-Oct-05	10.1	20.6	0	5.5
29-Oct-05	14.4	20.0	0	6.4
30-Oct-05	16.1	22.8	0	5.4
31-Oct-05	7.4	21.1	4.2	2.8
01-Nov-05	8.5	18.8	0.2	6.6
02-Nov-05	6.5	18.3	0	6.7
03-Nov-05	6.4	20.2	0	6.6
04-Nov-05	13.7	20.3	0	6.2
05-Nov-05	11.3	22.3	8.2	5.2
06-Nov-05	6.4	19.3	0.2	5.8
07-Nov-05	7.5	19.4	0	6.2

Date	Minimum temp (degrees C)	Maximum temp (degrees C)	Rainfall (mm)	Evaporation (mm)
08-Nov-05	9.6	20.4	4	4.4
09-Nov-05	10.2	18.4	0	6.6
10-Nov-05	5.1	18.8	0	6.9
11-Nov-05	10.5	20.4	0	6.7
12-Nov-05	8.3	23.4	0	6.6
13-Nov-05	13.3	24.3	0	7.3
14-Nov-05	11.9	21.5	0	7.4
15-Nov-05	14.3	28.9	0	8.5
16-Nov-05	14.0	32.9	0	8.1
17-Nov-05	14.2	23.5	0	6.9
18-Nov-05	10.3	24.6	0	7.6
19-Nov-05	14.1	25.3	0	7.9
20-Nov-05	13.4	29.5	0	8.2
21-Nov-05	14.4	25.4	0	7.9
22-Nov-05	14.7	30.3	0	8.4
23-Nov-05	14.2	28.6	0	7.8
24-Nov-05	15.2	31.1	0	7.8
25-Nov-05	10.7	27.3	0	7.6
26-Nov-05	12.6	28.8	0	8.9
27-Nov-05	13.0	25.6	0.4	6.8
28-Nov-05	17.8	33.3	0	7.6
29-Nov-05	14.5	21.2	2.0	3.2
30-Nov-05	12.2	19.7	0	6.4
01-Dec-05	9.7	19.9	0	7.1
02-Dec-05	12.0	22.7	0	7.9
03-Dec-05	15.6	25.8	0	7.8
04-Dec-05	16.9	21.6	0	5.9
05-Dec-05	15.2	22.7	1	5.1
06-Dec-05	14.3	19.2	0	7.1
07-Dec-05	12.8	19.2	0.2	5.2
08-Dec-05	12.4	20.3	0	5.2
09-Dec-05	11.9	21.3	0.4	5.2
10-Dec-05	8.2	20.9	0	7.2
11-Dec-05	14.1	22.1	8	5.7
12-Dec-05	10.5	18.9	0	6.5
13-Dec-05	13.8	19.7	0.6	5.3
14-Dec-05	9.9	21.6	0	6.8
15-Dec-05	11.9	20.8	0	5.9

Date	Minimum temp (degrees C)	Maximum temp (degrees C)	Rainfall (mm)	Evaporation (mm)
16-Dec-05	12.2	20.2	0	7.0
17-Dec-05	12.5	26.8	0	5.5
18-Dec-05	13.4	27.8	0	8.2
19-Dec-05	16.0	30.3	0	7.6
20-Dec-05	18.0	23.5	0	5.8
21-Dec-05	8.7	23.4	0	7.6
22-Dec-05	10.2	22.4	0	7.3
23-Dec-05	14.6	23.5	1.6	7.0
24-Dec-05	8.4	20.5	0	7.8
25-Dec-05	12.0	24.3	0.2	7.9
26-Dec-05	14.5	26.3	0	8.1
27-Dec-05	12.4	23.3	0	7.6
28-Dec-05	11.7	21.8	0	7.2
29-Dec-05	15.0	23.4	0	7.4
30-Dec-05	15.1	24.9	0	7.0
31-Dec-05	12.6	21.7	0	7.2
01-Jan-06	11.1	24.6	0	9.0
02-Jan-06	13.1	29.7	0	9.4
03-Jan-06	15.8	31.2	0.6	7.9
04-Jan-06	17.1	24.7	0	4.0
05-Jan-06	18.2	28.4	0	8.3
06-Jan-06	20.6	32.1	0	9.4
07-Jan-06	21.0	37.4	0	8.8
08-Jan-06	19.7	34.5	7.8	7.9
09-Jan-06	15.1	25.5	0.2	6.8
10-Jan-06	13.9	28.0	0	8.4
11-Jan-06	16.8	28.8	0	9.3
12-Jan-06	18.9	32.5	0	7.5
13-Jan-06	18.0	21.7	10.6	1.5
14-Jan-06	17.5	24.2	0	2.9
15-Jan-06	17.0	26.7	0	3.0
16-Jan-06	16.8	27.2	0	7.9
17-Jan-06	16.7	29.7	0	8.4
18-Jan-06	19.3	28.0	0	7.5
19-Jan-06	14.2	24.7	0	4.9
20-Jan-06	14.6	27.0	0	8.3
21-Jan-06	15.5	29.3	0	8.6
22-Jan-06	12.7	24.2	0	8.5
23-Jan-06	16.1	30.8	0	9.3

Date	Minimum temp (degrees C)	Maximum temp (degrees C)	Rainfall (mm)	Evaporation (mm)
24-Jan-06	23.9	35.5	0	11.2
25-Jan-06	20.8	28.3	36.0	1.4
26-Jan-06	14.5	27.1	0.4	4.7
27-Jan-06	13.7	28.5	0	8.5
28-Jan-06	14.0	26.6	0	8.1
29-Jan-06	12.9	26.9	0	8.5
30-Jan-06	14.0	24.5	0	7.6
31-Jan-06	11.9	24.5	0	6.2