Agronomic and postharvest improvement in iceberg and cos lettuce to extend shelf life for fresh cuts salads

Gordon Rogers
The University of Sydney

Project Number: VG03092

VG03092

This report is published by Horticulture Australia Ltd to pass on information concerning horticultural research and development undertaken for the vegetable industry.

The research contained in this report was funded by Horticulture Australia Ltd with the financial support of Harvest FreshCuts Pty Ltd.

ISBN 0 7341 1463 X

Published and distributed by:

Horticultural Australia Ltd

Level 1
50 Carrington Street
Sydney NSW 2000
Telephone: (02) 8295 2300
Fax: (02) 8295 2399

E-Mail: horticulture@horticulture.com.au

Know-how for Horticulture™

POST HARVEST IMPROVEMENT IN ICEBERG AND COS LETTUCE TO EXTEND SHELF LIFE FOR FRESH CUT SALADS

Horticulture Australia
Project Number: VG03092

Project Leader

Dr. Gordon S. Rogers
Applied Horticultural Research
Po Box 3114
BUNDEENA NSW 2230

Key Personnel

Gordon Rogers – AHR
Michael Titley – AHR
Brad Giggins – AHR
Bartley Bauer – AHR

Robin Poynton – OneHarvest
Adam Kocks – OneHarvest
Tom McAuliffe – OneHarvest
James Le Budd – OneHarvest

Funding Sources

This project is jointly funded by OneHarvest and Horticulture Australia Limited.

Funding by both the Industry and HAL is gratefully acknowledged by Applied Horticultural Research.

Date: December 2006

Table of Contents

Executive Summary

1. Crop Scheduling

- Preliminary Scheduling models have been prepared for Cos and Iceberg lettuce grown in several districts in Qld and Victoria. (Figures 5.1 to 5.4 and Appendix 2)
- For Iceberg lettuce planted in Gatton, Qld the time from transplanting to harvest varies from as little as 49 days for the May harvest extending out to 70 – 77 days for the mid-winter harvest and then decreasing back to 63 and 56 days for September/October harvesting. During this time yields can vary from 30t/ha (350g/head) in the May and October period, up to 45 – 50t/ha (1.5 kg) in the optimum harvest period in July through to August.
- For Cos lettuce grown in East Gippsland, Vic the time from transplanting to harvest varies from 95 –100 days for the early part of the season decreasing to 42 – 49 days in mid-summer and then extending out to 70 – 75 days for the late autumn harvest period. The yield per hectare during this time varies from a lower yield in mid-summer of 500 – 550g/head compared to 750 – 800g/head produced in the autumn and spring period.

Bolting is a major consideration for crop scheduling. The potential causes for bolting could include:

- Day length (especially long days)
- High diurnal temperature range e.g. maximum daily temperatures equal to or greater than 27°C and minimum temperatures dropping to 5°C.
- A combination of long days, high temperatures and transplanting into dry soil.
- Soil temperatures, both waterlogged and drought conditions.
- Number of leaves when transplanted (especially if the leaf number is greater than 7).
- Length of time Cos seedlings held in soil-less media once the optimum root ball has been developed.
- Stress, especially moisture, soil compaction and salt.
- Genetics, with some varieties exhibiting slow bolting tendencies

2. Harvest maturity

- The trials in Gatton in 2005 demonstrated how yields can be increased in this region and time of year without significant detriment to lettuce processing quality.
- This change in production practice is best suited to cooler periods in the season when growing conditions are optimal to avoid the issue of bolting.
- The results showed that yield increases as high as 60% could be obtained for Iceberg lettuce (cv. Titanic transplanted 26-04-05) and a 35% increase in Cos lettuce (cv. Cyclone transplanted 27-4-05).

- There was no impact on shelf-life when iceberg or Cos lettuce was grown for an extra seven days and the average core length in the plants from the later harvest, was well within the specification for lettuce processed as fresh-cut salads.
- These findings are specific to the conditions experienced during these trials and research encompassing a range of regions, seasonal timing and varieties is required to verify a broader application.

3. Postharvest handling

Storing and Trimming

- The results showed that storing the unprocessed heads for 5 days prior to processing resulted in a reduction in the quality by 22-31% (Fig. 109).
- The harder trimmed lettuce (55%) was able to maintain close to initial quality until day 8 whereas the normal trimmed lettuce (70%) was declining in quality from day 4.
- Once the lettuce quality started to decline, it seemed to be programmed on that track, and this may mean that shelf life assessment protocols could be developed with less assessment points, but which were aimed to identify the beginning of the decline in quality and the rate of change.
- The effect of storing lettuce for 5 days prior to processing results in a reduction in overall score of about 28% (10 score units).
- Storing heads reduces the starting quality by about 28% compared to using fresh heads for processing.
- Storing heads for 5 days then trimming to only 70% of initial weight resulted in a shelf life on only 8.0.

Reducing moisture in the bags

- The results show that having an absorbent sachet in the bag increased the shelf life of the product by about 3 days (Figure 113). This is an important result as it demonstrates the fact that the current processing can be improved.

Postharvest temperature Management

- Lettuce must be vacuum cooled with in half an hour of harvest to ensure maximum shelf life.
- Vacuum cooling 6hours after harvest did not improve shelf life compared to the forced air cooled samples.
- Vacuum cooling improved shelf life compared to forced air cooling
- A break in the cool chain (2 hrs at 15^{o}C) negated the benefits of on farm cooling and reduced the overall shelf life of the product

The physical impact of processing lettuce

- Other research shows that more cuts and blunter equipment increase the response and increase the rate of deterioration (Cantwell and Suslow, 2002).
- The translicer used in this processing line was not having a significant impact on the shelf life of the product compared to manual cutting with a sharp knife (Figure 117).
- The results in relation to the degree of trimming support those from the previous section. Trimming lettuce to 55% prior to processing significantly improves the shelf life of the processed product.

4. Variety Selection

- Trials with lettuce varieties are relatively easy to design, establish and grow to harvest. They are very time consuming making observations, collecting data, analysing and interpreting before making a decision on adopting a new variety as shown over the three years of the project.
- Attributes other than marketable yield (Nasonovia resistance for iceberg & slow bolting for Cos) must be taken into account when adopting new varieties.

5. Crop Nutrition

- It is essential that nutrients are applied at the appropriate ratio with other nutrients rather than simply applying elements independently if optimal yield and quality is to be achieved.
- Excessive nitrogen application can reduce both yield and quality (shelf-life)
- Phosphorous management is important for sustaining the maximum, long-term performance of the crop
- Phosphorous supply can be an issue on soils new to horticultural production, where relatively high rates may need to be applied
- Calcium foliar sprays are ineffectual in tip burn alleviation and cultural practices that aim to prevent excessive growth rates are a better strategy for reducing the incidence of tip burn.

6. Crop Establishment

- If the potential value of Cyclone, or similar varieties, is to be fully explored for the fresh-cut salad industry, specific cultural practices which optimise yield must be considered
- Cyclone yield has been shown to increase significantly when planting density is raised to 80 000 – 100 000 plants per hectare and the appropriate, supporting nutrition is applied
- The ability of direct-seeded lettuce crops to produce yields comparable to that of transplanted crops has been demonstrated, presenting a means to reduce planting costs

7. Soil Moisture Management

- Trickle irrigation can be used successfully to grow lettuce with higher water use efficiency than using sprinkler irrigation.
- Lettuce plants should be maintained free of water stress right up to harvest for maximum yields.

Standout results

- **Identification of the most productive times** and shelf life for each of the main lettuce production regions in Qld and Vic.
- **New Varieties** – The identification and agronomic work on important new lettuce varieties including Cyclone, Challenger and Nr varieties.
- **Effect that trimming** and time held before processing has on shelf life of Cos lettuce.
- **Later harvesting** - improvements in yield without adverse effect on shelf life or core length by later harvesting (main production season).
- **Development of crop scheduling** for predicting days to harvest and yield.
- **Trickle irrigation** can be used to produce high yielding and quality lettuce with significant water savings compared to overhead irrigation.
- **Rapidly cooling lettuce** as soon as possible after harvest significantly improves shelf life.

Introduction

Fresh cut lettuce is an expanding category for supermarkets in Australia. In an effort to meet this market demand processors need a year round supply of good quality product. OneHarvest create a year round supply by sourcing Australian Iceberg and Cos lettuce from different regions throughout the year. They source product from Queensland (Lockyer valley and Toowoomba) and from Victoria (Bairnsdale and Robinvale). There is a summer and winter location in both Queensland and Victoria to ensure a year round supply of fresh product.

The lettuce is processed in the winter in Brisbane (Harvest Fresh Cuts) and in Bairnsdale (VEGCO) in the summer. The processed products are then sold Australia-wide, mainly through the supermarket chain stores. The key to growing this category is to supply customers with a consistent quality product. The difficulty comes in achieving this when environmental conditions change between districts and seasons. This project aims to identify management strategies that can help growers produce a quality product during sub-optimal seasonal periods.

The long-term prospects for the fresh-cut salad industry are excellent. The current Australian market share for fresh cut products is around 3% of the total fruit and vegetable sales. This is in comparison of other markets where the market share is much larger. For example in the US fresh cuts account for 12% of the total fresh market sales and in Europe it accounts for 18% of fresh sales (OneHarvest, pers. comm). This data shows that there is enormous potential to expand the fresh-cut market segment if products meet consumers' needs.

A key issue for the success of the fresh-cut industry is the consistency and length of shelf-life of the product. Currently in Australia washed and processed products have a shelf life of 10 days. In the US they achieve a 14 day shelf life which greatly increases the opportunity cost for this product.

This project will identify varieties, agronomic factors and processing and handling issues that influence shelf life with the aim of identifying a "best practice" approach to ensure a quality product with a longer shelf life.

The overall objective of the project is to develop specifications for irrigation and nutrient management, harvesting and postharvest techniques and specification which will consistently extend postharvest life of fresh-cut lettuce from the current 8-10 days to 14 days for lettuce grown in the Lockyer Valley, Toowoomba, Bairnsdale and Robinvale.

General Agronomy

A review of lettuce production and processing was presented to the Lettuce Industry conference in June 2000 (Titley 2000). The key issues raised in that review are summarised below.

Crop Establishment: A consistent germination rate ensures a consistent growth and maturity rate of the crop which is a key quality parameter. Some varieties in some districts and seasons have erratic germination which is caused by high temperature induced dormancy. This issue can be overcome by using transplant seedlings and efficient mechanical transplant methods which minimise transplant shock (Titley 2000).

Minimising transplant 'shock' is important as it has a major impact on the incidence of bolting and long cores during mid summer and early autumn. Both factors reduce final harvest quality. The critical stage is the 10 – 14 leaf stage where heat stress during this period potentially results in long core and bolting (Kim et al. 2000). It is important to note that transplanting cool stored seedlings and/or old seedlings also increases the percentage bolting. Professional nurserymen should provide actual seeding dates on delivery batches to minimise the risk of supplying 'old' seedlings to growers.

The root structure of direct seeded crops is different to transplants. Cell grown seedlings and transplants have a much shallower but extensive root system in the upper 30cm of the profile compared to a deep 1.2 – 1.5 m tap root on direct seeded crops (Jackson 1998). This major change presents crop management challenges to producers in the 21st Century particularly in relation to water management.

Crop Nutrition: Crop nutrition also influences product quality. The classic nutritional work was done by Zink & Yamaguchi (1962) for direct seeded lettuce in California. This work provides the benchmark for nutrient removal of a 50 tonne/hectare crop. Lettuce crop nutrient removal/ hectare is estimated to be;

100	kg	Nitrogen
18	kg	Phosphorus
180	kg	Potassium
33	kg	Calcium
15	kg	Magnesium

and small amounts of Sulphur and micronutrients.

Sanchez et al. (1989) tested a wide range of N, P and K rates over many seasons. This work showed that there was a response to N at rates up to 250 kg/ha, especially during periods of cool temperatures or heavy and frequent rainfall. There were responses to phosphorus at rates up to 500 kg P/ha when there were low soil P levels and there was a response to potassium applied at rates up to 625 kg K/ha when the soil K content was low.

The work showed that the leaf N concentration was not closely related to yield. They also showed that the critical concentrations of P and K in 6- to 8-week-old leaves were 0.44 and 5.6%, respectively. Shelf life was not affected by N, P and K application levels although the trimming losses of stored lettuces increased with increasing N application rate. Other work linking nutrition to shelf life has shown some affects. Yano and Hayami (1978) found that high rates of phosphorus fertilizer prolonged lettuce shelf life and Steenhuizen and Boon (1985) found a link between growing lettuce using a high N regime and poor shelf-life. More research is needed in this area to optimise crop nutrition for optimum yield, quality and shelf life.

Organic Supplements: There has been increasing interest in added nutrients to crop by using organic supplements. Zodape (2001) found that fertilizing plants with seaweed extracts was able to extend shelf life and a similar study by Yano and Hayami (1978) also found that organic fertilizers produced longer-lasting heads than lettuce grown using inorganic fertilizers. This research suggests the need for a better understanding of the link between crop nutrition and the product shelf life.

Tipburn: An important physiological disorder of lettuce is tipburn. Traditionally this disorder has been associated with low calcium levels in the developing heart tissues. A recent study investigating tipburn control in lettuce by Murdoch et al. (2000) found that the application of calcium was actually ineffective in controlling the disorders.. This research found that the most effective control strategy was to slow the growth rate of the lettuce, and reduce the nitrogen supply to the plants.

There is recent evidence that some disorders which have been traditionally attributed to calcium deficiency such as bitter pit in apples, may in fact be caused by high Gibberellic acid levels which slows calcium transport and encourages rapid cell expansion (Saure, 2001). The low calcium may be a response to the disorder rather than the cause. It may be possible that tipburn in lettuce is similar to bitter pit in apples where the low calcium in the tissues is a symptom rather than a cause. This would explain why lowering growth rate was effective and calcium sprays were not.

Salinity: Another issue for Australian growers is soil salinity. Lettuce is classified as a moderately salt sensitive crop, therefore producers should account for any salinity effects from soil or irrigation water. This is important for some Southern growing regions which have experienced below average rainfall over the past 3 – 4 years and have seen 'salt burn' on lettuce during mid summer which has impacted on iceberg lettuce quality and quantity (Titley 2000).

Moisture sensitive stages: To ensure a good quality crop of lettuce it is important to avoid water stress at critical times. For lettuce the most critical stages are during germination, seedling establishment and from the cupping stage until harvest. Research has shown that 70 % of the fresh weight is accumulated from the cup stage until harvest (Salter and Goode 1967).

Pest Control: Pest management is always an important part of crop agronomy and the supply of insect-free lettuce for processing is crucial. Strategies for pest control in lettuce in the future will include initiatives such as, routine crop scouting, introduction of 'new' chemistry, strategies to build up native predators, crop rotation, adequate spray coverage and trap crops.

Bolting: Bolting can be a problem for lettuce growers although new varieties are bred to be bolting resistant. Bolting is the undesirable formation of flowers and seeds. Bolting destroys the flavour of the leaves by making them bitter and tough. Bolting is induced by high temperatures, long periods of high light intensities, and drought. Research has shown that lettuce has an internal counter that keeps track of the number of daylight hours the plant receives. Once a critical number of hours have been received then the plant sends up its flower stalk. The exact number of hours varies from cultivar to cultivar. The plant can handle environmental stresses when vegetative. However, once the lettuce reaches the intermediate growth stage, environmental stresses, such as high temperatures or drought, will cause the plant to bolt. Growers must schedule their planting to ensure that harvesting is finished before hot temperatures occur. This is the reason that processors in Australia often have Northern and Southern states supplying product for processing.

Harvesting: In the US, a practice has been developed where iceberg and Cos lettuce are being de-cored in the field. This results in less waste material being transported back to the processing factory.

Immediately after coring, a protein-based solution is sprayed into the cut surfaces of the lettuce, and this solution has the effect of protecting the cut surfaces from enzymic (PAL) browning. Once the lettuce reaches the factory, the protectant solution is washed off in the normal washing process and the lettuce is processed normally.

Kraker et al. (1996) found that if lettuce is harvested in the early morning, when the head is fully turgid, that it is highly susceptible to internal cracking. The research showed that delaying harvest until the outer leaves were dry, significantly reduced internal cracking.

Storage and Postharvest Techniques

General Storage Conditions: Reyes (1996) has written a review of the general storage conditions for minimally processed vegetables. The review outlines recent improvements in packaging, preservation systems, refrigeration and antioxidants. Some of the recent improvements are summarised below.

Controlled Atmosphere storage (CA): Research has shown that gas concentrations of 2% O_2 and 5 % CO^2 will extend the post harvest life of lettuce. This concentration of gasses is suitable for lettuce, even though the temperature through the cold chain may vary from 0^oC which is optimum (O'Hare et al. (2000).

The effects of ultra low oxygen (ULO) concentrations in combination with high and low levels of CO_2 on the storage and quality of butterhead lettuce (cv. Krolowa Majowych), was studied. Butterhead lettuce stored in a controlled atmosphere (CA) containing 1% O_2 + 3% CO_2 retained green colour of leaves and a high content of vitamin C during 21 days at 1 ^oC (Adamicki 1997).

CA storage could be an option for processors in the future for holding over product. At the moment the infrastructure Costs are too high for it to be a commercial reality. A commercial option may be the same atmospheres using modified atmosphere packaging.

Modified Atmosphere Packaging: For lettuce equilibrium modified atmosphere (EMA) should be 2-3% O_2, 2-3% CO_2 and 94-96% N_2 (Jacxsens et al. 1999). The critical success factor for the use of MA packaging is a good cold chain where temperatures can be maintained at between 0 to 4^oC.

Control over the atmosphere can also be achieved using Modified Atmosphere packaging (MAP) (Beaudry 2000). Martinez and Artes (1999) found that 5% O_2 and 0 % CO_2 , applied using 30 mm active perforated polypropylene were best for overall visual quality of lettuce.

The use high CO_2 to control enzymic browning can be used, however the CO_2 should be kept below 5% when O_2 levels are low. Potassium leakage from the cells was a good indicator of damage caused by high CO_2 (Varoquax et al. 1996).

When packing shredded lettuce in low density polyethylene, a flush of 5% O_2, 5% CO_2 and 90% N_2 resulted in a shelf life of 14 days.

Effects of MAP on Microbial Growth: Research has shown that modified atmospheres do not inhibit microbial growth. The main effects of MA's are on the sensory quality of the lettuce (Jacxsens et al. 1999).

Vacuum Cooling: Temperature management is the best tool for extending the postharvest shelf life of lettuce. Vacuum-cooling has been shown to reduce the incidence of both pink rib and heart leaf injury during storage (Martinez and Artes 1999).

Nitrogen Flushing: Koseki and Itoh (2002) report that Nitrogen flushing of bags is effective in extending the shelf life of fresh-cut lettuce. 100% N_2 at packing should stabilize to about 1.2-5% O_2 and 0.5-3.5% CO_2 after 5 days at 5 ^oC.

Use Of Heat Shock Proteins To Control Post Harvest Enzymic Browning: Browning of the cut surfaces of lettuce is a major quality defect for consumers. The browning results from wounding and the breaking of cells. The wounding leads to the rapid accumulation of phenolic compounds which cause tissue browning via an increase in the activity of enzymes of phenolic metabolism such as phenylalanine ammonia-lyase (PAL). This enzymatic browning has been controlled through the application of antioxidant compounds such as ascorbate.

Research has shown that exposure of cut lettuce to 45 ^oC for 90 seconds prevents an increase in phenolic compounds and hence browning, if administered either 4 h before or 2 h after wounding. This diversion of wound-induced protein synthesis by heat shock might be used to prevent browning in other crops that normally have low phenolic content, such as celery and lettuce. The effects of heat treatment last for 15 days in lettuce held at 5 ^oC.

This heat treatment offers a new way to control browning in lightly processed fruits and vegetables. The design of processing lines using a heat shock to extend the shelf-life of fresh-cut lettuce will need to be modified from existing designs to take full advantage of the effect of the heat treatment.

Summary of the Experimental Approach

Four regions with significant production value to the Australian lettuce industry were chosen as trial locations for the three year duration of the project. There were 2 districts in and two areas in Victoria. The locations chosen included:

1. ***Queensland*** - Gatton (27° 33' S, 152° 17' E) and Toowoomba (27° 33' S, 151° 58' E). Gatton, 82km west of Brisbane, provided a site for winter production in this state. Toowoomba, although only 35km west of Gatton, experiences significantly different temperatures due to it's elevated position on the Great Dividing Range. Toowoomba's altitude is 700m above sea level (cf: 89m at Gatton) and is used for summer production of lettuce during the shoulder period.

2. ***Victoria*** - Bairnsdale (37° 55' S, 147° 43' E) and Robinvale (34° 34' S, 142° 44' E). Bairnsdale, 306km east of Melbourne, is a major location for the summer production of lettuce in southern Australia and Robinvale, 438km north-north-west of Melbourne, was used for winter production in Victoria.

All trials were conducted on commercial properties that supply fresh cut processors. Two growers in the Gatton area and one grower in Toowoomba provided field sites in Queensland. The postharvest research for these trials was done at the OneHarvest facility in Brisbane.

In Victoria, one grower's property was used in Robinvale and two grower's properties were used in the Bairnsdale area. There were field sites in the surrounding production districts of Lindenow and Boisdale. The OneHarvest facility in Bairnsdale provided the resources for the postharvest evaluation of the Victorian field trials.

Field Trial Design: The field trials were set up as completely, randomised block designs with the blocks running down a bed. The nutrition trials and early variety screening trials were designed with each treatment having two to four replicate plots per block. Each block was on a separate bed. Each treatment plot comprised of 7m lengths of bed, including a buffer of unused plants at each end.

Once the initial screening trials were completed the field trials were scaled up in size. The trials had fewer treatments but larger plot areas. . This was valuable as a means of assessment after initial screening trials had selected the best performing varieties. This was also an efficient way of providing large samples (for both field and postharvest assessment) throughout a growing season, this design was integrated with commercial production and therefore allowed variety performance to be measured within the context of typical grower practices.

For the large field trials small plantings of the test varieties were transplanted within a block of the grower's standard varieties. The size of each planting varied but the number of plants always exceeded 100 plants. This provided sufficient plants for sampling to assess yield, quality and shelf-life.

In all trials the commercially recommended plant spacing was used. The planting configurations were three rows of lettuce on beds with 1.5m centres or four rows on beds with 2m centres. Intra-row spacing varied but plant density was always in the order of 60 000 plants per hectare.

Assessment of Yield and Quality: The measurement of yield and quality at the time of harvest was consistently executed using a standard protocol.

The standard unit sample was twelve plants, which was taken from each replicate of each treatment. The samples were taken twice from the plots of commercial-scale trials, resulting in two replicates. Samples were always taken using plants representative of the entire plot. Plants from the edges of the plot were never taken.

The following measurements were made from the twelve plants in a sample:

1. The trimmed weight was recorded for all plants (the weight of a head of lettuce trimmed as it would be in a commercial harvesting operation, for processing)
2. For two of the plants an untrimmed weight was also recorded (the biomass of the above ground parts of the plant)
3. The core length and dimensions of the heart were also measured for all plants and
4. Any incidence of disease or disorders was also documented along with any other observations of note.

Shelf Life assessment: For the assessment of shelf-life, a sufficient amount of lettuce was harvested per treatment, for processing at either of the two plants. Six standard cartons per treatment (a total of 72 heads per treatment) provided ample material for processing in the factory. The harvested treatments were vacuum cooled before being sent to the processing plant. The commercial temperature management (approx. 4^{o}C) was used during periods of storage before processing.

The field treatments were processed as per the routine operation of each processing facility. The final product was a fresh-cut salad, packaged with only one type of lettuce. Iceberg lettuce was processed as shredded lettuce and Cos lettuce was processed as a Caesar salad. These bags, commercially sold at retail level, were stored in their treatments at 7^{o}C, to simulate the conditions experienced in a chain store. A 7^{o}C storage regime is the protocol OneHarvest use for their in house quality and shelf life evaluation for their products.

<u>Quality Rating</u> – During the postharvest evaluation each treatment was rated for seven aspects of quality: visual, crispiness, odour, taste, damage, consistency and overall freshness. Each score comprised a number between 1 and 5, with 5 indicating excellent quality and 1 being unacceptable quality with respect to purchase. This is the protocol OneHarvest use for their in house quality and shelf life evaluation.

For the work presented in this report the scores for each category were totalled for each day of assessment, to give a total quality score out of 35. The total quality scores were averaged for replicates and when this average score reached 12.5 or less, the treatment was said to be unsaleable. The end of shelf-life of a treatment was defined as the number of days until it became unsaleable or reached a quality score of 12.5.

<u>Statistical Analysis</u>
In most field experiments the data was analysed as a completely randomised designs with the plots being the treatment replicate. In some locations it was possible to design the field trials as

completely randomised blocks when more resources were available. The shelf life trials were analysed as completely randomised designs with appropriate replicates. The analysis of variance was computed using Genstat ver 8.0 (VSN International Ltd, Lawes Agricultural Trust 2005). Multiple mean comparisons were performed using LSD generated in Genstat ($p = 0.05$).

4. Variety Selection

Introduction

The tendency with Cos varieties is to go away from the Parris Island Cos types which have been the main industry benchmark for years where the variety Verdi dominated with now seeing the emergence of three quarter closing Cos which have the tendency to be slower growing and hence slower bolting and also a little bit tolerant of tip burn.

Prior to the turn of the century the Australian lettuce industry was dominated by varieties bred by Dan Trimboli of Yates (now part of Enze Zaden). However, as we've move into the new century two other seed companies have become very active in supplying material; those being Rijk Zwaan and Enze Zaden itself. This has meant that we now have a more diverse range of varieties that now cope with the fluctuating high and low temperatures which are characteristic of the east coast of Australia during the year round supply of lettuce. We do not have the luxury in Australia of having a Salinas type climate available at our disposal and we have to cope with daily maximums of 35 – 40^{o} and greater and minimum temperatures in the summer as low as 7 – 10^{o}. This along with the day length at the time causes major stress on a developing lettuce plant.

With the arrival of the lettuce aphid on mainland Australia in May 2005 growers are now evaluated where Nasanovia resistant varieties fit into their schedule. Our experience to date is that Nas varieties are maturing 4 – 5 days earlier than their non-Nas equivalents which has to be accounted for in transplanting by variety schedule.

Selection of the most appropriate variety is one of the most important decisions commercial lettuce growers must make each season.

Some factors to be considered before adopting a new variety should include:

- Yield of trimmed heart/head at least equivalent or greater than current variety
- Disease and insect pest resistance (especially downy mildew and Nasanovia) is the most economic and effective means of disease and insect pest management.
- Adaptability of new varieties under Australian conditions up to 30^{o}C diurnal range especially during the transitional periods.
- Tolerance to physiological disorders such as tipburn, rib discolouration, bolting and russetting.
- Marketable hearts must exhibit acceptable horticultural traits.
- Maturity range you need to mange your season, supply your market, and reduce the risk of weather related crop failures.

5. Crop Nutrition

Crop nutrition has a large influence on yield and quality. Hussein Ajwa (pers. comm) found for iceberg lettuce the best quality and yield resulted from supplying balanced NPK fertiliser at rates in excess of 100 kg/ha N, P and K. He also found that if high rates of N only were applied, shelf life was reduced.

The classic nutritional work was done by Zink & Yamaguchi (1962) for direct seeded lettuce in California. This work provides the benchmark for nutrient removal of a 50 tonne/hectare crop. More research is required to tailor this benchmark to meet the needs of new varieties and new growing districts in Australia.

Surprisingly, there has been little work reported in the literature on lettuce nutrition, particularly with a focus on the effects of nutrition of shelf life and quality.

Methodology

Nutrition field trials were conducted over the three year period at all sites. In all trials, a randomised block design was used with three replicates on single bed 10m plots. A standard iceberg or Cos lettuce variety was chosen for the relevant region and time of year and treatments (Figure 5.1) were applied just prior to transplanting, as basal fertiliser. During the season, the cooperating growers' usual cultural practices, including side-dressings, were administered. A pre-plant soil analysis and at least one plant analysis (at early hearting) was conducted for each nutrition trial.

The control treatment in all studies consisted of an application equivalent to 50kg of nitrogen, 60kg of phosphorus and 80kg of potassium per hectare. In each of the other treatments, two of the nutrients were kept at the same level as the control, while a third nutrient level was varied over two or three treatments, in order to investigate the effects of this nutrient in isolation.

Various levels of calcium were also applied, with the primary nutrients kept equal to the control. Treatments that applied 50% and 100% more fertiliser (in the same nutrient ration) than the control treatment were also included in the trials as well as a nil fertiliser treatment. The various applied quantities for each nutrient for each treatment are shown in Table 5.1.

At crop maturity, the standard measurements of yield and quality were taken. Samples from each treatment were processed and packaged as a fresh-cut salad product and then evaluated with respect to shelf-life (see description in the Experimental approach section).

Table 5.1: Treatments used in fertiliser field trials

Treatment	Applied Quantity of Each Nutrient (kg/ha)			
	N	P	K	Ca
Control	50.00	60.00	80.00	0.00
Nitrogen 1	30.00	60.00	80.00	0.00
Nitrogen 2	100.00	60.00	80.00	0.00
Nitrogen 3	200.00	60.00	80.00	0.00
Phosphorus 1	50.00	30.00	80.00	0.00
Phosphorus 2	50.00	100.00	80.00	0.00
Potassium 1	50.00	60.00	0.00	0.00
Potassium 2	50.00	60.00	40.00	0.00
Potassium 3	50.00	60.00	200.00	0.00
Calcium 1	50.00	60.00	80.00	50.00
Calcium 2	50.00	60.00	80.00	100.00
Calcium 3	50.00	60.00	80.00	200.00
Control x 1.5	75.00	90.00	120.00	0.00
Control x 2	100.00	120.00	160.00	0.00
Nil fertiliser	0.00	0.00	0.00	0.00

An experiment was also conducted in the final season in Gatton, to investigate the effect of foliar-applied calcium on the incidence and severity of tipburn. Carinus, a standard Cos lettuce variety for a late season (August) planting, was chosen. 3.5m long plots were used and treatments were replicated four times. In all other respects the trial layout reflected the complete, randomised block design, used throughout the project. A soil sample was taken prior to transplanting and leaf samples were taken from each plot just prior to harvest, for nutrient analysis.

Three weeks after transplanting, weekly sprays were commenced and continued for the life of the crop. Plots were sprayed with a solution of calcium chloride or an organic chelate of calcium. In either case, calcium was delivered at an equivalent rate of 600 g/ha, each application. Control plots received only water and the standard surfactant which was used throughout the trial.

All plants were grown for slightly longer than usual (by approximately one week) to advance tipburn to a stage where visual differences between treatments were reasonably apparent. The usual yield and quality assessment used for all trial harvests were carried out with a particular emphasis on scoring each plant for tipburn (score was 1 to 10, 10 = maximum damage).

Results

5.1 Balanced Nutrition is the Key to Higher Yields

The general trends observed in trial results were generally consistent across sites and seasons. Figures 5.1 and 5.2 show results for one experiment which was indicative of the other sites. These figures illustrate the two key findings in the area of plant nutrition, i.e. the need to supply nutrients in the correct balance and the detrimental impact of excessive rates of nitrogen. Figure 5.2 shows the highest head weight obtained with an application of 75:90:120

kg/ha of basal NPK fertiliser. The head weight (yield) is higher for this balanced fertilizer application than it was any level of N alone up to 200 kgN/ha.

This 43% yield increase, relative to the control, displays the potential to improve yields through increasing applied nutrition, when the elements are kept in a suitable ratio. Figure 5.1 shows the head weight response to increasing nitrogen levels alone. There is a trend for the head weight to increase with increasing nitrogen applied up to 100 kg/Ha. Nitrogen applied at 200 kg/Ha showed a negative effect on head weight, indicating toxicity. High levels of nitrogen also had a negative effect on shelf life (Figure 5.6) with nitrogen applied at a rate of 30 Kg/Ha giving the best result.

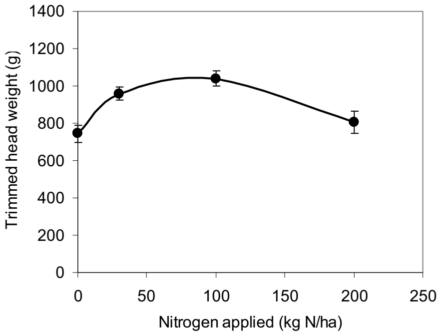

Figure 5.1. There was a significant difference between the trimmed head weight of Iceberg lettuce in response to different levels of nitrogen added.

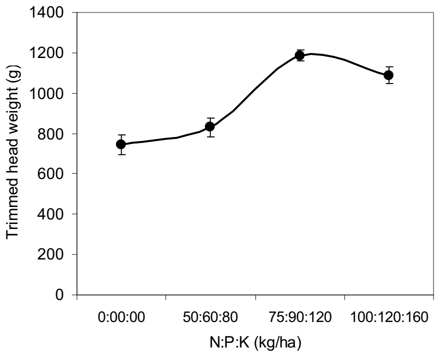

Figure 5.2. Effect of changing fertiliser quantities with nutrient ratios constant on the trimmed head weight of Iceberg lettuce

A similar result was found for Cos lettuce (Figure 5.3). Although the overall rate of applied nutrition was increased, an appropriate ratio of key nutrients was maintained, resulting in an increase in both yield and quality.

Higher balanced fertilizer rates also surprisingly reduced core length, a key indicator of maturity for processing lettuce. Plants in the 46-51-43 treatment had an average core length which was within product specification for processed lettuce, while core lengths in the control were well outside this specification (Figure 5.2).

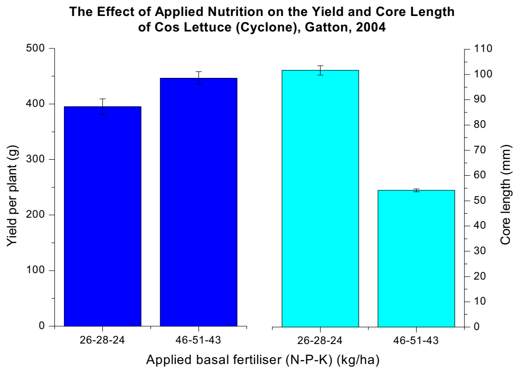

Figure 5.3. The effect of two levels of balanced NPK fertilizer on the yield per plant and core length of Cos lettuce, cv. Carinus.

5.2 Excessive Nitrogen Rates of Application Have a Negative Impact on Both Yield and Quality

Supplying iceberg lettuce with either different rates of N alone, or with rates of a balanced NPK fertilizer had similar effects on shelf life to that on yield. Increasing N supply, while holding other nutrients constant, reduced shelf life from 10 days at 0 kg/ha N to 7 days at 100 or 200 kg/ha N (Figure 5.4). When N was applied at up to 100 kg/ha in a balanced NPK form, the shelf life improved from 9 days at 50 kg N/ha to 10 days at 100 kg N/ha (Figure 5.5). This relationship between high nitrogen rates and reduced shelf-life, supports the work of Steenhuizen and Boon (1985).

5.3 The Importance of Adequate Phosphorus for Optimal Production

A strong plant growth response to applied phosphorus was observed in many trials throughout the project. Phosphorus removal by a lettuce crop (direct seeded) yielding 50t/ha has been estimated at 18kg P/ha (Zink and Yamaguchi, 1962). At some trial sites however, applications of phosphorus as high as 100kg/ha proved beneficial.

Such rates of application provided significant yield improvement on “new ground”, where horticultural production had not previously taken place. Phosphorus was also found to be limiting growth in some trials where soils had been double-cropped in a season or cropped continuously for a number of years without a fallow period or green manure crop.

Soils that are supplied with inadequate phosphorus for horticultural production are reasonably common in Australia. It is critical to be aware of phosphorus requirements in the situations described above, through the interpretation of a pre-plant soil analysis.

High rates of phosphorus application have also been found to improve lettuce shelf-life, in previous research (Yano and Hayami, 1978).

An example of a trial conducted on soil that had never been used for lettuce production is shown in Figure 5.6. A very significant yield increase is associated with the addition of 83kg P/ha.

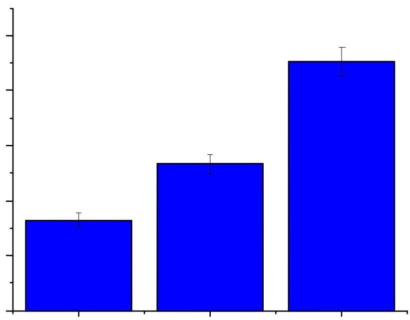

Figure 5.6. An example of the yield response to phosphorus, typically observed at sites new to horticultural production.

5.4 Foliar Applications of Calcium are Inefficient as a Prevention for Tipburn

Weekly foliar sprays of a calcium solution, applied to Cos lettuce, failed to provide adequate control of tip burn. Although there was a small, significant difference between the level of tip burn in untreated, control plants and those treated with foliar calcium (see Figure 5.7) this slight improvement would have made no difference in a commercial sense. From a processor's viewpoint, the level of the disorder in all plots would have appeared similar and unacceptable.

Both calcium chloride and a low molecular weight, organic chelate of calcium were tested, with the same units of calcium applied per plot in both treatments. A tank-mix of calcium chloride provides a simple solution of dissociated calcium ions while there is some evidence of superior uptake of organically chelated products. No significant difference in product performance was detected between calcium chloride and the chelated product.

This finding confirms the work of Murdoch et al. (2000). Aiming to maintain an even and moderate growth rate throughout the season remains the most effective strategy for minimising tip burn. Cultural practices such as irrigation and nitrogen applications will influence the disorder; however temperature, a factor that lies largely outside of a grower's control, can also play a large role.

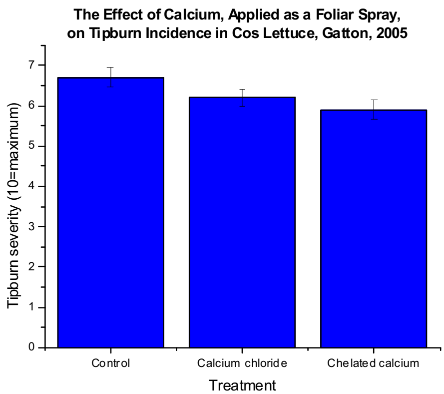

Figure 5.7. Although weekly calcium sprays provided a small, experimental reduction in tipburn severity, the treatments had no impact on the commercial outcome.

Key Findings for the management of soil nutrients for lettuce

- It is essential that nutrients are applied at the appropriate ratio with other nutrients rather than simply applying elements independently if optimal yield and quality is to be achieved.
- Excessive nitrogen application can reduce both yield and quality (shelf-life)
- Phosphorous management is important for sustaining the maximum, long-term performance of the crop
- Phosphorous supply can be an issue on soils new to horticultural production, where relatively high rates may need to be applied
- Calcium foliar sprays are ineffectual in tip burn alleviation and cultural practices that aim to prevent excessive growth rates are a better strategy for reducing the incidence of tip burn

6. Crop Establishment

The Cos lettuce variety Cyclone is about 75% of the size of the standard Paris Island Cos, and when planted at normal densities of about 66,000 plant/hectare, yields are lower than the standard Paris Island Cos varieties. It is therefore proposed that Cyclone yields could be improved by increasing planting densities.

If the number of plants per hectare were increased, then plant size is likely to be reduced because of competition for light, water and available nutrients which would limit the overall fresh weight yield per hectare. It may be possible to partially overcome the effects of competition, by increasing crop inputs such as water and nutrients.

Most lettuce in Australia is established by growing seedlings and then transplanting them into the field. Transplanting can overcome some significant establishment issues such as high temperature induced dormancy, weed competition and pest and disease problems with seedlings. Such problems can be overcome by using transplant seedlings and efficient mechanical transplant methods which minimise transplant 'shock' are available for growers to use (Titley 2000).

Minimising transplant 'shock' is important as it has a major impact on the incidence of bolting and long cores during mid summer and early autumn. Both factors reduce the final harvest quality. The critical stage is the 10 – 14 leaf stage where heat stress during this period potentially results in long core and bolting (Kim et al. 2000). Transplanting cool stored seedlings and/or old seedlings can also increase the incidence of bolting.

The root structure of direct seeded crops is different to transplants. Cell grown seedlings and transplants have a much shallower but extensive root system in the upper 30cm of the profile compared to direct seeded crops which have a deep 1.2 – 1.5 m tap root (Jackson 1998).

In the studies reported in this chapter, the establishment of lettuce by transplants and direct seeding have been compared using two varieties of iceberg lettuce. In separate experiments, three planting densities and two levels of fertilizer inputs have been evaluated in a factorial experiment using Cos lettuce in Gatton, Qld.

Summary of the Key Findings from Crop Establishment Trials

- For processing lettuce, it is essential to evaluate yield as kg lettuce/ha not heads/hectare. If you are being paid per tonne.
- Increasing plant density reduces individual head weight but applying additional fertiliser can increase total yield (kg lettuce/ha)
- Higher fertilizer inputs are required to maximise yields at higher plant densities.
- Direct seeding lettuce can result in comparable or higher yields compared to lettuce established using transplants.
- Risk factors associated with direct seeding need to be considered when choosing this as a method for establishing the crop.

7. Soil Moisture Management

Introduction

Most of the lettuce grown in Australia is irrigated by hand shift, or solid set sprinklers. This method is popular because it applies water over the whole bed area, which is an advantage in a multi-row per bed crop like lettuce.

Sprinkler irrigation however has some limitations. These are mainly:

- low water use efficiency;
- variable coverage due to sprinkler design;
- susceptibility to wind which can affect uniformity of water;
- wets the foliage making it more susceptible to disease.

For these reasons, the alternative of trickle irrigation can be an attractive option for growers. Trickle irrigation has two major advantages over sprinkler. It places water directly into the crop root zone, increasing water use efficiency; and provide a means of utilising water resources that are too high in salts for application via overhead irrigation.

At the same time however, the challenge with trickle is to get enough lateral movement of the water across the bed for all plants to get adequate water.

The limited availability of irrigation water is another major concern for many lettuce producers around Australia. The use of trickle irrigation is a potential option for reducing water consumption in the industry but at present is poorly adopted. Trickle irrigation might also provide benefits through a decreased labour requirement for operation and the opportunity to inject dissolved fertilisers into the irrigation water for direct delivery into the root zone. As well as distributing water to the crop more efficiently, this system can, to some extent, provide a means of utilising water resources that are too high in salts for application via overhead irrigation, where leaf burn may result.

In the Gatton region, growers situated on the Lockyer Creek have had a very limited water supply for a number of years and water salinity has also been a major issue. One of the cooperating growers is situated in this area and had installed a trickle irrigation system prior to the project's commencement, as his water was unsuitable for overhead irrigation due to a high concentration of chloride ions. The project's other cooperating grower in the Gatton region produces on properties situated north-east of this site, where water is well supplied and overhead irrigation is used.

Although it was not possible to directly compare both irrigation systems as treatments within a trial at a single site in this project, the opportunity was presented to compare the two types of production over a three year period, where the same varieties of iceberg and Cos lettuce were transplanted at the same time in concurrent trials and assessed using the same methodology. In comparing the yields, shelf-life, growth period and head quality obtained by each system, the objective was to establish whether trickle irrigation is a valid alternative to the standard practice of overhead irrigation, which has a greater water requirement per unit of production.

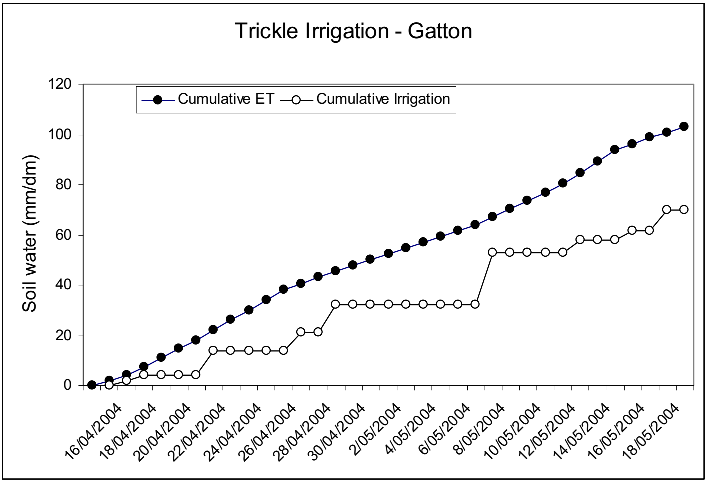

Figure 7.10. Crop water use and Irrigation applied for a trickle-irrigated iceberg lettuce crop in Gatton, Autumn 2004.

Discussion

While yields for both Cos and iceberg lettuce were generally higher when irrigated with an overhead system, there was some indication that trickle irrigation can improve shelf-life, particularly of Cos lettuce (Figure 7.4). Further investigations into the value of trickle irrigation to the fresh-cut lettuce industry may benefit from addressing iceberg and Cos types separately.

The magnitude of yield response to irrigation type also indicates that Cos lettuce may be more sensitive to the choice of system. Yield differences obtained between the two systems in 2005 were higher for Cos lettuce (Figure 7.7) than iceberg lettuce (Figure 7.5). While the greatest yield increase that irrigation selection provided for iceberg lettuce was 40% in September, overhead irrigation produced yields in Cos lettuce that were 85%, 50% and 68% greater than for trickle irrigation production in May, June and August respectively.

Cos lettuce also displays a greater yield response to irrigation type in the 2004 trials where overhead irrigation provided a significant increase in head weight. Reviewing the iceberg (Figure 7.1) and Cos lettuce (Figure 7.3) yield results for that year, shows an 18% improvement for iceberg and a 23% increase for Cos lettuce in July. In September there was 10% increase in iceberg lettuce yield but Cos lettuce yielded 17% higher when grown with overhead irrigation.

The nature of the experimental design in Gatton does not allow for direct comparisons of performance between the two irrigation types. The spatial separation of plots irrigated with the different systems limits the conclusions that can be drawn from the data generated. In particular, the lesser quantity and quality of water available to the site on the Lockyer Creek supports the possibility that yields generated from trickle irrigation may compete better with those from overhead irrigation in a more controlled study at a single site.

As a long-term study of what is possible in real commercial operations, however, this aspect of the project has been successful. It has shown that trickle irrigation is a viable alternative that requires further research. Although yield was usually higher in production utilising overhead irrigation, there was occasions when trickle irrigation results were comparable or better. This variation suggests that refining the management of trickle irrigation in lettuce crops may improve the performance and consistency of this system.

When other potential benefits of this irrigation system are considered, such as reduced water consumption and improved shelf-life of fresh-cut salads, further work in this area can be justified. Studies that target better management and higher yields using this system will benefit the industry with improved efficiency and greater returns on investment.

Conclusion

- Trickle irrigation can be used successfully to grow lettuce with higher water use efficiency than using sprinkler irrigation.
- Lettuce plants should be maintained free of water stress right up to harvest for maximum yields.