Agronomic programme to improve the uniformity of broccoli for once-over mechanical harvest

Dr Gordon Rogers
Applied Horticultural Research P/L

Project Number: VG06053

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

The research contained in this report was funded by Horticulture Australia Ltd with the financial support of:
Matilda Fresh Foods Pty Ltd
Applied Horticultural Research P/L

ISBN 0 7341 24813

Published and distributed by:
Horticulture Australia Ltd
Level 7
179 Elizabeth Street
Sydney NSW 2000
Telephone: (02) 8295 2300
Fax: (02) 8295 2399

HAL

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HAL Project Number: *VG06053*

(Completed Nov 2009)

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Gordon Rogers et al

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Horticulture Australia
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Statement of Purpose:

This project was a collaboration between Matilda Fresh, a commercial broccoli processor, Sakata and SPS, commercial seed companies and Applied Horticultural Research. The research aimed to determine the optimum agronomic management of broccoli to ensure uniform crop maturity and quality for once-over mechanical harvesting.

Funding

This project is jointly funded by Matilda Fresh, Sakata Seeds Corporation, South Pacific Seeds and Horticulture Australia Limited.

Date: November 2009

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Media Summary

Broccoli production can be an expensive, labour intensive exercise, with much of the Australian crop hand-harvested. It would be far more cost effective for broccoli to be mechanically harvested. Matilda Fresh, the National Food Industry Strategy and Horticulture Australia have together invested in the first successful development of a commercial mechanical broccoli harvester. However, the highest percentage cut currently achievable by this mechanical harvester is 50% of the available heads.

In this project, AHR, Matilda Fresh, Sakata Seeds and South Pacific Seeds worked together to develop agronomic management strategies to improve the uniformity of the plant stand and, in turn, the efficiency of the mechanical harvester. The trials were run over three seasons in Gunalda, Qld, Toowoomba, Qld, Gatton, Qld and Armidale, NSW.

This project was able to improve the harvest percentage by up to 90%, by ensuring a uniform plant stand. It was found that by increasing the plant density from 60,000 plants per hectare to 90,000 plants, the heads produced were taller with straigher stems, which made them well suited to mechanical harvesting. The varieties Gypsy and Atomic consisently produced tall straight stems with small heads when planted at a high density. It is important to note that the season (autumn or winter) and the district had a greater influence on yield than the individual variety. This result highlights the importance of growing a crop in the correct seasonal and geographic location for optimum yield and quality.

The trials also showed that planting with a single-row planting gave a more uniform plant stand than a double-row planting. As a result, a single-row planting is recommended for mechanical harvesting of broccoli. It is also important to have uniform irrigation and nitrogen applications for a uniform plant stand. Variations in these two inputs across a planting will produce variability in plant height and reduce the efficiency of the mechanical harvester.

Technical Summary

Broccoli production can be an expensive, labour intensive exercise, with much of the Australian crop hand-harvested. In an effort to reduce the harvest input costs Matilda Fresh, the National Food Industry Strategy (Food Industry Grant Project No. 0026) and Horticulture Australia (Project No. VG03083) have together invested in the first successful development of a commercial mechanical broccoli harvester. However, the highest percentage cut currently achievable by this mechanical harvester is 50% of the available heads. This low percentage mechanical cut is due to variability in the rate of crop development. In this project, AHR, Matilda Fresh and Sakata Seeds and South Pacific Seeds aimed to develop agronomic management strategies to improve the uniformity of the plant stand and in turn the efficiency of the mechanical harvester. The trials were run over three seasons in Gunalda, Qld, Toowoomba, Qld, Gatton, Qld and Armidale, NSW.

The research showed that the key improvements in crop uniformity can be made by increasing the plant density from 60,000 plants per hectare to 90,000 plants per hectare. The high density improved the head resistance to damage, by producing smaller heads. The high density plantings also produced heads with taller straigher stems that suited mechanical harvesting. The varieties Gypsy and Atomic consisently produced tall straight stems and small heads when planted at a high density in these trials. It is important to note that the season (autumn or winter) and the district had a greater influence on yield than the individual variety. This result shows the importance of growing a crop in the correct seasonal and geographic location for optimum yield and quality.

The trials also showed that planting with a single-row planting gave a more uniform plant stand than a double-row planting. As a result a single-row planting is recommended for mechanical harvesting of broccoli.

Another factor that was thought to affect the uniformity of the plant stand was the germination rate. In this work, the germination rate of raw, encrusted and primed seed was compared. There was no difference in the coefficient of variation (%CV) for the three treatments. This indicates that other factors other than seed treatment are causing the variability in germination. Another factor that could affect germination is the planting depth and our results showed that the highest germination percentage (80%) was achieved when seeds were planted at a depth of 6 to 15 mm.

The research also showed that uniform irrigation and nitrogen applications are important for a uniform plant stand. Variations in these two inputs across a planting will produce variability in plant height and reduce the efficiency of the mechanical harvester.

For mechanical harvesting to be successful it is important to have a uniform plant stand. This is best achieved with a dense single row planting of a suitable variety planted in an appropriate growing season. It is important that the key inputs of water and nitrogen are also uniformly applied.

1 Introduction

Broccoli production can be an expensive, labour intensive exercise, with much of the Australian crop hand-harvested. In an effort to reduce the harvest input costs Matilda Fresh, the National Food Industry Strategy (Food Industry Grant Project No. 0026) and Horticulture Australia (Project No. VG03083) have together invested $2,324,000 in the first successful development of a commercial mechanical broccoli harvester (Bon 2003; Bon 1997; Dellacecca 1996). However, the highest percentage cut currently achievable by the mechanical harvester is 50% of the available heads. This low percentage mechanical cut is due to variability in the rate of crop development. In this project we aimed to develop agronomic strategies and introduce and evaluate new broccoli varieties, which together resulted in a minimum 90% once-over mechanical harvest. If this could be achieved it would mean a 65% reduction in the cost of harvesting a broccoli crop by eliminating the need to hand-harvest.

The problem: Crop uniformity. It was proposed that if crop uniformity could be improved though new varieties (genetics) and agronomic management, a minimum 90% once-over harvest would be achievable, making hand-harvesting redundant. The opportunity to improve crop uniformity to enable a once-over mechanical harvest depends on a uniform plant height and uniform stage of development. The following aspects of broccoli production account for the majority of crop variability.

Genetics and plant architecture

Broccoli varieties are likely to have a major influence on uniformity and suitability of the plant for mechanical harvesting (Hulbert and Orton 1984). A variety with high developmental uniformity and a head which stands relatively clear of leaves and reaches full height rapidly and then fills out would be better suited to mechanical harvesting than current varieties. Current developments include 'new' elongated stem varieties with crowns (heads) which stand above the tops of leaves. These new varieties would be ideally suited to mechanical harvesting (Fyffe and Titley 1989; Tan, Wearing et al. 1998).

Planting and crop establishment

Most commercial large-scale broccoli worldwide is established by direct seeding (Kahn and Motes 1988; Parish, Bergeron et al. 1991). Poor establishment is currently the major issue for Matilda Fresh in Queensland and results in seedling losses of up to one-third of the 90,000 seeds per ha.

This poor establishment is important because it results in uneven spacing between plants which reduces crop uniformity. Some of the possible reasons for this seedling loss include:

- Soil crusting (Royle and Hegarty 1977)
- Poor soil moisture uniformity
- Variable seed vigour
- Insects and diseases (Maude, Bambridge et al. 1986)
- Variable planting depth
- Rain during establishment causing crusting; this is a significant problem and needs to be investigated.

Another option to consider is plant density; it may be that while increasing plant density does not improve overall yields it may significantly improve plant uniformity. This is likely because gaps that are left by plants which don't establish successfully would have a less significant effect on adjoining plants if densities are higher. It is likely that improvements in crop establishment (i.e. increasing the proportion of planted seeds that develop into mature plants) will have a major effect on eventual crop uniformity (Sorensen and Grevsen 1994). Some beds on the Matilda Fresh property run east/west and others run north/south. Plants on the northern side in the east/west-running beds get more sun than those on the southern side of the bed and this probably contributes to variability. Plants on either side of the north/south-running beds are more evenly developed.

Another issue to consider is crop scheduling. A lot of research has been done on broccoli scheduling for older varieties but little is known about the new varieties bred for mechanical harvesting (Tan, Birch et al. 2000a; Tan, Birch et al. 2000b; Tan, Wearing et al. 1998; Tan, Wearing et al. 1999a; Tan, Wearing et al. 1999b).

Irrigation and soil water

Variability in the distribution of soil moisture is also likely to be another major issue relating to crop uniformity. Furrow irrigation is used on the winter site at Matilda Fresh, Brookstead, and on the Darling Downs in Qld and sprinkler is used on the summer and transitional sites. The summer site is located at Armidale, NSW and the transitional site (autumn and winter) is at Gunalda, near Gympie in Qld. Both of these irrigation methods have well-known problems with uniformity of water distribution in the soil profile. One of the issues with furrow irrigation is that plants along the row do not get equal amounts of water.

Seed variability

Seed variability is another potential source of plant variability. For example, germination rates quoted on seed containers are in the order of 98%, and yet established plant populations can be as low as 60-70% of the number of seeds planted. The possible contribution of seed germination and/or vigour was investigated in order to assess its contribution to crop variability (Almeida, Rocha *et al*. 2005; Finch-Savage, Rayment *et al*. 1991).

Plant nutrition

It is likely that variations in the distribution of available plant nutrients in the soil may also be a significant factor in explaining some of the variation in crop maturity (Hegarty 1976; Rooster and Spiessens 1999). The variability in the levels of available plant nutrients and the effect of this variability on broccoli head uniformity was investigated.

2 General Material and Methods

Matilda Fresh grows broccoli at Brookstead, Queensland on 'Wando' farming operation. They currently grow broccoli on 220ha of a 2000ha farm. Other crops include onions, wheat and cotton. In general, the irrigation method is furrow, sourced from the Condamine River or from underground storage that feeds one of three on-farm storage dams. The soil type is black alluvial, self-mulching clay. All of the irrigation blocks have been laser-levelled to within 2cm accuracy. Rows are installed and planting done with the assistance of GPS. Current yields are about 9500 kg/ha, giving a total production of about 2000 tonnes per year.

The Gunalda site is located about 30km northwest of Gympie, Queensland, on a site which borders the Mary River. It has about 150ha under cultivation for lettuce and broccoli. The soil types on the farm range from alluvial flats to undulating clay-loam and water for irrigation comes from the Mary River.

The Armidale farm in New South Wales supports about 200ha of broccoli and lettuce. It is located 10km east of Armidale. The soil type is mainly loamy sand. High quality water for irrigation comes from Governor's Waters.

Planting and establishment

Seed at Matilda Fresh is direct-seeded using a Monosem™ vacuum seeder, established on twin rows on 1m-wide beds. The current planting density is 90,000-93,000 plants/ha, planted with a vacuum seeder. The resulting stand from this initial plant population is in the order of 60,000 - 70,000 plants/ha. This loss of up to one-third of the plant stand is likely to be a major source of variability in crop maturity and head size.

Irrigation

Water for irrigating the crops is supplied is via furrows which are 400 - 450m long. The sequence of operations is that the seed is sown into a dry seed bed which is then watered up. After emergence of the crop and weed seeds have started to germinate, the soil is cultivated with tines that run between broccoli plants. This cultivation is for weed control and for aeration. A second irrigation is then applied about one week later and this helps to reset the broccoli plants after the cultivation. Three weeks later, a side-dressing of nitrogen and potassium fertiliser is applied and followed by a third irrigation. Sometimes there is a fourth irrigation to provide water for the final stage of head expansion. The initial irrigations are along every furrow; some later irrigations are on alternate furrows.

Crop nutrition

Plant nutrients are supplied using a combination of basal pre-plant fertiliser application and a single side-dressing just before flower initiation. The basal fertiliser programme is composted chicken manure at 5 tonnes per ha plus NPK fertiliser. The fertiliser strategy is to supply a small amount of the nitrogen, all of the phosphorus and some of the potassium, pre-plant. The remainder of the nitrogen and potassium is then applied using a side-dressing just prior to flowering.

Harvesting

At the time the experiments were conducted, Matilda Fresh was harvesting for 18 - 20 weeks from May to September. They used two 22-person harvesting crews to pick about 150 bins per day. The labour used for hand harvesting represents 35-40% of the total labour used to produce the crop (Jauncey, pers. comm).

Each bin of harvested broccoli heads fills 20 cartons. This amounts to about 3,000 cartons per day. All broccoli is Hydrovac^{TM} cooled. The aim is to get the harvested broccoli heads into the Hydrovac^{TM} cooler within half an hour of harvest and reduce the head temperature to 2^{o}C. The cooled bins are then transported from the farm to the packing shed which is a half-hour trip in refrigerated trucks. Once at the processing shed, the bins are passed along a grading and packing line that uses robotics for grading the heads.

The best quality heads are packed in ice in polystyrene containers (for the domestic market) or in ice in wax cartons (for the Japanese market). The cartons can then be transferred directly to a refrigerated truck for delivery in Australia, or into a pre-cooled refrigerated container for export. The processing factory has a very good setup for loading trucks and containers and at no stage throughout the packing or loading operation does the broccoli need to come out of the cool environment. Airlock bays are used that allow the truck or container to be backed directly into the cool room. Heads that are outside of specifications for the fresh market or that have been grown specifically for florets, are passed through the floreting machine and through a series of washing steps. They are then packed into plastic trays with a MAP film placed over the surface.

Broccoli harvester.

Broccoli stand after machine harvesting.

Crop Rotation

There is currently a five-year rotation on Matilda Fresh farms at Brookstead. In years 1 and 2, broccoli is grown over autumn/spring/winter and then the field is used to grow an onion crop as a rotation. The fourth crop is wheat and the fifth is fallow, after which the land is laser-levelled again. In between crops the land is left fallow.

Important Note

In the final year of the project, the project partner and VC contributor Matilda Fresh went into receivership and subsequent liquidation. While this had some impact on the project, it did not render the objectives of the project unachievable. The issue was brought to the attention of the HAL Project Manager at the time. The mechanical harvesting aspects of the project were ahead of schedule at the time of the liquidation, and we were also able to continue trials on the three farms whilst Matilda was in receivership.

The final field trials were able to be completed on other farms in the same climatic regions and were not compromised. The VC funds were paid by AHR in the final stages and this had a negative impact on the amount of funding available for the project. We have worked to minimise the impact of this shortfall on the research output.

This final report outlines clear recommendations on how to maximise yield and quality of broccoli for once-over mechanical harvesting and will be a valuable resource document when interest in mechanical harvesting of broccoli is inevitably re-ignited.

3 Field and Small Plot Assessment of New Broccoli Varieties for Mechanical Harvesting

Introduction

A significant component of this project was the assessment of existing and new broccoli lines which were bred by Sakata Seed Company specifically for mechanical harvesting. The growth characteristics of broccoli are highly sensitive to the length of the growing period and temperature. It is therefore necessary to evaluate potential new varieties over the range of environments in which it will be grown, if a credible 12-month supply schedule is to be developed (Dufault 1996; Grevsen 1998).

Broccoli has been classified into four major classifications and several sub classifications (Kuwamura Manabu Sakata breeder pers. com). This has been driven primarily by broccoli breeders who developed varieties adapted to a range of climatic conditions. The classifications include:

1. **Extra-early:** warm, hot humid conditions in tropical and sub-tropical latitudes e.g. 'Green King' (Known-You)
2. **Early:** warm conditions in mid to high latitudes environments e.g. 'Green Magic' (Sakata)
3. **Mid-early**: e.g. 'Greenbelt'
4. **Mid:** transitional varieties that perform in late autumn/early winter and spring/early summer e.g. Marathon
5. **Mid-late**: 'Avenger' 7 days later than 'Marathon'
6. **Late:** cool to cold season varieties that tolerate moderate to severe frosts and have some tolerance to water staining/bacterial soft rot e.g. 'Green Veil' (Sakata)

The extra-early types are characterised by very quick maturing, particularly in sub tropical and tropical conditions, and they have been identified as inducing floral initiation at the appropriate leaf number at temperatures of 21-23^{0}C. An example of these types includes 'Green King' from Known-You Seed Company in Taiwan.

The early maturing varieties such as 'Green Magic' and 'Greenbelt' are used in the mid-season transitional season and these varieties have been recorded as changing from vegetative to reproductive initiation at temperatures around 17-18^{0}C.

The mid and mid-late maturing cool-weather types include the variety 'Marathon' from Sakata Seeds. These mid and mid-late maturing varieties only required 5-7^{o}C to initiate their floral primordia at the appropriate leaf number.

The late maturing types that have had only a minor place in the Australian industry, such as in Western Australia, are characterised by the Sakata variety 'Samurai'. These were recorded as initiating their floral primordia at 2-3^{0}C. They have a very narrow harvest window in the late winter/early spring period.

With the majority of the Australian broccoli industry located in the southern states, the cropping-schedule-by-variety information for this region has been well documented (Chung 1982; Grevsen 1998).

Now, with broccoli increasingly being grown in the winter time in south east Queensland, the same type of cropping schedule information has to be developed and made available to producers in that region. This will enable them to select varieties for harvesting from May to September that can cope with the climate.

Materials and Methods

The 2007 variety trials were set up at Matilda farms, at Brookstead, Queensland according to the following schedule.

All varieties were established as transplants and were planted using the standard farm fertiliser rates and agronomic practices. The seedlings were irrigated as soon as possible after planting using furrow irrigation. The planting configuration was: beds spaced at 0.9m between centres and 2 rows of plants per bed with 30cm between plants (60,000 plants per ha). In 2007, comparisons of varieties were also made at densities of 30,000 and 90,000 plants per hectare.

Table 3.1. Seeding Schedule for Broccoli Project Variety Trials 1 to 4.

No.	SPS Name	Other Name	Transplant date	Number planted	Relative days to maturity
1	SPS 563-4	Brumby	12/04/2007	Sow all 16 grams	110-115
2	SPS 494-3	Patron	12/04/2007	2,500	105
3	SPS 1151-5	Gypsy	12/04/2007	2,500	93
4	SPS 905-8 (Control)	Atomic	12/04/2007	2,500	90
5	SPS 627-6	Emerald Pride	12/04/2007	2,500	95
6	SPS 905-8	Aurora	12/04/2007	2,500	
7	SPS 1112-5	Bridge	12/04/2007	2,500	115

No.	SPS Name	Other Name	Transplant date	Number planted	Relative days to maturity
1	SPS 1112-5	Bridge	2/05/2007	2,500	115
2	SPS 608-6		2/05/2007	2,500	110
3	SPS 494-3	Patron	2/05/2007	2,500	
4	Control	Mascot	2/05/2007	2,500	
5	Control	Evergreen	2/05/2007	2,500	

No.	SPS Name	Other Name	Transplant date	Number planted	Relative days to maturity
1	SPS 568-6		16/05/2007	sow all 4 grams	115
2	SPS 1112-5	Bridge	16/05/2007	2500	115
3	SPS 608-6		16/05/2007	2500	110
4	Control	Evergreen	16/05/2007	2500	

No.	SPS Name	Other Name	Transplant date	Number planted	Relative days to maturity
1	SPS 1112-5	Bridge	31/05/2007	2500	115
2	SPS 608-6		31/05/2007	2500	110
3	Control	Bravo	31/05/2007	2500	

Please note: variety Trials 3 and 4 were not able to be machine-harvested due to heavy rain (we have pictures of the harvester bogged when attempting this!). These trials were hand-harvested and the data collected.

Yield and Quality Assessments

Mechanical Harvest

At least 1000 heads were harvested per plot, irrespective of quality or stage of maturity from a data area selected out of the trial area. Of the harvested heads, 100 heads were sub-sampled and graded according to damage caused to the head and to the stem. The scale used was:

1 = undamaged and suitable for export
2 = slight damage and suitable for the domestic market grade 1
3 = more damage but still suitable for the domestic market grade 2
4 = more damage again, and only suitable for floreting
5= unmarketable

Other data collected

1. *Area harvested:* The area harvested for trial 1 was 70m long x 4 beds (8 plant rows) wide (=1860 plants) and for trial 2, each area harvested was 50m long x 4 beds (8 plant rows) wide (=1300 plants).
2. *Yield*
3. *Harvest efficiency* – ie % of marketable heads at harvest. This was achieved by harvesting 1000 heads including small, over-mature and damaged heads (sub-sample taken and counted)
4. *Ratio of marketable heads*: classified and counted (Crown/Processing/unmarketable head (small)/unmarketable (over-mature head)

5. *Damage during mechanical harvest* – ratio of damaged heads during mechanical harvest – number of marketable but damaged heads/1000 heads

Note: the time taken for harvesting was not reported because it was so variable, and would not be a true representation of potential commercial harvest time.

Table 3.2. Quality parameters used to assess the small plot variety trials

Criteria	Unit of Measure
Head diameter	mm
Head weight	g
Head colour	rating (1=blue green, 2=dark green, 3=green, 4=lime green, 5=yellow)
Stalk (butt) diameter	mm
Hollow stem	rating 1-5 (1 = no sign, 5 = severe)
Head density	Rating 1-5 (1 = dense buds, 5 = open head)
Lodging	Number lodged (knocked over by harvester)

In 2008 and 2009 these trials were repeated as described for 2007 at Matilda Farms, Brookstead, Qld. In 2008 the broccoli was harvested from the 1st – 4th of July with the following Sakata varieties: Gypsy, Patron, 07-1117, K6-091, NA-6900, Brumby, Aurora and Atomic. In 2009 the broccoli was harvested from commercial farms in Gatton, Qld. The varieties and harvest dates are in Table 3.3.

Table 3.3. Varieties and harvest dates for the 2009 variety trials.

Trial 1		Trial 2		Trial 3	
Harvested	21/06/2009	Harvested	31/07/2009	Harvested	10/09/2009
1	Atomic	1	Atomic	1	Bridge
2	Aroura	2	Aroura	2	Aroura
3	Brumby	3	No seed	3	K6 -091
4	Bridge	4	Bridge	4	Na 690
5	K9-609	5	K9-609	5	07-1117
6	Na 690	6	Na 690	6	Patron
7	07-1117	7	07-1117		
8	Patron	8	Patron		

Results and Discussion

Mechanical Harvest Trial 1, 2007

Small plot quality and yield assessments were carried out on all varieties but due to limitations with rain, it was only possible to mechanically harvest three varieties from that trial. The results are summarised below.

1. Variety 494-3

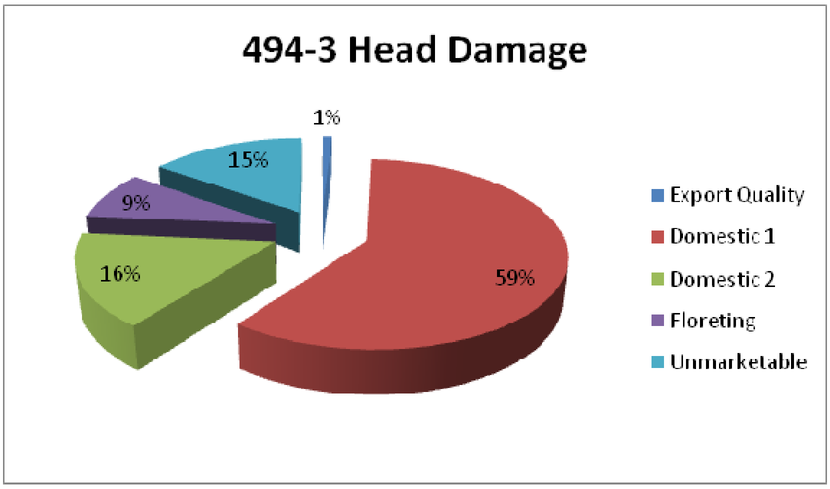

Figure 3.1. Variety 494-3 head damage after mechanical harvesting

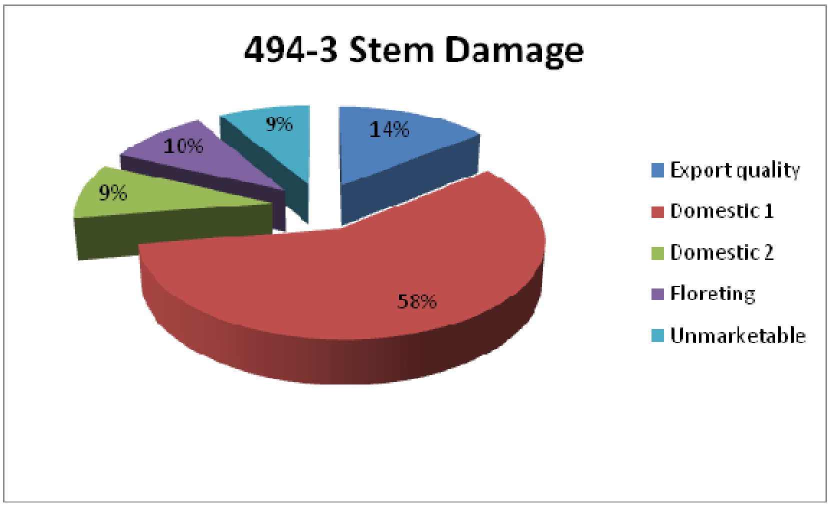

Figure 3.2. Variety 494-3 stem damage after mechanical harvesting

Variety 494-3 was very resistant to damage caused by mechanical harvesting. While very little product was completely undamaged, around 60% was still suitable for grade 1 domestic use. About 15% (head damage basis) was unmarketable due to excessive damage. The head damage was more of a limitation to quality than was stem damage.

2. Variety Aurora

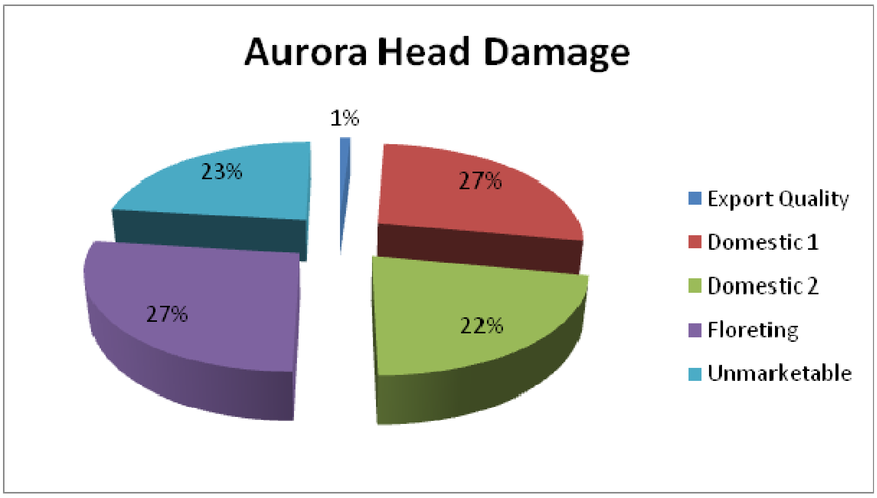

Figure3. 3. Variety Aurora head damage after mechanical harvesting.

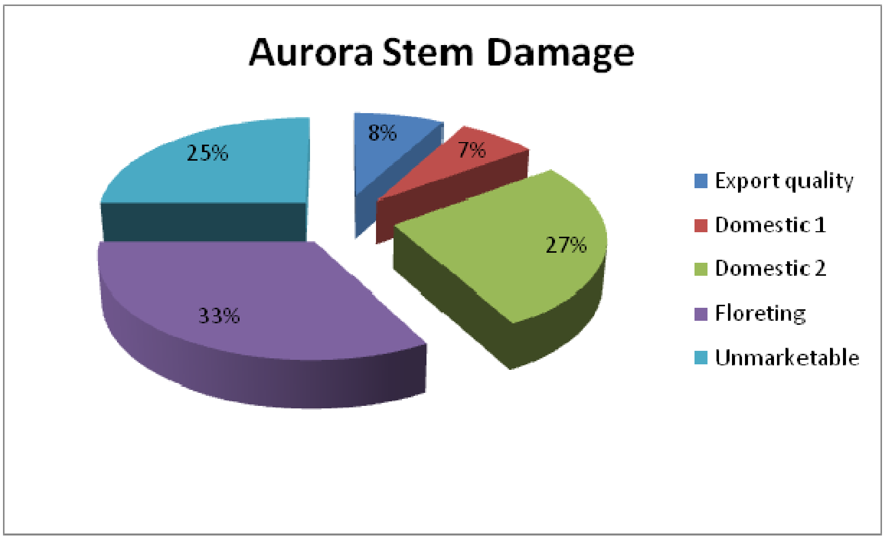

Figure 3.4. Variety Aurora stem damage after mechanical harvesting.

The variety Aurora was more susceptible to damage than 494-3. Again, only 1% of heads were completely undamaged and 27% were suitable for domestic grade 1 product. In the case of Aurora, stem damage was more of a limitation than for 494-3.

3. Variety Brumby

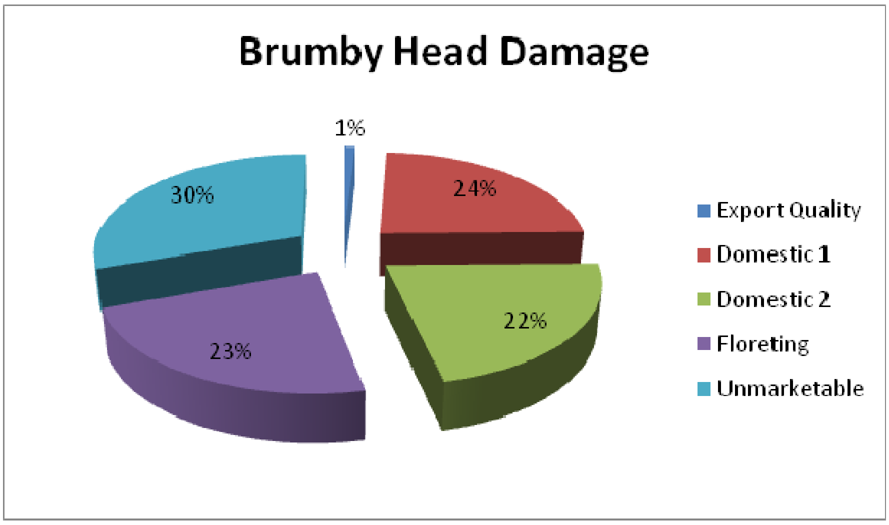

Figure 3.5. Variety Brumby head damage after mechanical harvesting.

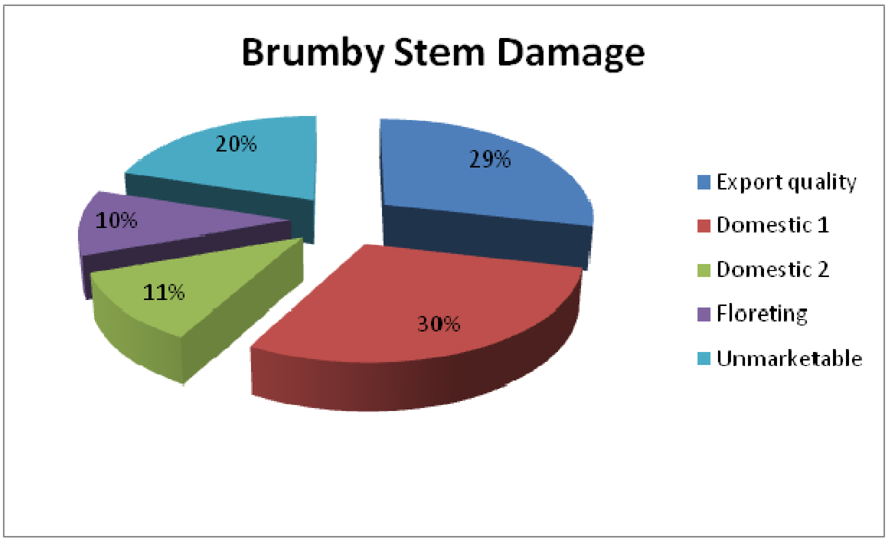

Figure 3.6. Variety Brumby stem damage after mechanical harvesting.

The head damage response for Brumby was similar to that for Aurora. The stems of Brumby, however, were more resistant to damage with 29% remaining undamaged.

Mechanical Harvest Trial 2

1. Variety 1112-5

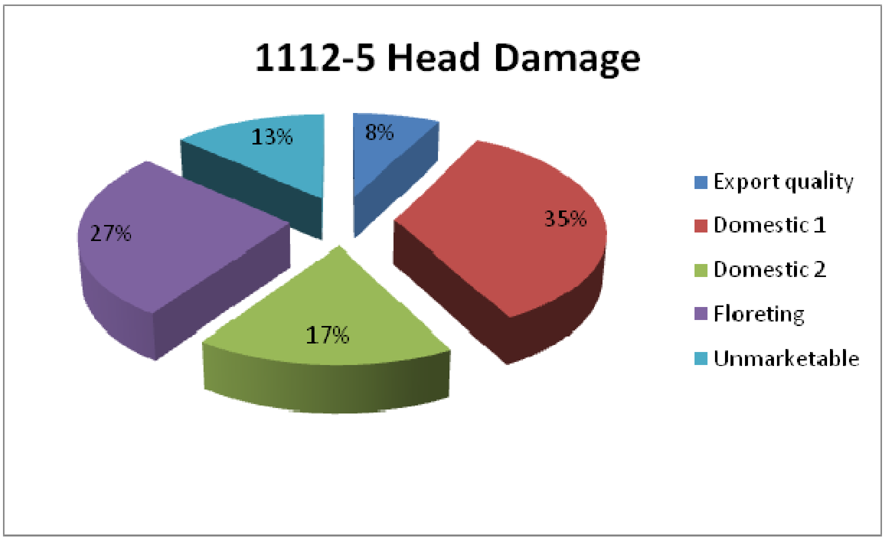

Figure 3.7. Variety 1112-5 head damage after mechanical harvesting.

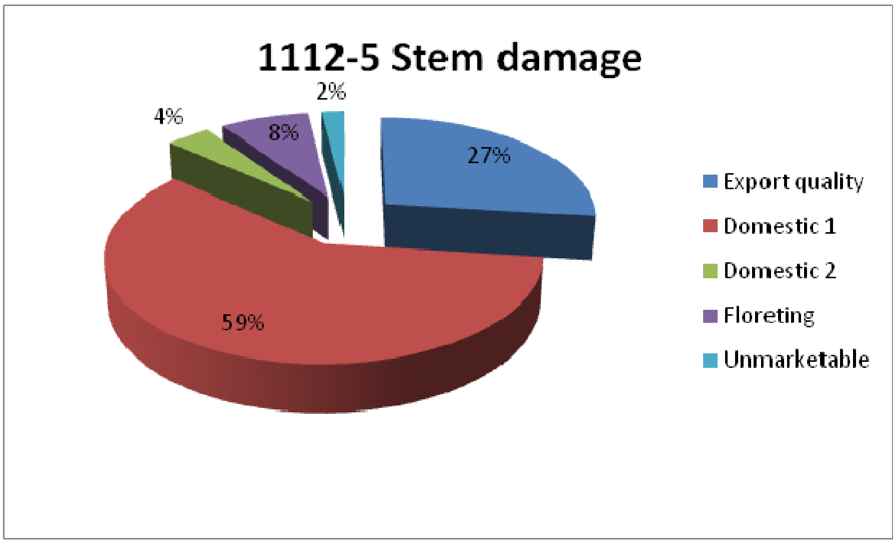

Figure 3.8. Variety 1112-5 stem damage after mechanical harvesting.

The 1112-5 head was moderately sensitive to damage from the mechanical harvester with over half of the heads still marketable to the fresh market. The stems, however, of this variety are very resistant to damage.

2. Variety 494-3

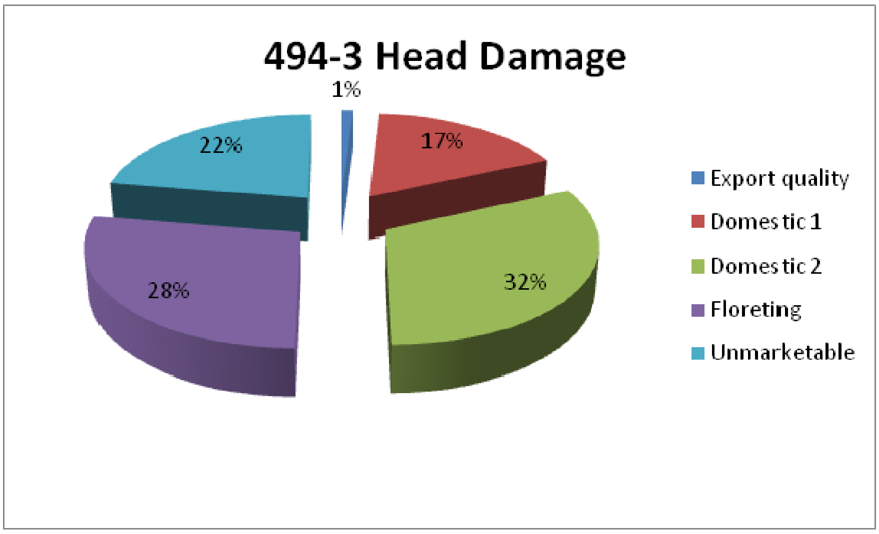

Figure 3.9. Variety 494-3 head damage after mechanical harvesting.

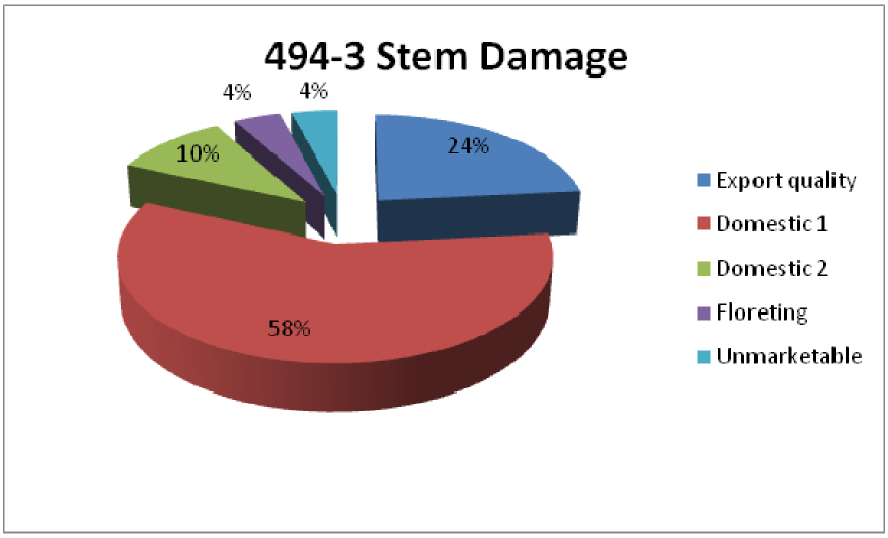

Figure 3.10. Variety 494-3 stem damage after mechanical harvesting.

In this trial, 494-3 heads were not as resistamt to damage as in the first trial. However, the stems were highly resistant.

3. Variety 608-6

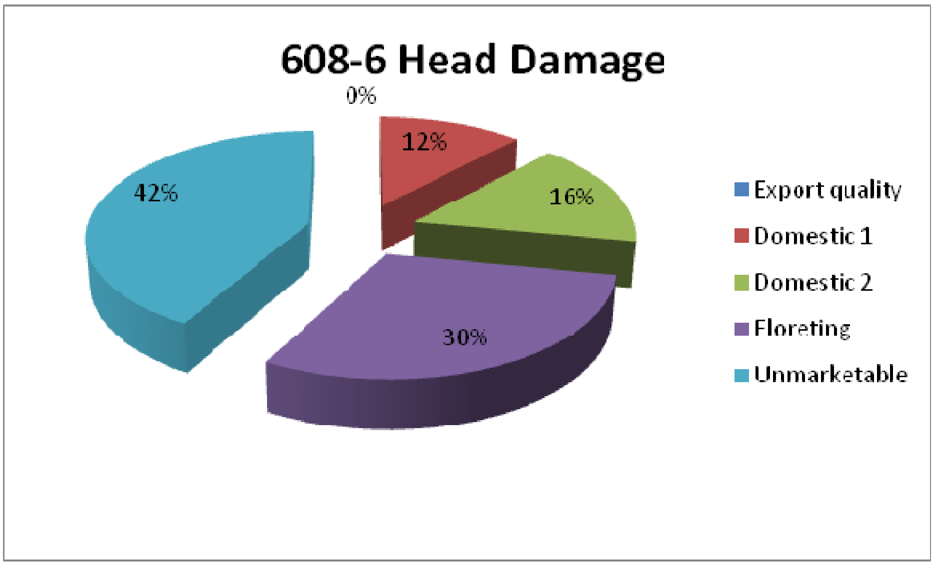

Figure 3.11. Variety 608-6 head damage after mechanical harvesting.

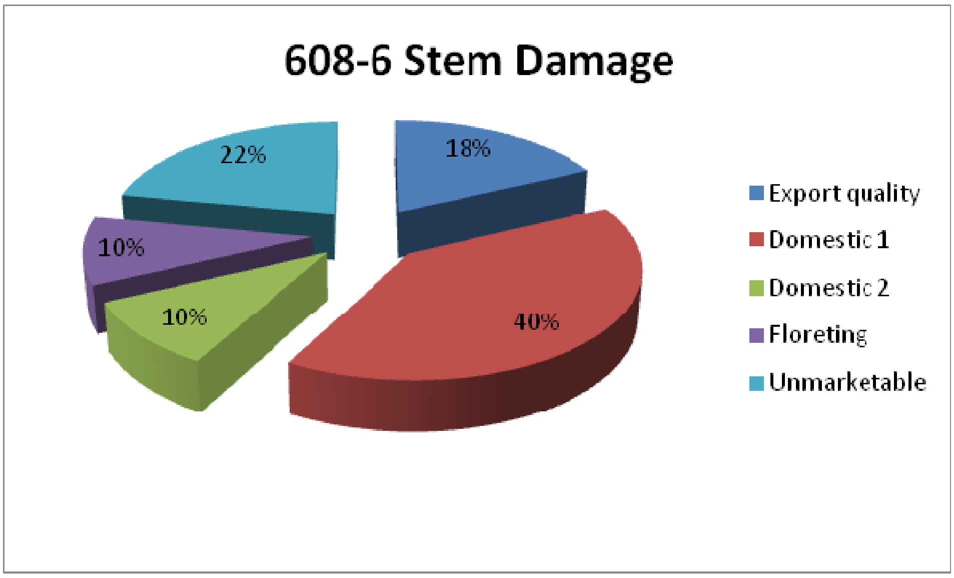

Figure 3.12. Variety 608-6 stem damage after mechanical harvesting.

Variety 608-6 heads were highly susceptible to damage from the harvester with 72% either unmarketable or suitable for processing only.

4. Variety Mascot

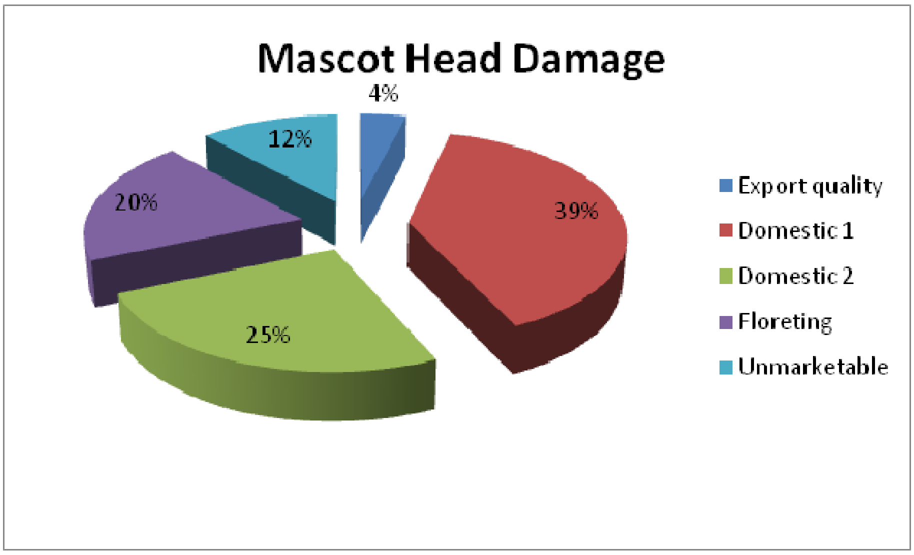

Figure 3.13. Variety Mascot head damage after mechanical harvesting.

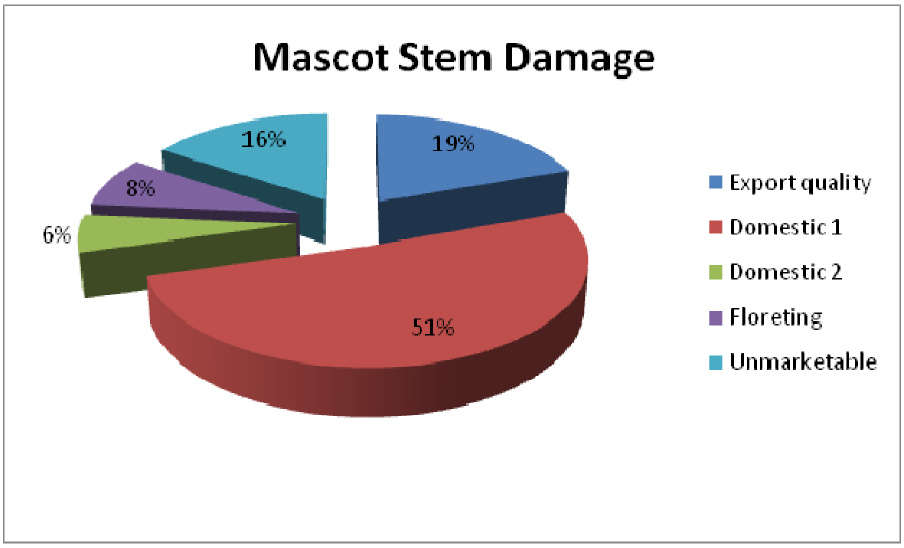

Figure 3.14. Variety Mascot stem damage after mechanical harvesting.

Mascot heads were moderately resistant to mechanical damage.

5. Variety Evergreen (control)

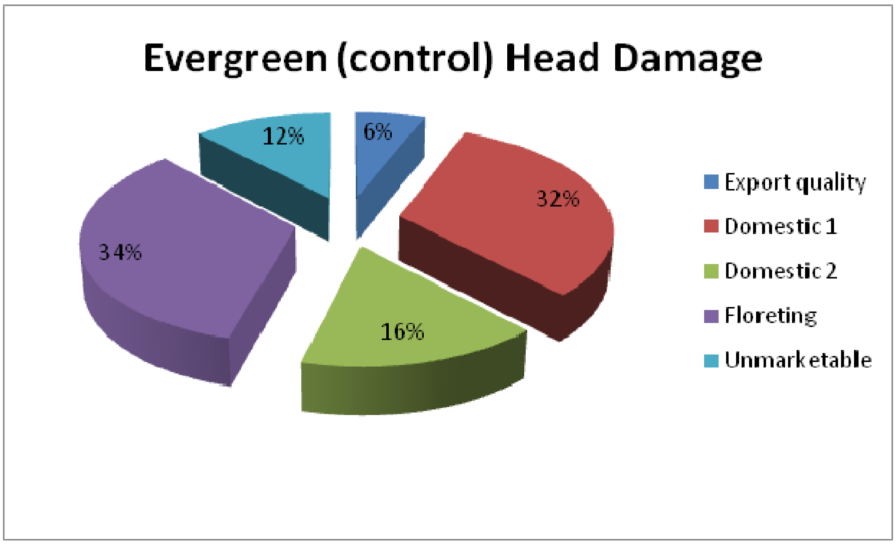

Figure 3.15. Variety Evergreen (control) head damage after mechanical harvesting.

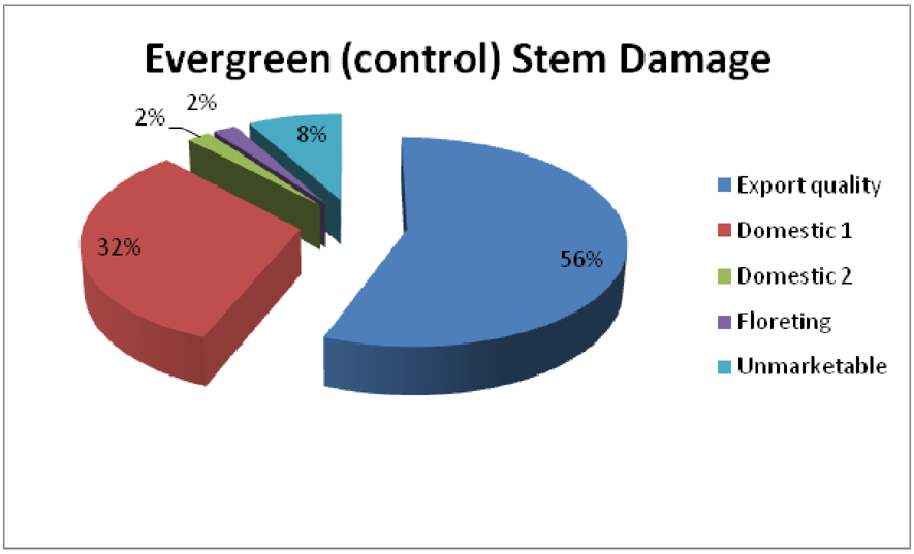

Figure 3.16. Variety Evergreen stem damage after mechanical harvesting.

Evergreen heads were only moderatley resistant to mechaincal damage, but the stems were very highly resistant. This was the most resistant of all the varieties tested in 2007.

6. Variety Evergreen (High density 90,000 plants/Ha)

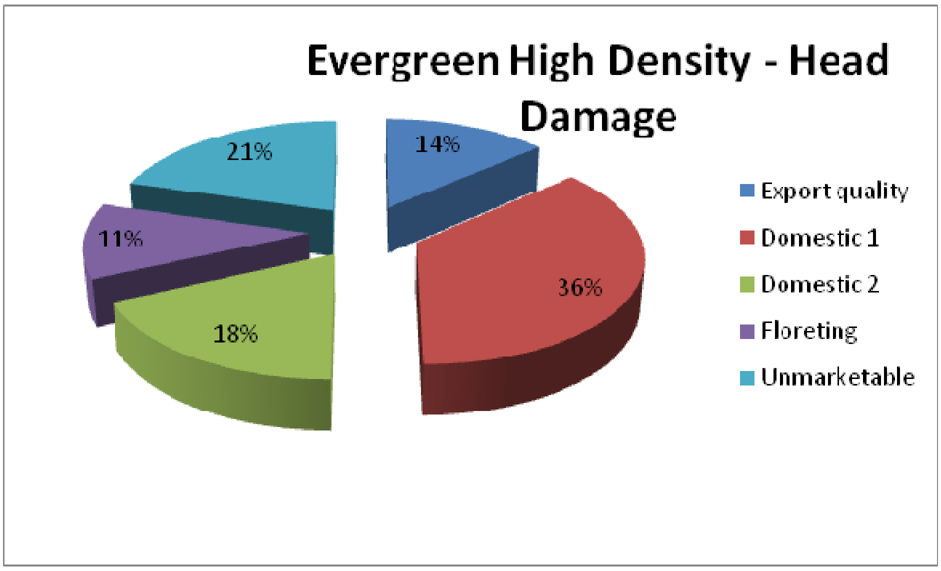

Figure 3.17. Variety Evergreen head damage after mechanical harvesting after planting at high planting density.

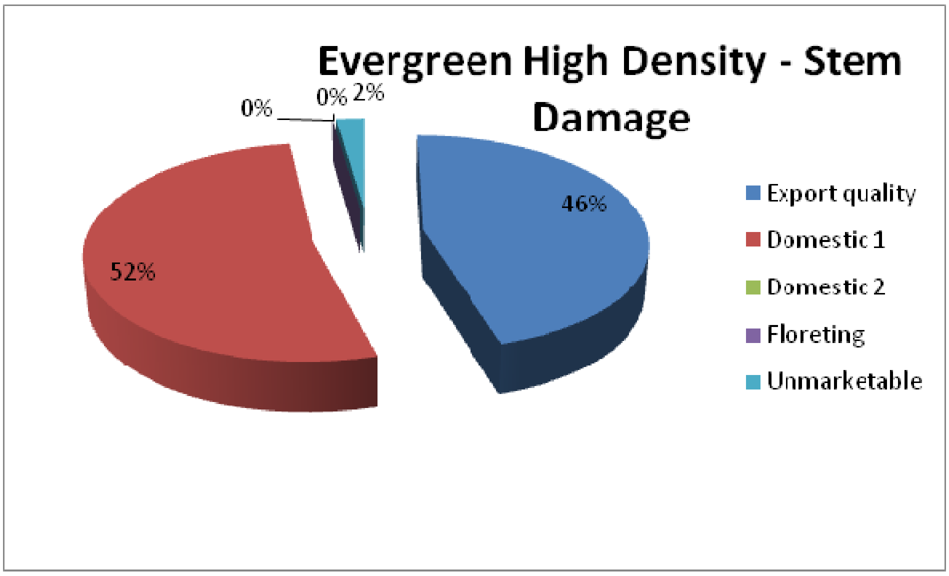

Figure 3.18. Variety Evergreen stem damage after mechanical harvesting after planting at high planting density.

Increasing the plant density from 60,000 plants per hectare to 90,000 improved the head resistance to damage. This may be have been due to smaller heads that were produced as a result of the higher density (Fig. 3.18).

7. Variety Evergreen (Low density 30,000 heads/Ha)

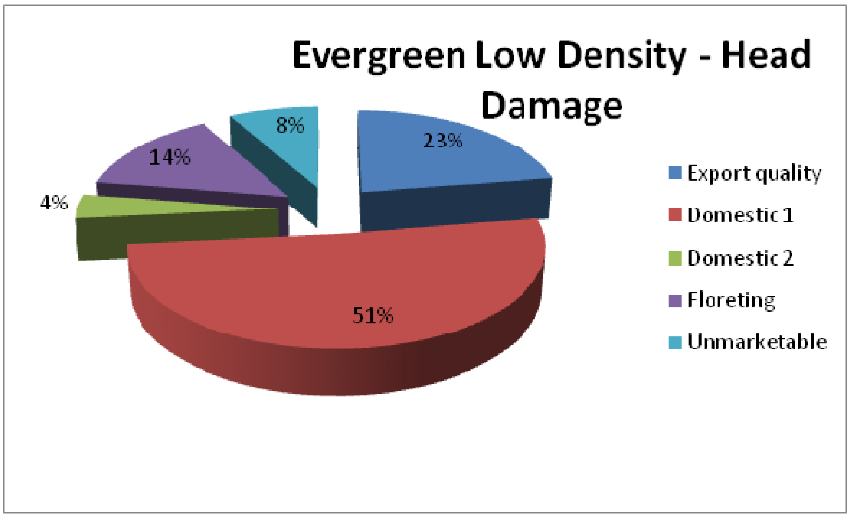

Figure 3.19. Variety Evergreen head damage after mechanical harvesting after planting at low planting density.

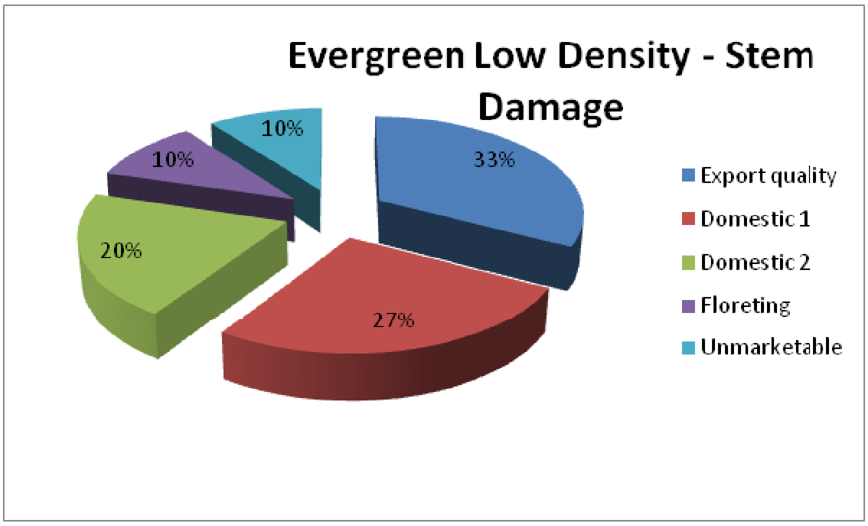

Figure 3.20. Variety Evergreen stem damage after mechanical harvesting after planting at low planting density.

Growing plants at a higher planting density had a significant effect on improving the heads' resistance to mechanical damage caused by the harvester (Figs 3.17 and 3.18). This may have been due to the plants being taller and straighter than standard-density plants.

The average head weights (Fig. 3.21) suggest larger heads may be more susceptible to mechanical damage. Figure 3.21 shows that variety 608-6, which was the most damaged during mechanical harvesting, had the largest heads.

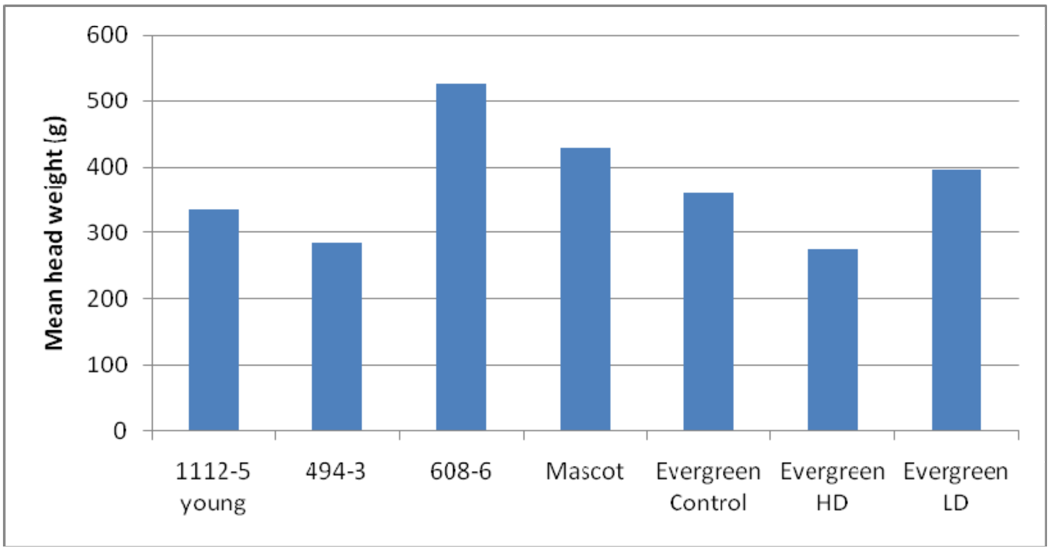

Figure 3.21. Average head weights of the machine harvested head samples.

Relationship between head diameter and head weight

There was a good relationship between head weight and crown diameter for the three varieties harvested in the first trial in 2007. The relationship was logarithmic and the R^2 values were all high, indicating a strong correlation. The relationship was similar for all varieties.

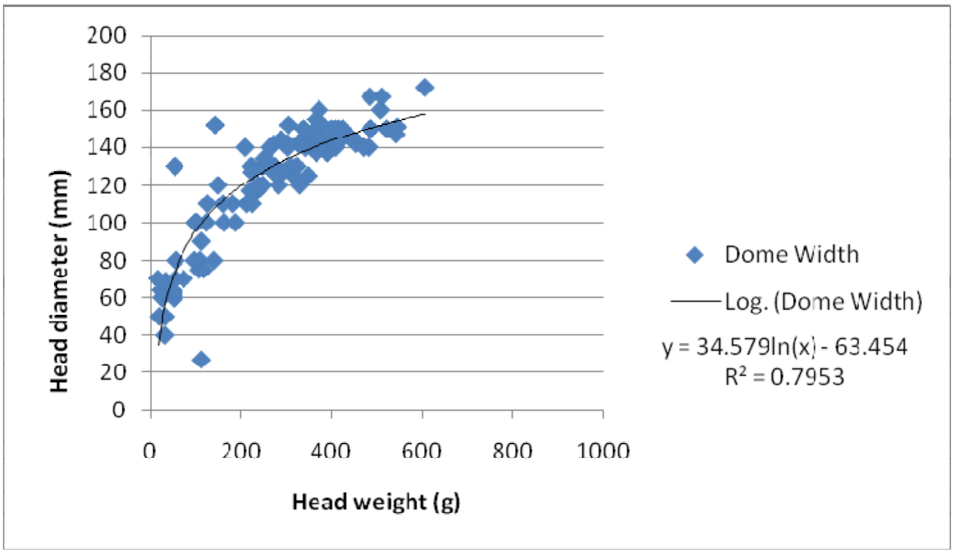

Figure 3.22. Head weight and diameter for 494-3.

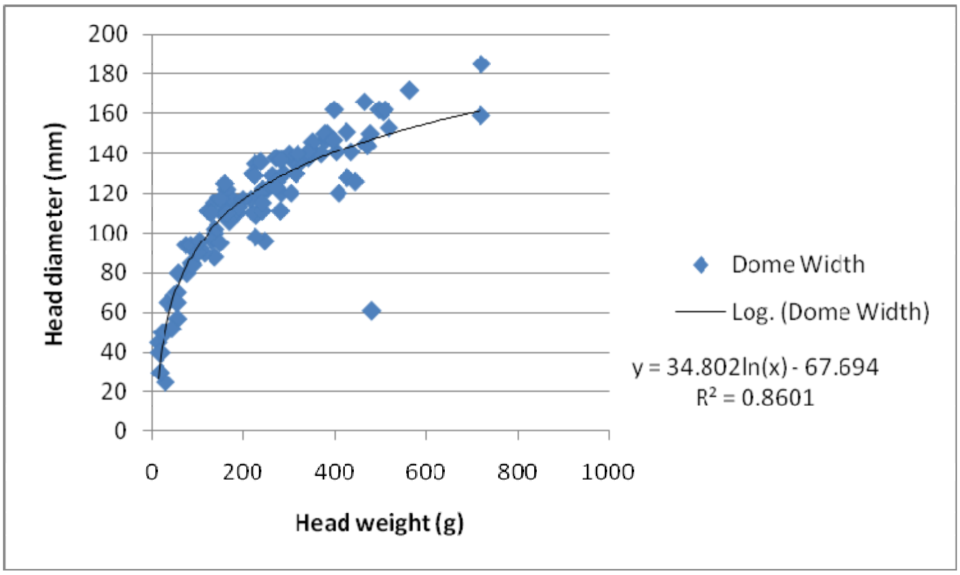

Figure 3.23. Head weight and diameter for Aurora.

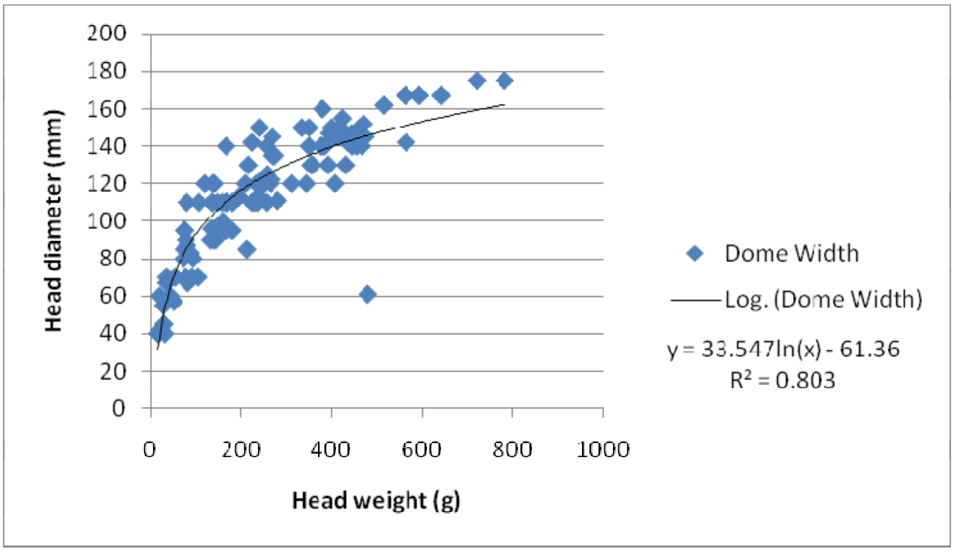

Figure 3.24. Head weight and diameter for Brumby.

Small plot comparison of broccoli head quality after mechanical harvesting

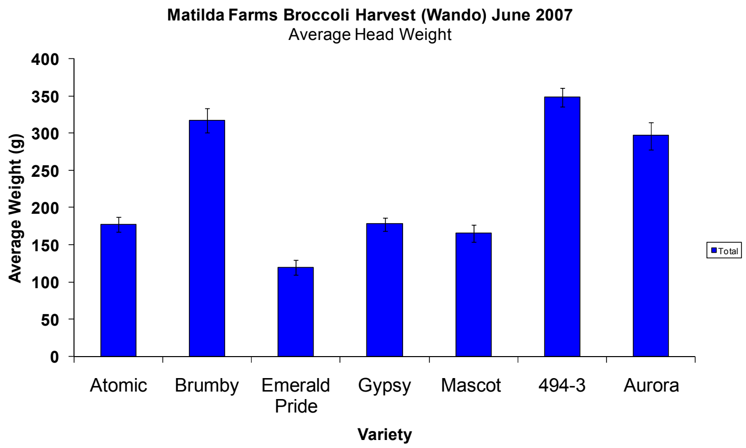

Figure 3.25. Average head weight for the varieties assessed in Trial 1, Gunalda Qld, 2007.

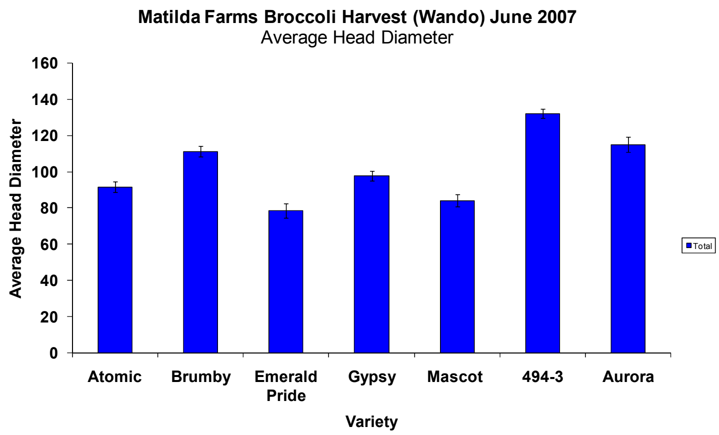

Figure 3.26. Average head diameter for the varieties assessed in Trial 1, Gunalda Qld, 2007

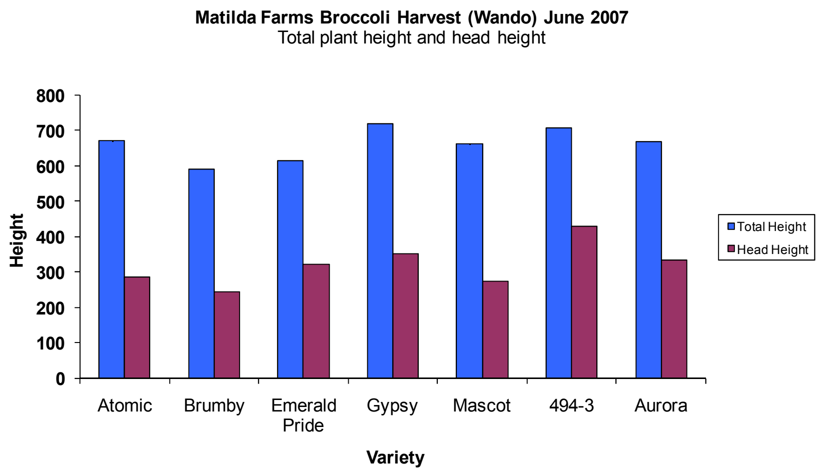

Figure 3.27. Average plant height and head height for the varieties assessed in Trial 1, Gunalda Qld, 2007.

There were no significant differences between the varieties in terms of the head weight, diameter, plant height and head height. However, it can be noted that variety 494-3 had a high weight and diameter and was of good quality after mechanical harvesting.

Variety Trial Results 2008

Determining the best variety to grow at a given time is a complex decision. The results from the variety trials for 2008 show that Variety K6-091 had the highest percentage of harvested heads (Figure 28) and the lowest percentage of heads left (Figure 29) in the field or lodged (knocked down) in the field (figure 30) for harvest 1. However, this variety did not perform as well for harvest 2 (Figure 31).

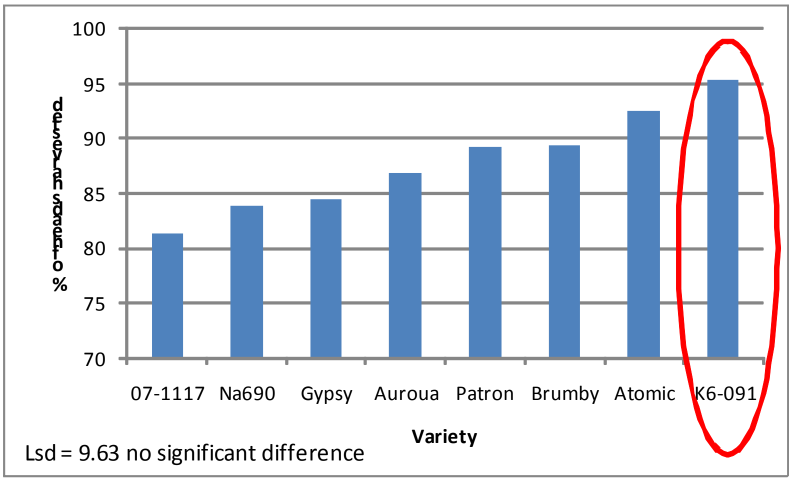

Figure 3.28. Comparison of the percentage of heads harvested for different varieties of broccoli Gunalda, Qld, 2008.

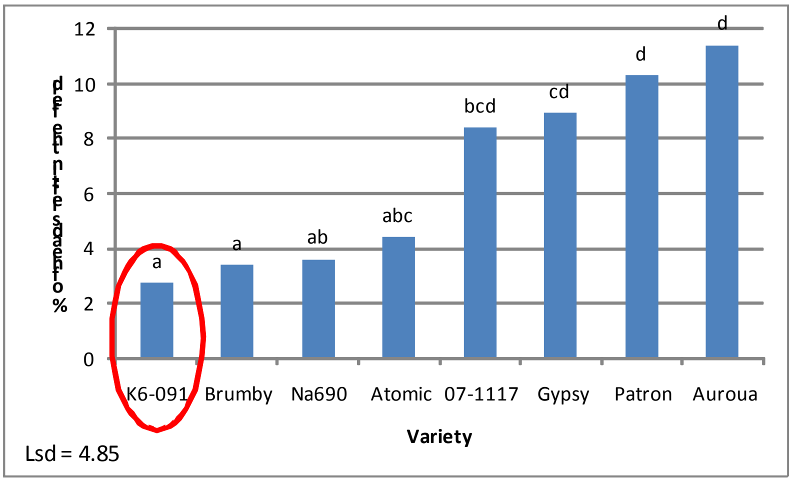

Figure 3.29. Comparison of the percentage of heads left in the field for different varieties after mechanical harvesting 2008.

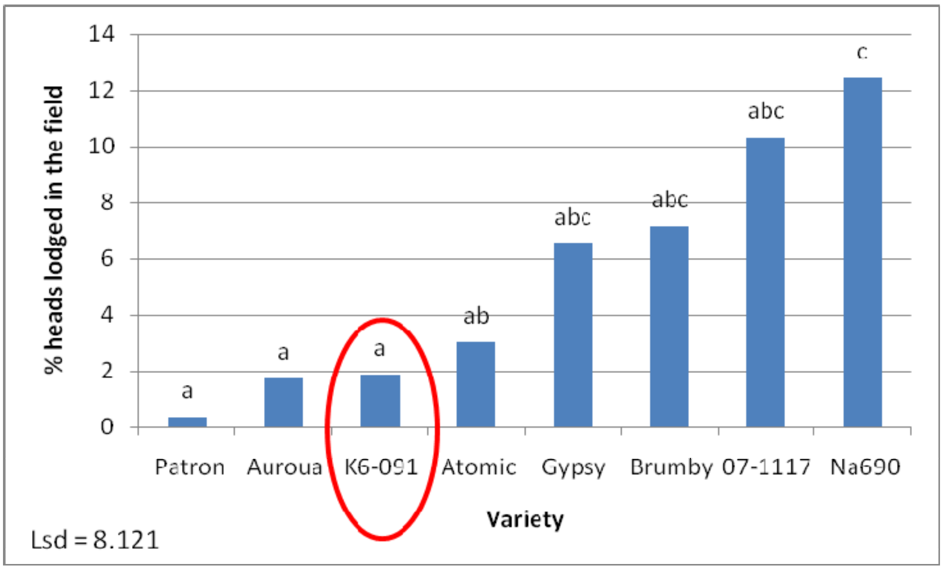

Figure 3.30. Comparison of the percentage of heads lodged (knocked over) in the field of different varieties after mechanical harvesting 2008.

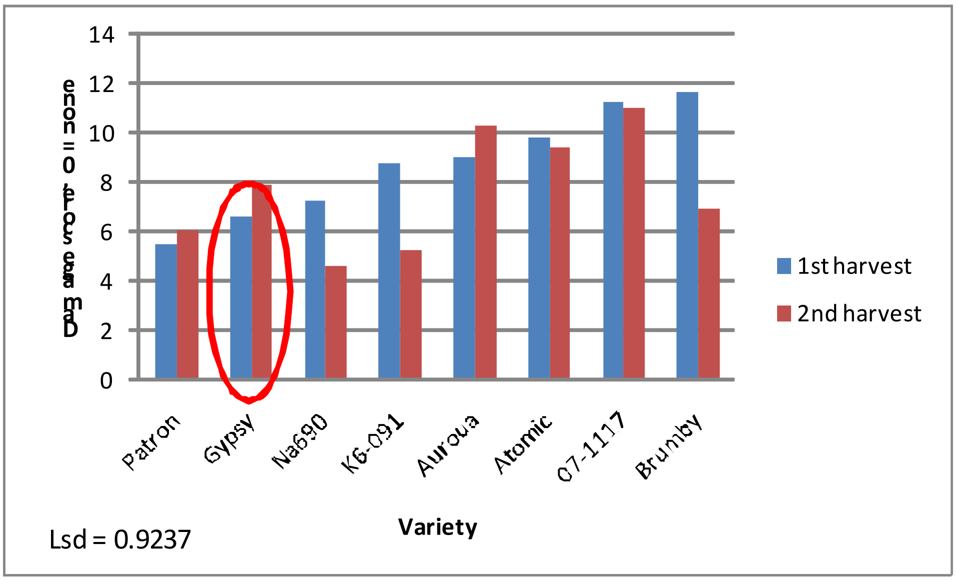

Figure 3.31. Comparison of the damage score for different varieties after mechanical harvesting.

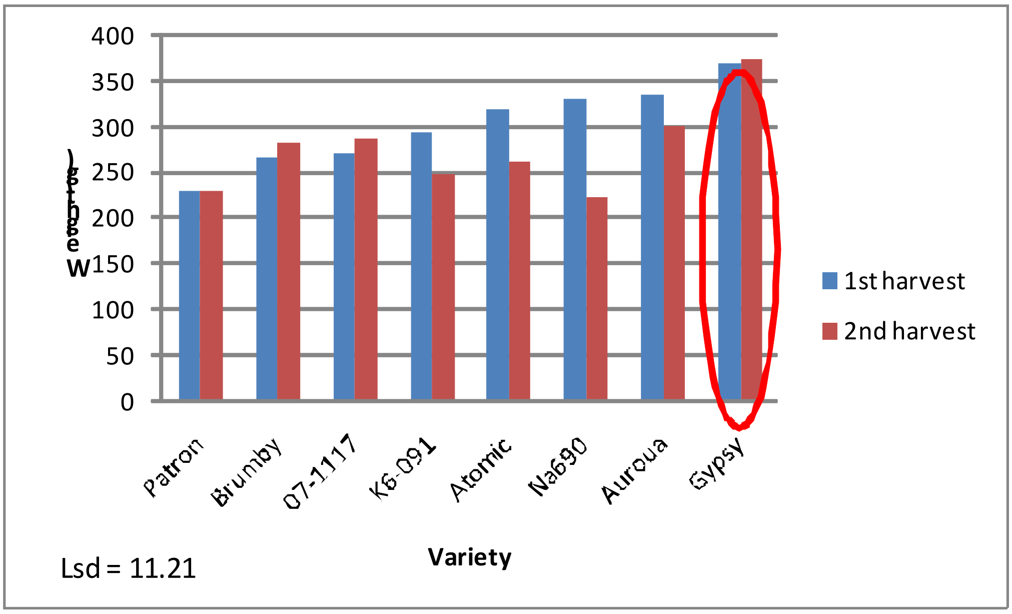

Figure 3.32. Comparison of the head weight for different varieties after mechanical harvesting.

When the results for the two harvests are compared, the variety Patron has the lowest damage score and the lowest number of heads lodged in the field after mechanical harvesting. But unfortunately, it also has the lowest head weight, resulting in the lowest yield (Figure 32). The idea of a smaller head suffering less damage supports the results from 2007.

When the damage score, number lodged and yield are considered, the varieties Gypsy and Atomic are a good compromise. They have tall straight stems which may make them more suitable for mechanical harvesting than some of the other more squat varieties, although this is a difficult parameter to quantify.

The variety Gypsy: long, straight stem

The variety Atomic: straight stem

The variety Brumby: more compact stem

Observations of varieties and machine harvesting 2008

Variety number	Variety name	Suitability	Floreting/Fresh market	Mechanical harvest performance notes
8	Gypsy	Early variety. Purpling in cold weather. Suitable for processing, not enough weight in head for fresh market.	Processes ok but discolours in response to frost.	Prone to lodging.
7	Patron	Not so good as a fresh-market variety.	Good for floreting.	Not much lodging.
6	07-1117	Maybe ok for hand-cutting in the field and floreting. Very low head, small bead size.	Suitable for floreting and fresh market.	Cannot get cutter bar low enough, top blade cuts into the head.
5	K6-091	More of a heat-tolerant type. Very nice looking, domed head – suitable for fresh market. Not suitable for processing – doesn't floret well.	Good fresh market, not floreting.	Fair amount of damage during harvest.
4	NA-6900	High head position. Large heads with separated florets. Potential for floreting as long as firmness holds up. Yield good.	Good for floreting.	Upright plant with not too much lodging.
3	Brumby	Looks good, large flat head.	Good for floreting.	Jams in the harvester (3 times in 100m).
2	Aurora	Low head and fairly leafy. Note: plant count 20% down in field.	Good for fresh market florets well but some yellow	Low head can make mechanical harvesting difficult
1	Atomic	High yield – 50% higher than others. Heads appear to resist damage well.	Both floreting and fresh market.	Not much lodging (only 4 plants in whole plot).

Examples of different growth habits of some of the broccoli varieties trialled.

Results for 2009 small plot variety trials in Gatton and Toowoomba, Qld.

In 2009, the variety trials were repeated to determine the effect of season and district. The trials were run in Toowoomba and Gatton over the autumn and winter period.

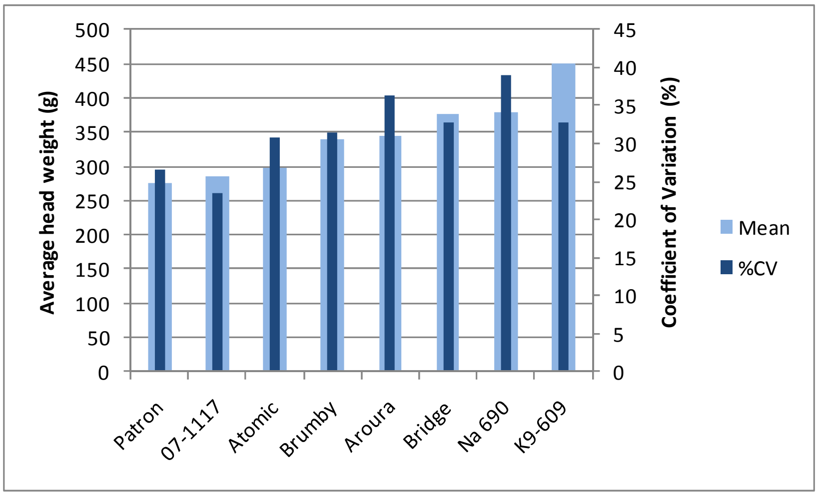

Figure 3.33. Average head weight and coefficient of variation for broccoli varieties from Trial 1, Gatton 2009.

Figure 3.33 shows that there was a difference between the varieties. There was a high coefficient of variation in this trial for variety K9-609 indicating an uneven plant stand which may not be suitable for mechanical harvesting. All varieties had head weights suitable for processing with Aurora and Na 690 having the highest head weights of the varieties trialled.

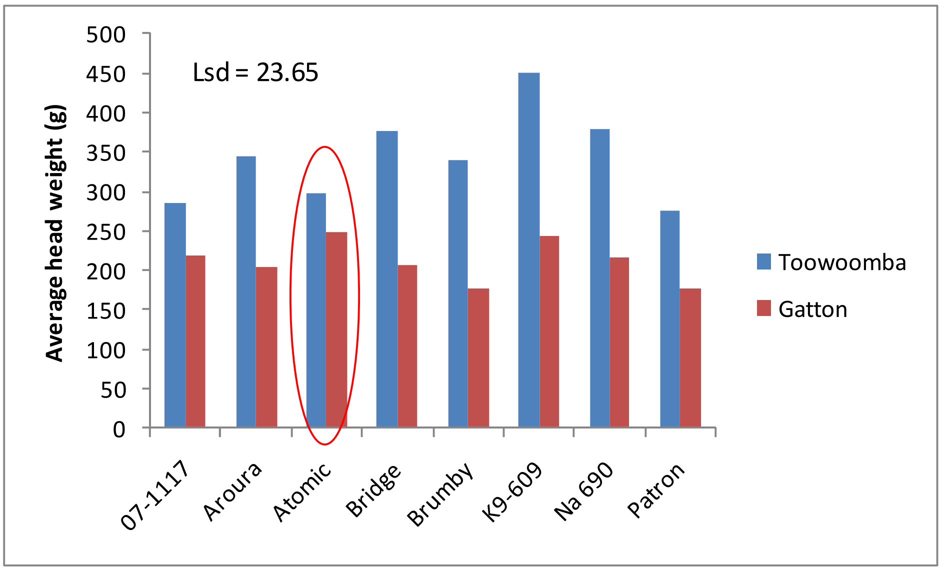

Figure 3.34. Average head weight of broccoli varieties from the first trials in Toowoomba and Gatton, Qld 2009.

When the head weights for the varieties were compared between districts (Figure 3.34) the variety Atomic was the most consistent performer. The variety K9-609 had the highest yield in Toowoomba but this result could have been due to a late harvest and a more mature head relative to the other varieties tested. When the results for the Gatton and Toowoomba sites were combined there was a significant difference between the head weights relative to growing season and relative to district. Winter heads and heads from Toowoomba were heavier (Table 3.3). There was no significant interaction between these 2 parameters and variety. This means that the district and the season in which the broccoli is grown has a bigger impact on yield than the selected variety. This demonstrates the importance of growing a crop in the correct seasonal and geographic location for optimum yield and quality.

Table 3.4. Effect of season and district on the head weight of broccoli.

Season	**Head weight (g)**	**LSD**
Winter	365.9	a
Autumn	292	b
District	**Head weight (g)**	**LSD**
Gatton	249.6	a
Toowoomba	386.2	b

(Values followed by a different letter are significantly different. The interaction between season or district with variety was not significant.)

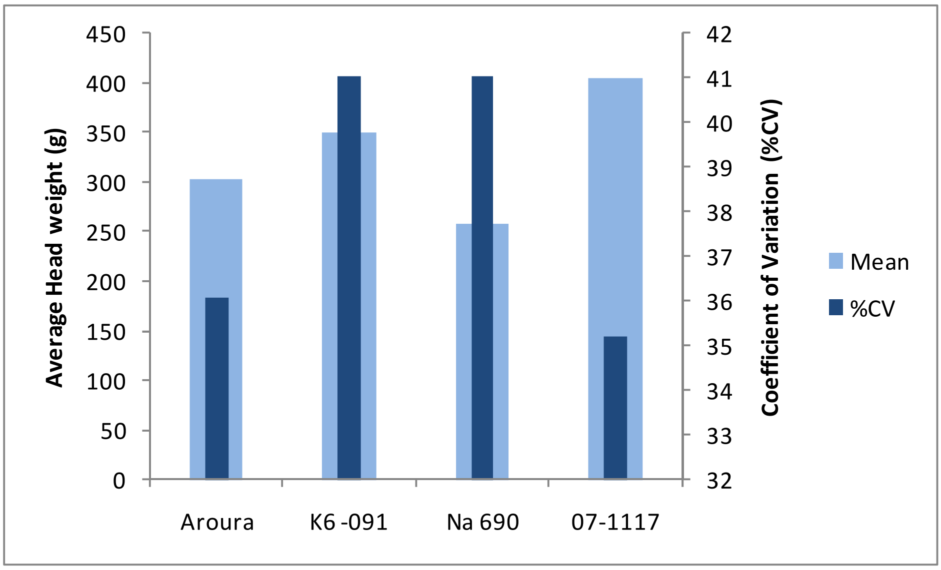

Figure 3.35. Average head weight and coefficient of variation for broccoli varieties from Trial 3, Toowoomba 2009.

For mechanical harvesting to be cost-effective compared to hand-harvesting, a uniform plant stand is a critical factor. The coefficient of variation for the third small plot variety trial shows that the varieties Aurora, 07-1117 and K6-091 had high coefficients of variation and so would be unsuitable under these conditions for mechanical harvesting. In this trial the variety Na 690 produced a more uniform head weight across the plot.

Table 3.5. Summary of the quality parameters assessed for the broccoli heads at harvest, Toowoomba Trial 3, 2009.

	Variety	Aurora	K6 -091	Na 690	07-1117
Bead size	Mean	2.456	1.994	2.57	2.19
	%CV	14.19	24.76	14.77	54.94
Bead uniformity	Mean	1.825	2.425	2.244	2.256
	%CV	32.94	13.57	20.37	24.17
Density	Mean	2.45	2.69	2.49	2.325
	%CV	15.77	15.77	15.98	20.84
Head colour	Mean	3.26	3.27	3.27	3.67
	%CV	17.58	17.54	17.54	14.54
Head shape	Mean	2.89	3.56	2.75	2.71
	%CV	18.38	12.81	15.03	13.04
Head weight	Mean	303.1	350.6	258	404
	%CV	36.08	41.02	41.03	35.2

In all the variety trials the quality of the head was determined using a range of parameters (Table 3.5). The quality of the head of all varieties was reasonably consistent as shown by relatively low coefficients of uniformity. However, the variety 07-1117 had a highly variable score for bead size (%CV = 54.94) and this may make this variety less appealing as a processed product. Variety 07-1117 also had a variable head weight and so would not be a good variety to choose for mechanical harvesting under the conditions of this trial.

Conclusions

- Increasing the plant density from 60,000 plants per hectare to 90,000 improved the head resistance to damage. This may have been due to smaller heads which were produced as a result of the higher density. Plants also had taller and straighter stems at higher densities.

- The average head weights suggest that larger heads may be more susceptible to mechanical damage. The 2007 data shows that variety 608-6 was the most damaged during mechanical harvesting, and also that it had the largest heads.

- When the results for the two harvests in 2008 are compared, the variety Patron has the lowest damage score and the lowest number of heads lodged in the field after mechanical harvesting. But unfortunately, it has the lowest head weight, resulting in the lowest yield.

- When the damage score, number lodged and yield are considered, the varieties Gypsy and Atomic are a good compromise. They have tall straight stems which may make them more suitable for mechanical harvesting than some of the other more squat varieties, although this is a difficult parameter to quantify.

- There was no significant interaction between season and district with variety in 2009. This means that the district and the season where the broccoli is grown had a bigger impact on the variation in yield between varieties than the selected variety alone. This demonstrates the importance of growing a crop in the correct seasonal and geographic location for optimum yield and quality.

4 Postharvest Evaluation of New Varieties

Introduction

Broccoli is a floral vegetable which is harvested when the flowering heads are immature and still growing rapidly (King and Morris 1994). This makes broccoli a very perishable vegetable as it is sensitive to ethylene as well as temperature. Exposure to ethylene and high temperatures promotes yellowing which is the main reason for the loss of shelf life (King and Morris 1994). Toivonen (1997) reported that the key factors for extending the shelf life of broccoli were to use hydro-cooling, a micro-perforated wrap and storage at 1^{o}C. A storage life of 3 to 6 weeks has been reported for broccoli if it is stored at 0^{o}C, and this shelf life can be extended with the use of closely managed MAP (1% O_2 and CO_2 < 6%) (Klieber and Wills 1991).

In relation to our work, Tan *et al*. (1993) reported cultivar differences with respect to shelf life. Their work showed that the cultivar 'Skiff' had a lower market and colour score than the varieties 'Green Belt', 'Marathon' and 'Shogun'. Tan *et al*. (1993) proposed that the difference was because the cultivar 'Skiff' had a higher respiration rate and produced more ethylene than the other cultivars. This work was done in the early 1990s and since then new varieties have been introduced. Therefor, the aim of this work was to identify currently available cultivars that are suitable for machine harvesting and which also have a good shelf life.

Methods

A range of broccoli varieties were planted at the different sites, depending on the availability and seasonality (Table 4.1). The broccoli grown at Brookstead, Queensland was planted as transplants on 4 April 2008 and was harvested on 30 June 2008 (86 days) The broccoli grown at Gunalda, Queensland, was planted as transplants on 6 August 2008 and harvested on 19 October 2008 (74 days) and the broccoli grown in Armidale was planted as transplants on 7 November and harvested on 6 January 2009 (60 days).

Once harvested, 20 heads per replicate per variety were stored and forced-air cooled to 0^{o}C and then stored at 1^{o}C. They were assessed for quality every 3 days. Each head was rated for odour and colour using a 1 to 5 scale, with 1 being a clean smell and a green head and 5 being an off smell and yellowing of the head. The shelf-life was determined as the number of days until the head received a score of 5 for either colour or aroma. This assessment was an extreme test with the shelf life being rated as longer than would be acceptable to consumers. However, it allowed the quality of the varieties to be differentiated in the experiment.

Table 4.1. Broccoli varieties planted at each site.

Gunalda, Qld	**Brookstead , Qld**	**Armidale, NSW**
Evergreen	Atomic	Atomic
Mascot	Gypsy	Aurora
07-1117	07-1117	Brumby
K6-091	Aurora	07-1117
	Na690	K6-091
	Brumby	Na690
	K6-091	

Results

Results for the three sites are shown in Figures 4.1 – 3. The graphs have the same Y-axis so that a cross-site comparison can be made. The data shows that the variety k6-091 has a significantly longer shelf life than many other varieties for all three sites and the variety Atomic had the shortest shelf life in both Brookstead, Qld and Armidale, NSW. Interestingly, the average shelf life was longest for broccoli grown in Armidale, NSW.

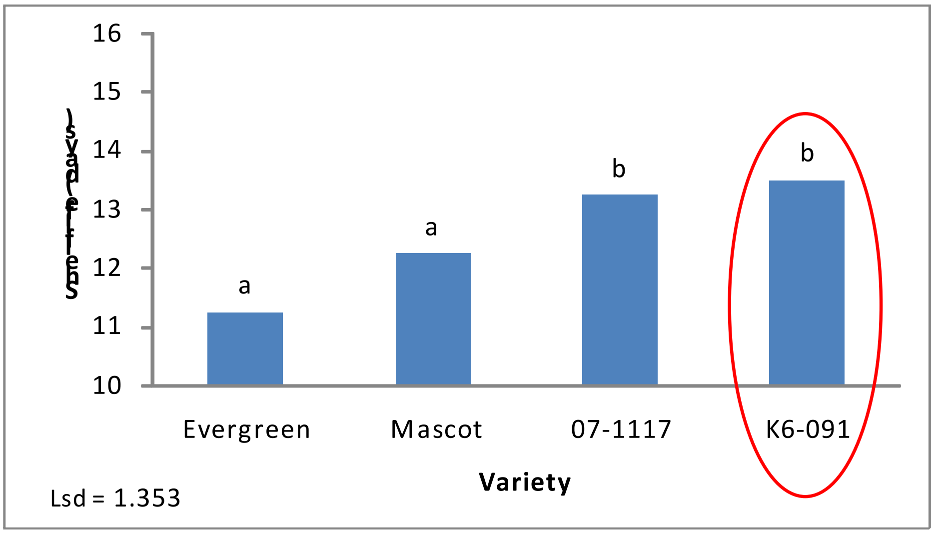

Figure 4.1. Shelf life of broccoli varieties grown in Gunalda Qld.

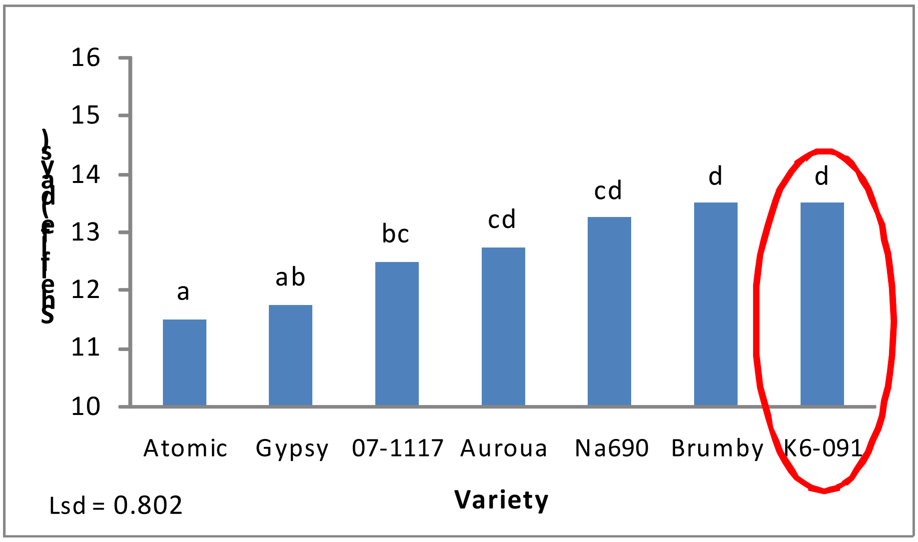

Figure 4.2. Shelf life of broccoli varieties grown in Brookstead, Qld.

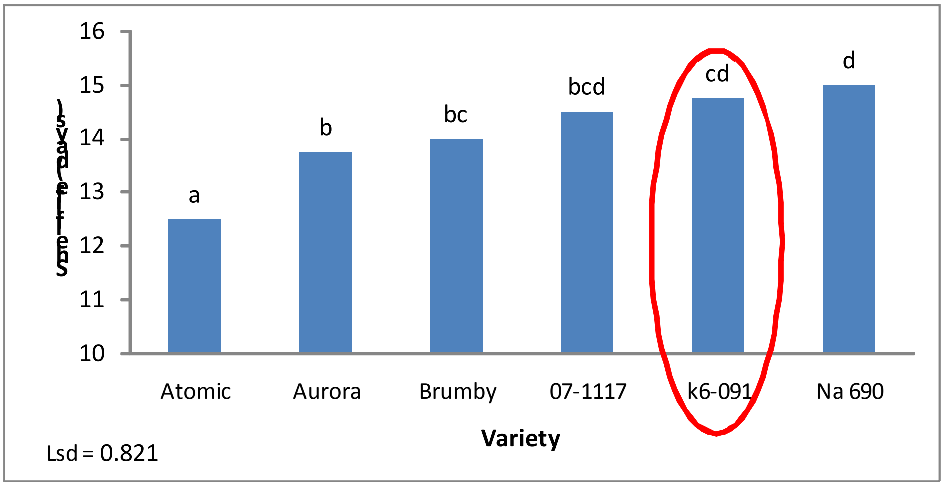

Figure 4.3. Shelf life of broccoli varieties grown in Armidale, NSW.

Discussion

The data shows that different varieties perform better than others, with the variety K6-091 consistently performing well across all three sites and the variety Atomic performing poorly.

There is considerable interest in broccoli because of its capacity to produce ethylene as well as its sensitivity to it. Endogenous ethylene production has been suggested as having an important role in the colour change of broccoli (King and Morris 1994). Recent work has identified three genes for the enzyme ACC Oxidase that is a key enzyme in the ethylene biosynthesis pathway (Higgins *et al.* 2006). The researchers antisensed these genes in broccoli and showed that if postharvest ethylene production could be reduced, chlorophyll loss would be delayed and thus the shelf life could be extended. This shows that future variety selection research could also include an analysis of the rates of ethylene and CO_2 production of the new varieties. This would enable selection of low ethylene-producing varieties that also have compact heads and a high yield.

It is interesting to note that the average shelf life of the broccoli was longest for the trial at Armidale in NSW. This site has seasonal weather that best suits growing broccoli. The sites in warmer Qld areas are capable of producing broccoli, but at its physiological growing limits. Product grown on the edges of the climatic optimum must be handled very carefully to ensure it has a shelf life that meets consumers' requirements. An effective and reliable cool chain is very important in these conditions.

Conclusions

- The variety K6-091 consistently had a long shelf life; up to 14 days for broccoli grown in Armidale.

- The variety Atomic did not have a long shelf life when grown in Armidale, NSW or Brookstead, Qld.

- The best shelf life is achieved when broccoli is grown in cooler regions such as Armidale, NSW.

5 Effect of Planting Density on Crop Uniformity

Introduction

Research has shown that competition between broccoli plants greatly affects head weights (Francescangeli *et al.* 2006). It is therefore possible to adjust head size to meet the requirements of the market by manipulating density. It is also possible that the manipulation of planting density will assist with creating uniformity for mechanical harvesting (Chung 1982; Salter *et al.* 1984).

Researchers have found that yield eventually reaches a plateau as plant density increases to the point where the heads become unmarketable (Chung 1982; Francescangeli *et al.* 2006). It is important to note that high-density plantings also relate to low numbers of secondary heads, low peduncle diameter and a lower incidence of 'hollow stem', all of which are positive parameters in terms of broccoli quality (Francescangeli *et al.* 2006). The aim of this research is to determine the optimum planting density to match the requirements of both the market and the mechanical harvester.

Another important consideration is the level of light absorbed by the plant inside the canopy and how the level changes with increasing plant density. Francescangeli (2006) found that as the level of shading increases the plant reacts by developing mechanisms to increase the photosynthetic active radiation (PAR) interception. They do this by increasing the leaf area ratio (LAR, leaf area: mass ratio) and decreasing the net assimilation rate (NAR, rate of increase of dry weight (*W*) per unit of leaf area (*L*)). This is achieved by increasing the stem length, plant height, leaf area index and upper leaf erectness. Interestingly, the head weight decreases as plant density increases and this is due to a decrease in the weight of the stem portion of the head without affecting the floral weight (Francescangeli *et al.* 2006; Francescangeli *et al.* 2007). As a result of its adaptive architecture, broccoli could be considered a relatively shade-tolerant crop (Francescangeli *et al.* 2007).

This research shows it is likely that an ideal spacing can be achieved for mechanically-harvested broccoli, especially when the heads are to be used as a processed product and the stem weight is less critical (Chung 1982).

Materials and Methods

Small Plot Trials

In 2007, four small plot trials were set up at Matilda Farms property in Brookstead, Qld. These small plot trials were aimed at determining the affect of planting density and variety on the quality of mechanically-harvested broccoli. Transplants were planted for four separate trials on the 2/8/07, 16/8/07, 29/8/07 and the 9/9/07. The plants were managed using best commercial practice in terms of weed, pest and disease, fertiliser and irrigation management.

The varieties used included Sakata varieties that had been bred specifically for mechanical harvesting. These included; 494-3, Atomic, Aurora, Brumby, Emerald Pride, Gypsy Mascot, Evergreen, 1112-5, 568-6, 608-6 and Bravo. More information on these varieties appears in Chapter 3. For the effect of density, plants were grown at low density (32,500 heads/Ha), medium density (65,000 heads/Ha) or high density (110,000 heads/Ha). The effect of row orientation was also investigated.

For each treatment, 8 plants in 4 rows were used as replicates (32 plants total) and the quality of the mechanically-harvested heads was assessed using the following criteria (Table 5.1).

Table 5.1. Criteria for assessing the quality of mechanically-harvested broccoli at harvest.

Criteria	Unit of Measure
Number of plants in 10m	Count (survival of viable plants)
Relative row position	North or south , east or west ect
Head diameter	mm
Head weight	g
Head colour	rating (1=blue green, 2=dark green, 3=green, 4=lime green, 5=yellow)
Stalk (butt) diameter	mm
Hollow stem	rating 1-5 (1 = no sign, 5 = severe)
Head density	Rating 1-5 (1 = dense buds, 5 = open head)
Lodging	Number lodged (knocked over by harvester)

Large Plot Trial

In 2008, two large plot trials were set up at Matilda Farms property in Brookstead, Qld. Each trial comprised two blocks, with each block having 10 replicate heads per treatment. The aims of the experiments were to determine which treatment gave the most uniform distribution of head sizes, and how different planting densities affected the growth of the broccoli. The large plot trials were planted on 5 April 2008 and were harvested on 30 June 2008.

The first trial evaluated eight different varieties at the standard density of 65,000 plants per hectare. The varieties used in the trial included: Atomic, Auroua, Brumby, Na690, K6-091, 07-117, Patron and Gypsy. These are all the Sakata seed company varieties.

For the density trials, the treatments are shown in Table 5.2. Combinations of double and single rows, north and south orientation and different plant numbers per hectare were compared.

The layout of the beds for trials 1 and 2 is shown in Figure 5.1. The plant line has either single or double rows, depending on the treatment.

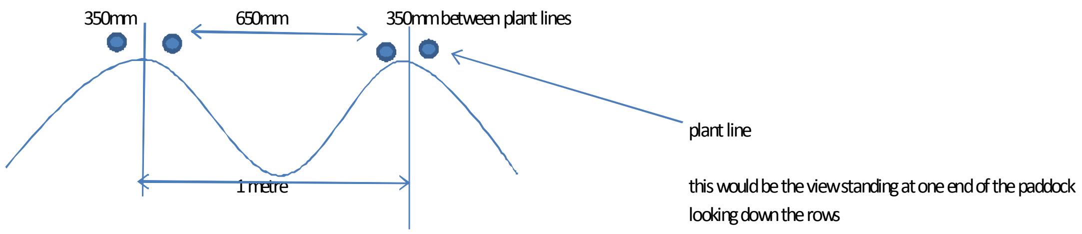

Figure 5.1. Layout of the broccoli beds for the trial planting.

The variety used was Evergreen. The plants were grown as seedlings and managed using best commercial practice in terms of weed, pest and disease, fertiliser and irrigation management.

Table 5.2. Different plant densities compared in trial 2 for mechanically-harvested broccoli .

Two row planted at 110,000 plants/ha (North and south row)
Two row planted at 35,000 plants/ha (North and south row)
Two row planted at 50,000 plants/ha (North and south row)
Two row planted at 65,000 plants/ha (North and south row)
Two row planted at 80,000 plants/ha (north and south row)
Single row planted at 17,500 plants/ha (north row)
Single row planted at 25,000 plants/ha (north row)
Single row planted at 32,500 plants/ha (north row)
Single row planted at 40000 plants/ha (north row)
Single row planted at 55000 plants/ha (north row)
Single row planted at 17,500 plants/ha (south row)
Single row planted at 25000 plants/ha (south row)
Single row planted at 32,500 plants/ha (south row)
Single row planted at 40000 plants/ha (south row)
Single row planted at 55000 plants/ha(south row)

For the purposes of mechanical harvesting the variations in density were achieved by manipulating the distance between plants along the row. Due to the nature of the mechanical harvester it was not possible to manipulate the distance between individual rows, as changing this distance would not have allowed plants to enter the cutting blades at the front of the machine. The head-width of 10 randomly selected heads was measured at weekly intervals and growth rate was calculated as mm per day. When the broccoli reached commercial maturity the blocks were machine-harvested and 10 randomly selected heads from each treatment per block were measured.

Results and Discussion

Small Plot Trial Results

The small plot trials aimed to understand the growth habits of new broccoli varieties, grown using different densities in an effort to determine the optimum for once-over mechanical harvesting. It is important to establish the optimum planting orientation, geometry and density in order to ensure maximum yield and quality at harvest.

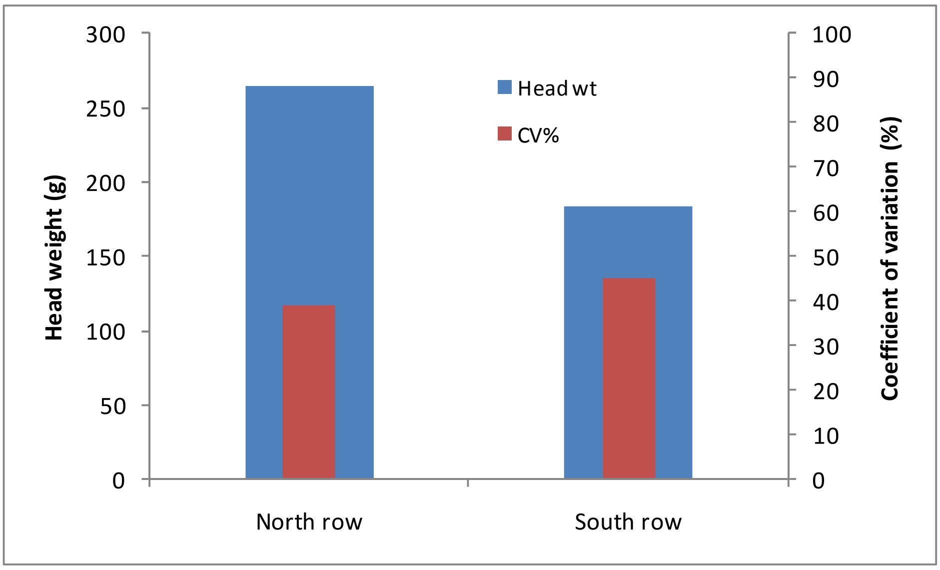

Figure 5.2. The effect of row orientation on the head weight of mechanically-harvested broccoli .

Figure 5.2 shows that row orientation had a significant effect on the head weight of harvested broccoli. The north-orientated plants had a head weight of more than 250g compared to the south-oriented heads that had a head weight of about 150g. This result is most likely due to the effect of temperature and light interception. Figure 3 shows the soil temperature at 8mm depth; during the middle of day the northern aspect is at least 3 degrees warmer than the southern side. The impact of row orientation is most likely due to an interaction between temperature and light.

Francescangeli *et al*'s (2006) work highlights how light penetration impacts the architecture of the crop, with more dense plants being taller with thinner stems and more erect leaves. In a commercial situation, this large amount of variation between rows has the potential to limit the usefulness of the machine harvester. It would not be economically viable to harvest when the north-facing row is at maximum 'maturity', as much of the southern row would be undersized. Conversely, delaying harvest until such time as a significant proportion of the southern row is of a mature size would mean much of the northern row would be over-mature. In light of this issue, further investigations were carried out in the final year of the project on evenly spaced rows to better understand this relationship.

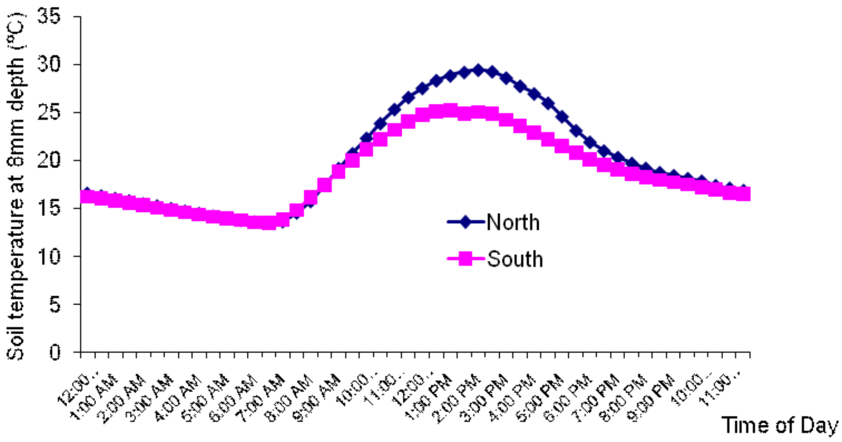

Figure 5.3. The difference in soil temperature (8 mm below the surface) for the north- and south-facing rows during the day.

The importance of temperature on the growth and quality of broccoli is also illustrated in Figure 5.4.

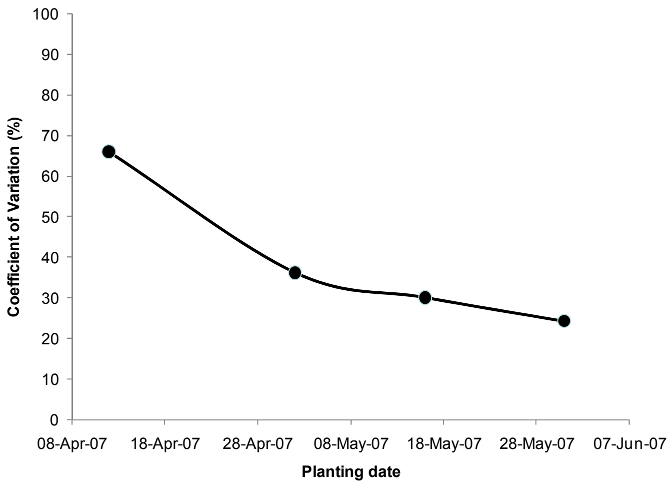

Figure 5.4. The change in the coefficient of variation for the different plantings of broccoli over the 2007 season.

Figure 5.4 shows the coefficient of variation (%CV) which is a "normalized measure of dispersion of a probability distribution" (http://en.wikipedia.org/wiki/Coefficient_of_variation, accessed 29/7/09). The %CV has no units and is a measure which is used to compare results across experiments. It is calculated as the ratio of the standard deviation to the mean. Figure 5.4 shows how the %CV declines with later plantings. This means that plants that are grown during the cooler months have more uniform growth habits than those grown during warmer weather. Salter *et al* (1984) found a similar result and suggested that the accumulated day-degrees above a base temperature of 20°C during the first half of the period from planting to maturity gave the closest correlation with good crop performance. Although many researchers have looked at alternate temperature models for scheduling the harvest of broccoli (Dufault 1996; Grevsen 1998), the key finding is that broccoli grown under optimum temperature conditions tends to produce a more uniform crop at harvest.

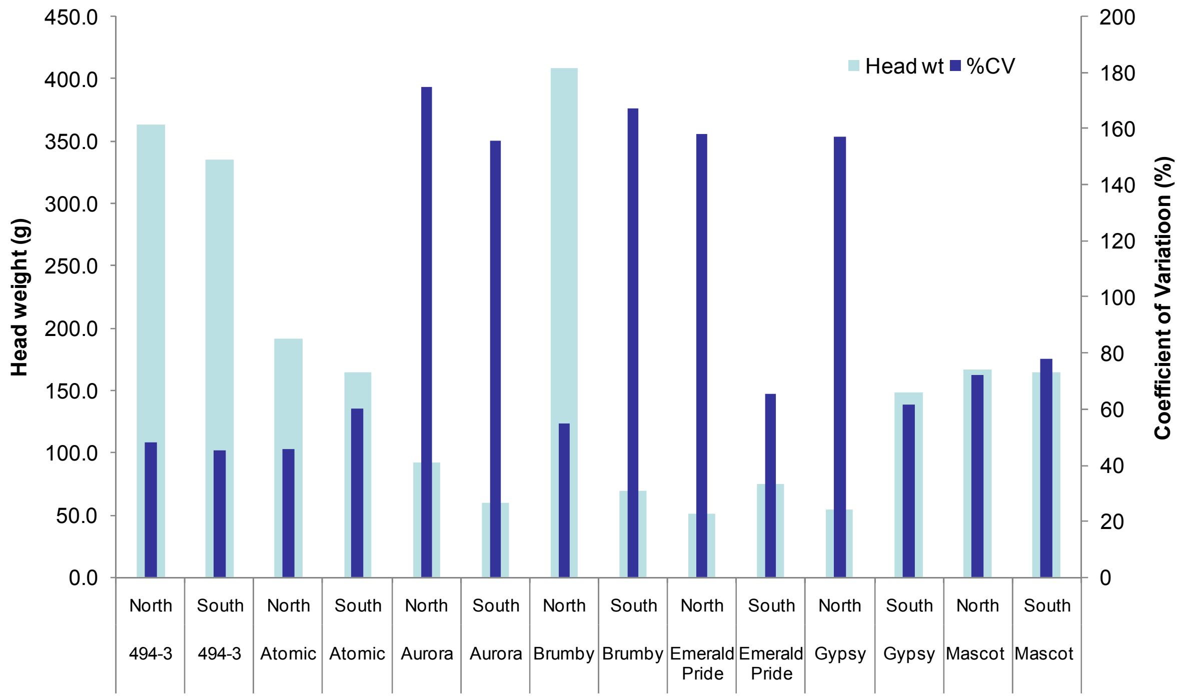

Figure 5.5. The comparison of the effect of variety and row orientation on the head weight of mechanically-harvested broccoli.

It is important to note that the small-plot trial variety data shows that when the head weights were compared at harvest (Figure 5.5) the variety had a bigger effect on head weight than the row orientation. Aurora and Emerald Pride had significantly higher head weights than the other varieties. This strong variety effect was also reported by Chung (1982). He reported that the varieties Gem and GSI responded differently to planting density and orientation compared to the Variety Futura.

The analysis of the quality data showed there were no significant differences between the varieties in the small-plot variety trials for head colour and head density across the four plantings. (Even so, the variety Emerald Pride consistently had lower scores than the other varieties.)

The effect of planting density on head weight was investigated in more detail in the small plot trials using the variety Evergreen. As you would expect, the head weight (Figure 5.6) and stem width (Figure 5.7) decreased with increasing plant densities, as has been reported by others (Chung 1982; Francescangeli *et al.* 2006).

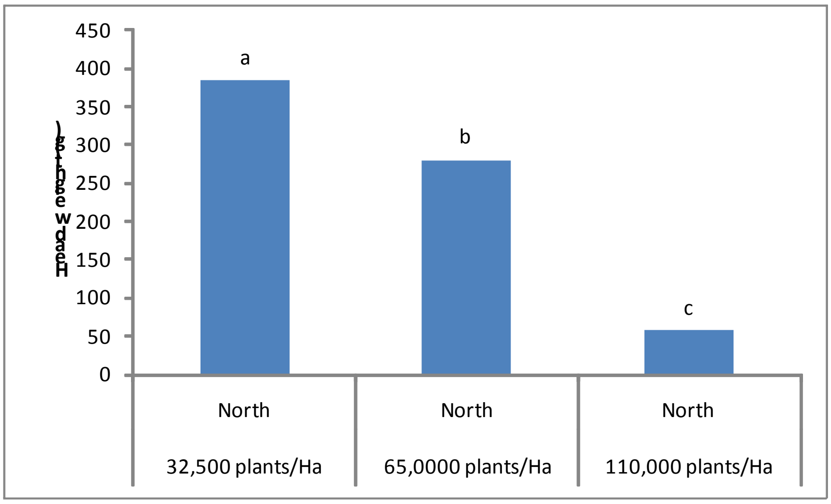

Figure 5.6. The effect of planting density on the head weight of mechanically-harvested broccoli.

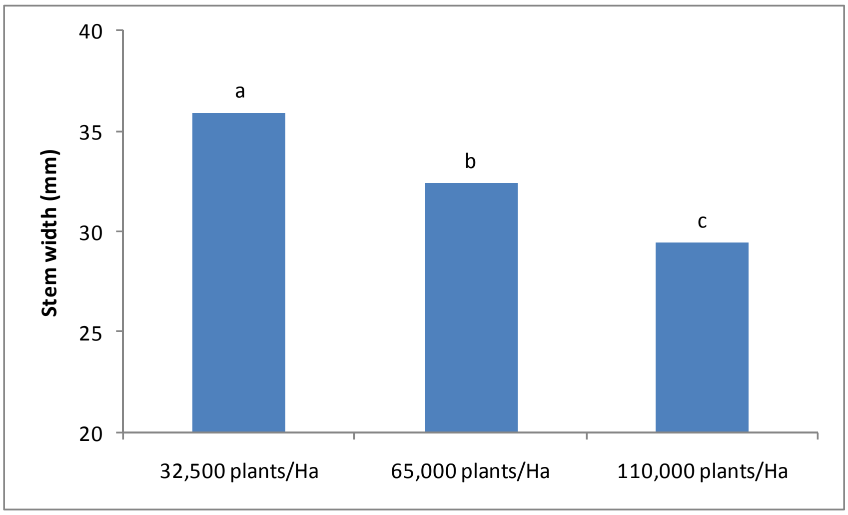

Figure 5.7. The effect of planting density on stem width of mechanically-harvested broccoli.

The small plot trials determined that planting time, geometry, density and variety all affected broccoli head quality after mechanical harvesting. Larger plot trials were then carried out to investigate the effects on a commercial scale.

Large Plot Trial Results

For the large plot trials the focus was on head quality for the processed broccoli floret market. It was important to have a high yield with a uniform head so that the quality of the mechanically-harvested product could be optimised.

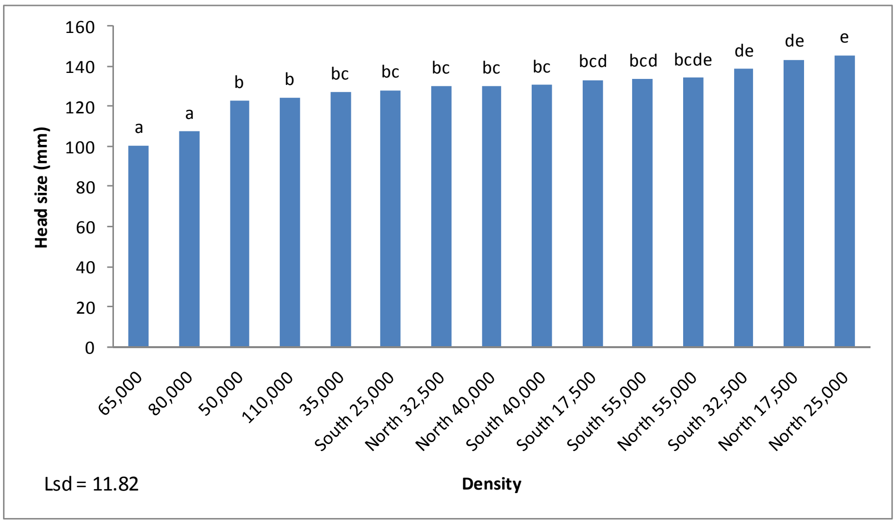

Figure 5.8. The effect of plant density and orientation on head size of large plot trials of mechanically-harvested broccoli .

The results show that plants grown at a double density (see Figure 5.1 for diagram of layout) had smaller heads than those planted at a single spacing (Figure 5.8). There is no clear pattern in the change in head width with density of the other single row treatments. This result is supported by the literature. Chung (1982) reports that the increase in head size for broccoli is asymptotic and that the head size approaches the maximum at relatively low densities (20,000 plants/ha). He reported that the head diameter of Gem and GSI decreased by about 50% from 2,800 to 30,000 plants/ha with little impact after that, and that plant density had no significant effect on the shape of the broccoli head. The treatment pattern for head growth rate was similar to Figure 8 (data not shown).

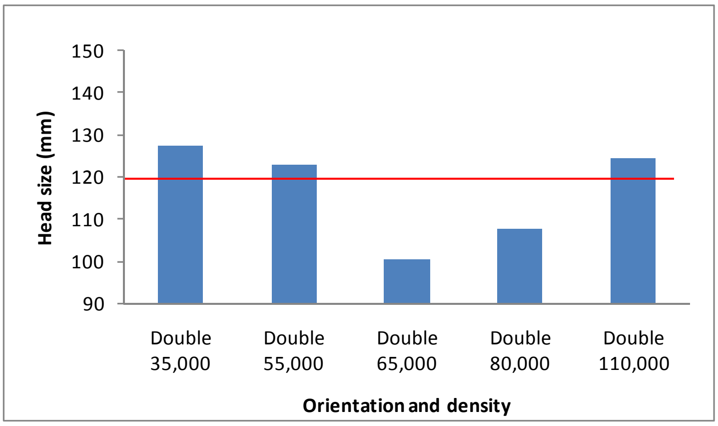

Figure 5.9. The effect of double plant densities and orientation on head size of large plot trials of mechanically-harvested broccoli.

Figures 9, 10 and 11 show the change in head size relative to density and orientation. The asymptotic effect is clearest for the broccoli grown on the northern orientation with increasing density having little impact above 32,500 plants per hectare (Figure 5.11).

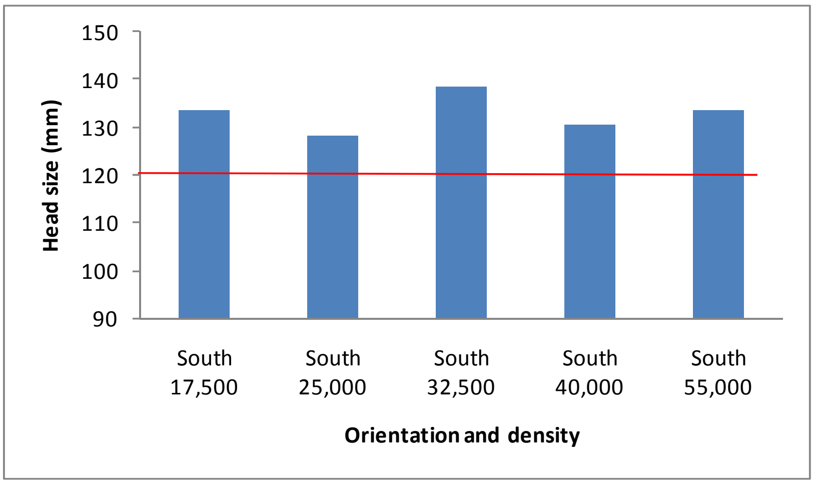

Figure 5.10. The effect of plant densities and southern orientation on head size of large plot trials of mechanically-harvested broccoli.

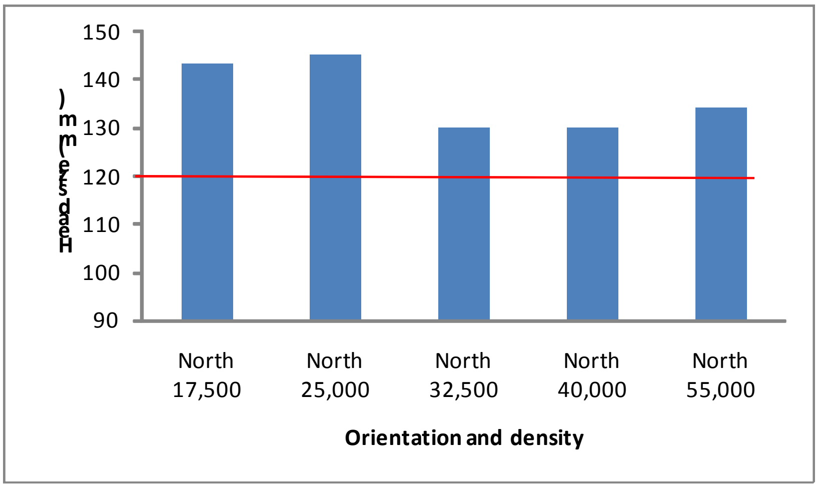

Figure 5.11. The effect of plant densities and northern orientation on head size of large plot trials of mechanically-harvested broccoli.

As mentioned earlier in this report, broccoli plants respond to increasing density by changing the partitioning of dry weight within the head. As the density increases the head weight also decreases, but this is due to the decrease in the weight of the stem portion of the head without affecting the floret weight (Francescangeli *et al.* 2006). Our results also show that increasing density doesn't affect head diameter, which is the critical factor for processed broccoli florets.

It is important to note that at all densities the time of harvest is critical. Chung (1982) reported that the maximum total marketable yield for all densities was obtained over a 4-day period (Days 89 to 92 for broccoli grown in Tasmania). Harvesting before this time resulted in lower yields because of the increased number of immature heads. Harvesting after that time reduced yields due to an increase in over-mature heads.

Table 5.3. Comparison of the coefficient of variation of head weight for different planting orientations as an indicator of plant stand uniformity.

Planting orientation	Mean (g)	Standard Deviation	%CV
Double 50,000	122.85	25.2	20.5
North 55,000	134.2	16.4	12.2
South 55,000	133.55	13.7	10.3
Double 35,000	127.125	33.0	25.9
North 32,500	145.15	19.4	13.4
South 32,500	138.6	18.0	13.0

For mechanical harvesting, the uniformity of plant stand is very important to ensure maximum harvestable yield. Table 5.3 compares the coefficient of variation (%CV) for planting densities with similar plant numbers per hectare in the large scale trials. The data shows that double-row plantings are more variable in terms of head weight than single-row plantings (higher %CV). As reported earlier, the head weight is also lower for double-planted rows. For maximum uniformity, matching the requirements of the mechanical harvester, a single-row planting is recommended.

Conclusions

- Our results show that the minimum head width at maturity is achieved at relatively low densities (32,500 plants/ha, north orientation). Therefore, increasing the density increases yield without compromising head width. If this head width is within the specification for processing, increasing the density increases the yield without decreasing quality. Even so, planting using a double-row does reduce plant head width more than single-row planting.

- A single-row planting gives a more uniform plant stand than a double-row planting. A single-row planting is recommended for mechanical harvesting.

- It is important to also consider harvest maturity, variety and seasonal temperatures, all of which impact on final head quality at harvest.

6 Evaluation of Different Methods of Crop Establishment

Effect of seed treatments on the establishment and yield of broccoli

Introduction

Most commercial large-scale broccoli crops worldwide are established by direct seeding. However, poor establishment is currently the major issue for Matilda Fresh in Queensland; it results in seedling losses of up to one-third of the 90,000 seeds per ha. There can also be variability within a crop as a result of irregular emergence in the field.

Seed establishment can often be improved by using treatments such as seed priming or seed coating. The process of seed coating involves sticking material onto the surface of the seed. The seed can either be pelleted, coated or covered with an adhesive film (de Almeida *et al.* 2005). This treatment is often used to even-up the size of the seeds to ensure even distribution during sowing. Primed seeds are those which have had a hydration treatment that allows controlled imbibition. The hydration treatment is stopped before desiccation tolerance is lost. Research has shown priming seeds enhances germination speed and synchronicity. However, a practical drawback of primed seeds can be that often there is a decrease in storability, resulting in the need for cool storage temperatures (http://www.seedbiology.de/seedtechnology.asp#priming, accessed 4/8/09).

This experiment aimed to determine if seed priming, or seed coating, improved the rate of emergence and reduced the variability of plant establishment of broccoli grown at Brookstead, Qld.

Materials and Methods

This trial was planted at Brookstead, Qld on 2 April 2007. Primed, coated and raw Brumby variety broccoli seed was used for this trial. The crop was sown at the commercial rate using a Monosem™ precision vacuum vegetable seeder.

The germination rate was assessed 13 and 17 days after planting. The broccoli was harvested on 12 June 2007. The trial layout and seed count quadrants are shown in Table 6.1. At harvest, 20 heads per block per treatment were collected. The heads were weighed and the head diameter was recorded.

Coated broccoli seed

Table 6.1. Layout of the seed treatment trials.

North →

	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Set 8	
	Raw Seed	Primed Seed	Standard Commercial Seed	Raw Seed	Primed Seed	Standard Commercial Seed	Raw Seed	Primed Seed	
whole Length of bay	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	head ditch
	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	mid head
	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	mid tail
	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	tail drain
	4 Beds								

1 entire bay wide (32 beds) Seeded 2-4-07

Plant Counts: 2 x 20m plant counts were taken at each of the areas marked (XXXX)

Each plant count consisted of a count from the row on the left and the right side of each bed these counts were recorded separately

The plant counted were always taken from beds 2 and 3 in each set.

Results and Discussion

Figure 6.1 shows the numbers of plants per hectare, 13 and 17 days after germination. There were significantly less plants per hectare when encrusted seed was used and there was no advantage gained from using primed seed compared to raw seed in this trial.

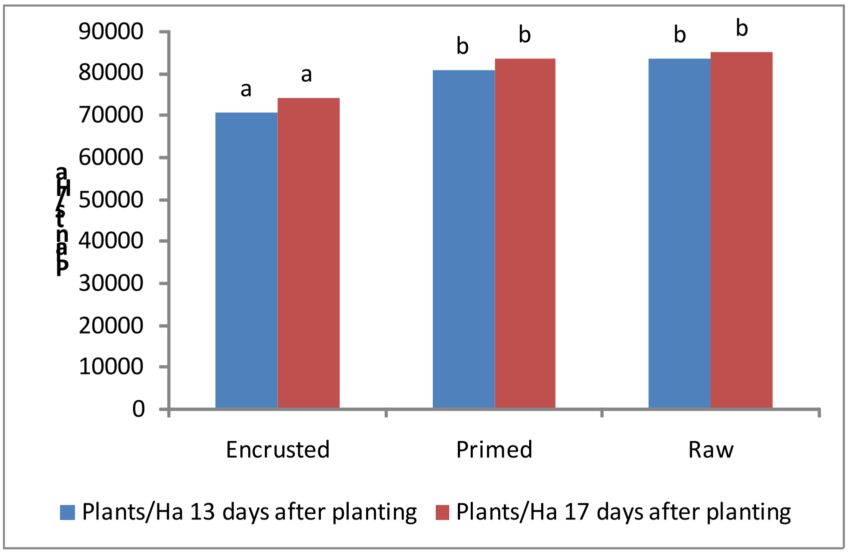

Figure 6.1. The effect of seed treatment on the germination of broccoli seeds.

When the quality of the broccoli heads were compared at harvest there was no significant difference in the head width (Figure 6.2) or head weight (Figure 6.3) when the three seed treatments were compared.

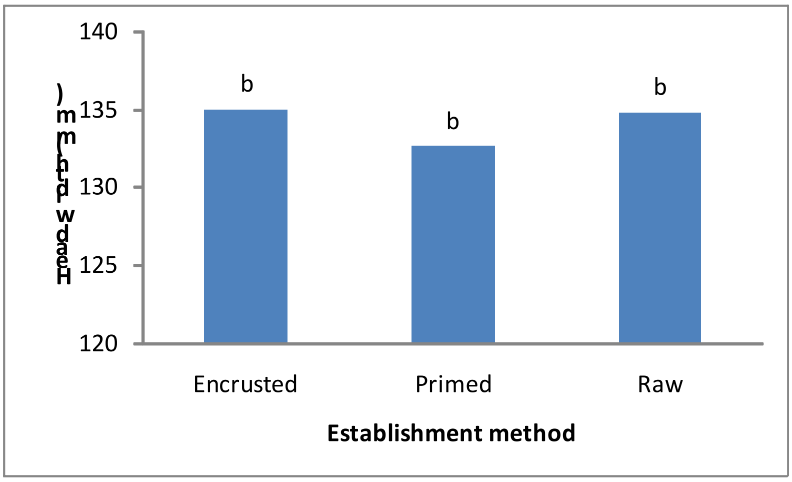

Figure 6.2. The effect of seed treatment on the head width of broccoli at harvest.

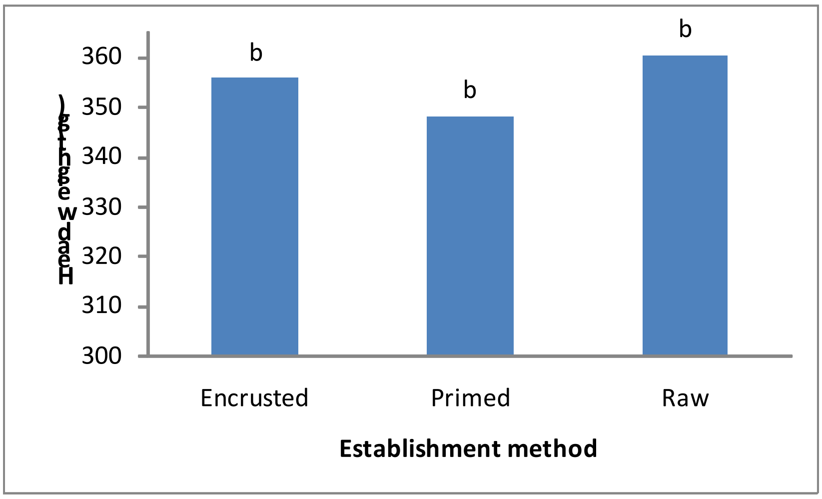

Figure 6.3. The effect of seed treatment on the head weight of broccoli at harvest.

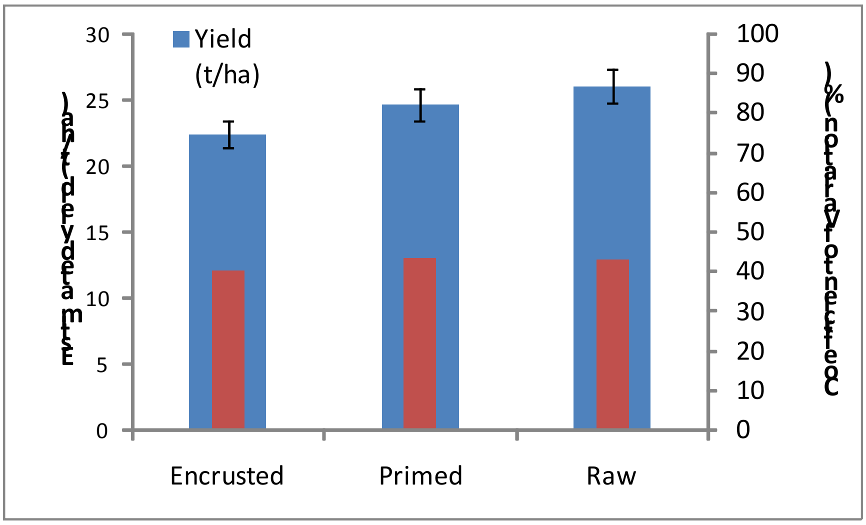

Figure 6.4. The effect of seed treatment on the yield and coefficient of variation for the different seed treatments.

Importantly, there was no difference in the coefficient of variation (%CV). The %CV has no units and is a measure which is used to compare the variability of results across experiments. It is calculated as the ratio of the standard deviation to the mean for the three treatments. This indicates that factors other than seed treatment are causing the variability in germination experienced by Matilda fresh in Queensland.

Conclusions

- Encrusted seed had a significantly lower plant number per hectare, at 13 and 17 days after harvest, compared to primed seed and raw seed.

- In this trial, seed encrusting or priming did not significantly improve the germination rate or yield, or reduce the variability of crop yield at harvest.

- Importantly, there was no difference in the coefficient of variation (%CV) for the three treatments. This indicates that factors other than seed treatment are causing the variability in germination experienced by Matilda fresh in Queensland.

Effect of planting depth on the percentage germination and the time to emergence of broccoli seeds

Introduction

It has been suggested that seedling vigour and time from germination to emergence of the cotyledons can have an effect on the overall time to maturity of broccoli crops. Field and laboratory trials were set up in an attempt to ascertain if this was, in fact, the case.

The depth under the ground that a seed is placed at the time of planting can have an effect on the time it takes the seedling to emerge (Keshtkar *et al.* 2009). In commercially planted direct-seeded broccoli crops, achieving a consistent depth of seed placement is influenced by many factors. A survey conducted prior to the commencement of the project, during the winter of 2006 at 'Wando' Brookstead, Qld, showed that seeding depth could vary within the one field and planting by as much as 400%. Placement depths varied from as little as 2-3 mm below the surface, to as deep as 15-20mm. The tilth and moisture of the soil at the time of planting can have a big impact on the ability of a Monosem™ vacuum seeder to achieve consistent depth.

The aim of this experiment was to quantify the effects of seeding depth on the days to emergence and germination percentage of broccoli.

Materials and Methods

A sample of top soil was removed from a commercial field at 'Wando'. This soil was then used to fill five seedling raising trays. The trays were filled to the top and levelled. Each of the treatments was sown to a specific depth using a pair of fine-nosed surgical tweezers. The trays were stored in a local wine cellar to provide a more stable environment, close to 17^{o}C (Figure 6.5).

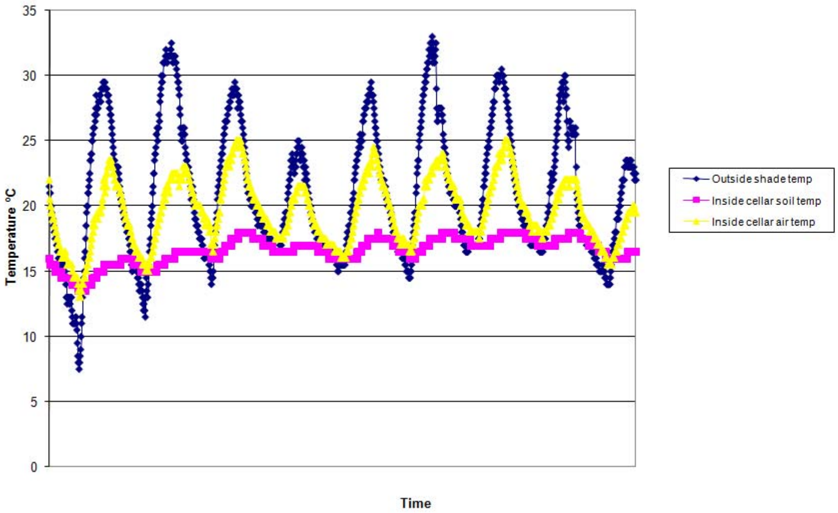

Figure 6.5. Temperature log germination trial: Typical temperature variation inside the cellar in air and in soil, as well as the relative outside temperature.

Figure 6.5 shows that the cellar environment has a more stable temperature than outside air. Elson (1992) found that a night temperature of 20°C and a day temperature of 32° reduced the germination rate and emergence of broccoli. This is supported by others: Wagenvoort (1981) found that temperatures above at least 11.5 °C were considered optional for germination of brassica species. We considered the cellar soil temperature variation from 15°C to 17.5°C to be ideal for the purposes of this investigation.

Once the trial was seeded the trays were irrigated to field capacity and allowed to drain. No additional water was added during the course of the trial. Seeding treatment depths were as follows: 0mm (surface), 2mm, 4mm, 6mm, 8mm, 10mm, 12mm, 15mm, 18mm, 20mm and 25mm. Each treatment was replicated 5 times. It should be noted at this point that some of the seed placed on the surface of the seeding tray at 0mm (surface) did sink into the tray to become at least level with the surface. This was due partly to the small nature of the broccoli seed and partly to the swelling nature of the black clay soil, which is common to the growing area. Emergence counts were made 4, 6, 8, 10, 12,15,18,20 and 25 days post seeding.

Results

The results show that there is a curved linear relationship between seeding depth and the time to seedling emergence (Table 6.2 and Figure 6).

Table 6.2. Days to first seedling emergence of broccoli seeds planted at different depths.

Treatment	Days to first seedling emergence
Surface	4
2mm	4
4mm	8
6mm	10
8mm	8
10mm	8
12mm	10
15mm	10
18mm	12
20mm	12
25mm	12

Figure 6.6 shows depth of seeding affecting the time taken for the first seedling to emerge. Deeper seeds took as long as 12 days to emerge, compared to 4 - 8 days for shallower planted seeds.

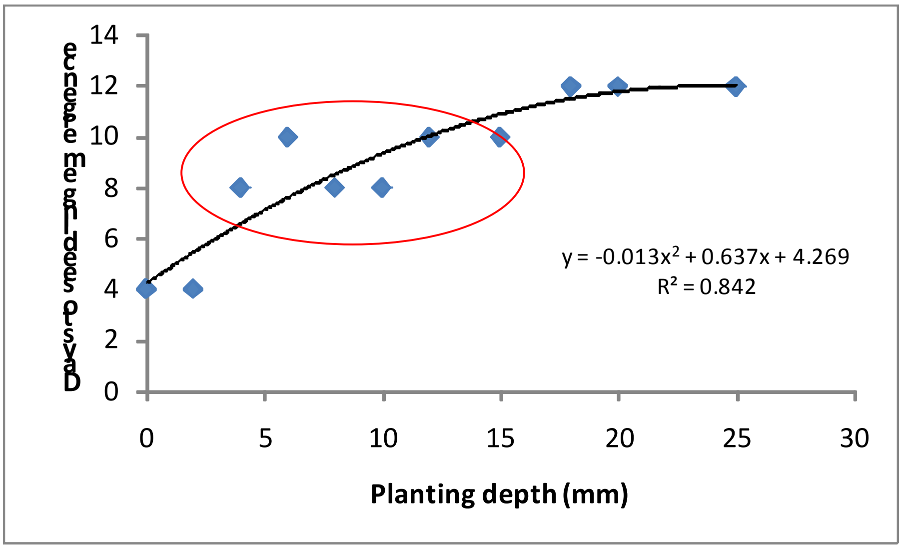

Figure 6.6. Relationship between the depth of planting and the emergence of the first seedling.

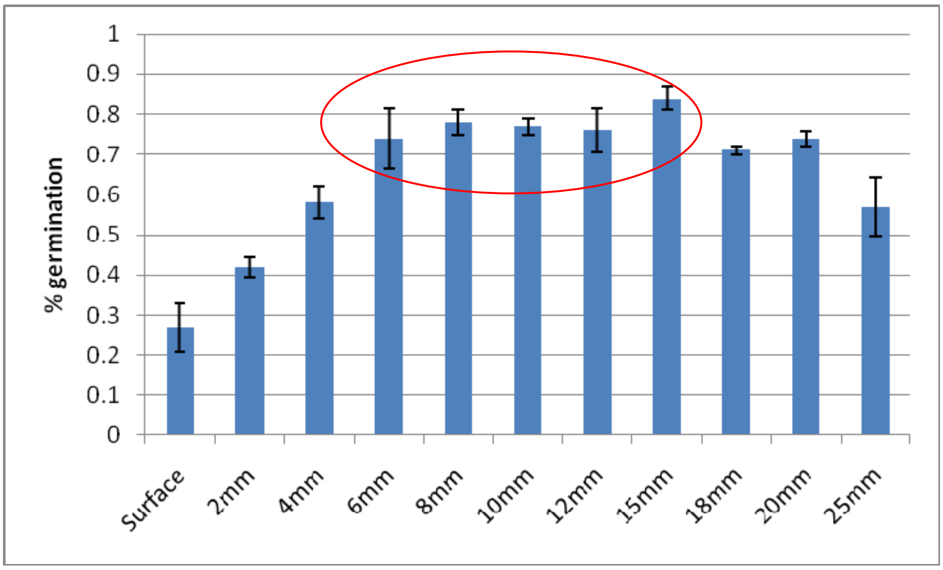

Figure 6.7. Germination percentage of broccoli seeds planted at different depths, 25 days post seeding.

Figure 6.7 shows that broccoli seeds planted at depths of less than 6mm and more than 15mm have a reduced rate of germination.

When the two sets of data are compared, we see that a planting depth of between 6mm and 15mm provides a high germination percentage of about 80% in 8 to 10 days after sowing.

Discussion

Germination percentage is a critical factor for establishing a consistent plant stand. These results show that the shallower seeding depths are most likely to show a reduction in the final emergence count due to a lack of moisture on the surface of the seeding trays. The reduction in total emergence in the 25mm treatment may have been caused by the small seed not having the reserves to push the seedling through at such a depth. The results show that variation in seeding depth can affect both the time to emergence and the final germination percentage.

The results show that in a commercial production system an even seedbed preparation, good soil tilth and even irrigation application can all impact on the time, evenness and total emergence of seedlings. If the aim is to produce a uniform plant stand for mechanical harvesting, preparation at planting is a critical step.

Conclusions

- Planting depth affects days to emergence as well as the final germination percentage.
- The highest germination percentage (approx. 80%) was achieved when seeds were planted at depths of between 6mm and 15mm.

- The results show that preparation of the bed is a critical step for ensuring a uniform plant stand suitable for mechanical harvesting.

7 Optimising Broccoli Crop Nutrition

Introduction

Key to the success of the project was identifying, and as far as possible addressing, factors affecting crop variability. Clearly crop nutrition plays a role in this and while identifying locations with highly uniform soils is vital, so is examining any critical nutrients that might also play a part in crop variability. The aim of this study was to look primarily at the three key nutrients most likely to affect head size – nitrogen, phosphorus and potassium. In particular, the aim was to ascertain whether subtle nutrient differences found in a typical commercial crop significantly altered head size. Rather than impose a complex range of treatments, (which also introduces multiple variables and that may cause difficulties in determining key causes of any effects observed), this study took a broad-based approach to the problem. The trial was set up to search for any correlations between head size and key nutrients that might occur over the normal ranges found in a typical commercial planting.

Methods

A single study was conducted on a broccoli crop cv. "Babylon" located near Gatton, Qld, on black self-mulching clay. The crop was planted 08 June 2009 and received a standard program of fertiliser from planting up to harvest 84 days later (31 Aug 2009).

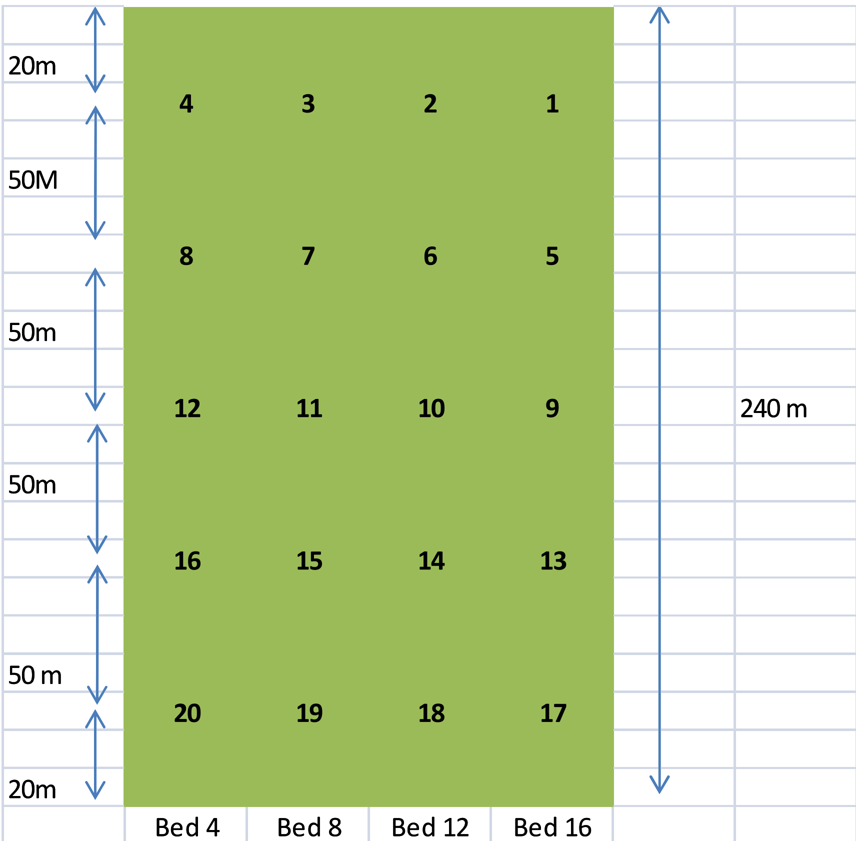

Table 7.1. Layout of the sampling locations in broccoli beds.

Sampling: At harvest, 20 locations were established in a grid pattern (Table 7.1) inside the crop, covering a representative area of the entire field. The top 5cm of organic matter and soil was removed from the centre of the bed at the sampling point prior to a single soil sample being taken from 5-30 cm below the surface. Immediately after this, 20 broccoli heads closest to the soil sampling point were cut from the pair of rows on the bed (10 from each row). Cut heads were immediately taken to a cool store (4°C) where they remained until the assessment was completed. Soil samples were immediately dispatched to the soil laboratory for next-day processing and analysis by overnight postage.

Assessment: Heads were weighed before being measured with a ruler across the top of the head and across the cut stem. Soil results were received within a week of sample dispatch from the analytical laboratory Yara Phosyn in Brisbane.

Literature Review – Key Broccoli Nutrition Requirements

Nitrogen

By far the largest volume of literature available on broccoli nutrition is related to nitrogen studies. The reason for this is clear. Broccoli has not only a high total demand for nitrogen, but requires a good supply from early crop development to achieve larger head yields. Yoldas *et al* 2008, showed that increasing N rates significantly increased yield, average weight of main and secondary heads and the diameter of broccoli with maximum yields obtained at 300 kg/ha of N. Elsewhere, the N requirement of broccoli is stated to range from 300-465 kg/ha (Feller & Fink 2005). In the same article, Feller & Fink found the early demand for N cannot be provided through delivering high pre-plant N to seedlings and that total and marketable yields are significantly increased by increasing N rates provided in the soil at planting. They also found that 80-118 kg/ha of N maximised yield, regardless of any topdressing rate applied 25 days later. At 200 kg/ha applied N, broccoli plants recovered essentially all of the estimated available N with little risk of N loss during the growing season (Bakker *et a*l - I, 2009), although most studies indicate higher rates around 298-309 kg/ha of N are required to provide the best economic return on N expenditure (Bakker *et a*l - II, 2009). Rapid uptake of applied N appears to begin as early as 3 weeks after transplanting seedlings into the field (Vagen *et al*, 2007). In the same article, it was noted that an increase in the harvest index was associated with increasing rates of N, indicating the stronger effect of N on the head relative to other above ground biomass.

Soil sampling for the current study (as described in the Materials & Methods Section) was conducted in accordance with the findings of Goodlass *et al* 1997, who found measurements from the 0-30cm depth band most closely reflected crop N requirements.

Phosphorus

Cutcliffe *et al* (1968), found phosphorus application rates have a highly significant effect on broccoli yield, particularly when the application rate was raised from nil to 49-65 kg/ha P. As Australian soils are typically very deficient in P, this may be an important limitation to broccoli head size unless properly managed with adequate P.

Potassium

In contrast to N & P, the K requirements of broccoli appear to be rather moderate (Cutcliffe *et al* 1968). In this study, where 0-140 kg/ha K was applied, as well as in another conducted by Mahmud *et al* (2007) where no yield response was achieved through 0-100 kg/ha of K_2O, base-level soil K was adequate. However, there is some evidence that a more consistent supply of K through fertigation can significantly improve head size, compared with conventional application methods using a pre-plant soil-incorporated application of K followed by a post-planting K side-dressing (Vidal-Martinez *et al*, 2006).

Secondary and Minor Nutrients

An exhaustive review of all trace elements and their specific influence on head size in broccoli production was neither possible, nor a prime objective of this project. (This is not to detract from their importance – clearly minor element deficiencies such as the well documented association between "whiptail" and molybdenum deficiency are extremely important.) However, as trends in this trial were observed with both calcium and manganese, these two nutrients were briefly reviewed.

Calcim: General references on the importance of calcium for plant cell wall growth or more specific studies on calcium nutrition for improved postharvest qualities such as shelf life were readily found. However, no specific references were found relating to broccoli growth and yield with calcium nutrition.

Manganese: Kowalenko (1989) found that in a controlled greenhouse situation using a sand culture system, broccoli and cauliflower were grown from seed for 90 days in a minus-Mn nutrient feed with no clear reduction in growth compared with plus-Mn supplied plants. This occurred despite lower tissue Mn levels being recovered in the min-Mn plants. These plants were apparently able to extract sufficient Mn from the sand culture system. Helman (1967) found that the use of certain pre-plant soil fumigants reduced the amount of exchangeable manganese to levels that induced a Mn deficiency. The deficiency was manifest through foliar symptoms (interveinal chlorosis) rather than any specifically-noted reduction in plant growth. Further, this was fairly successfully remediated through foliar Mn sprays applied with a wetting agent. It would have to be concluded then, based on the limited information and lack of priority in research, Mn deficiency and any consequential growth effects are very rare in broccoli.

Results and Discussion

While very few results showed significant correlations between harvest measurements and specific nutrient levels in the soil, some general trends are worth noting. The R^2 values were broadly similar across the harvest measurements made for each nutrient. This reflects heavier heads also being wider across the stem and head as would reasonably be expected. The converse was also true: lighter heads were also narrower across the stem and head. Thus, no specific nutrients were associated with any obvious changes in the ratio of different head dimensions (head shape).
The focus of this trial was the three major elements, nitrogen, phosphorus and potassium. However, as complete soil tests were conducted, levels of all key nutrients were measured, so all results are presented. Interestingly, the only significant results were seen with **calcium** and **manganese** so it was worthwhile reviewing the minor nutrients as well.

Nitrogen (Figures 7.1-7.3)

Nitrate nitrogen is notoriously difficult to accurately measure in soils, mainly due to microbial activity after collection. However, there is no reason to suspect samples weren't directly comparable as they were collected together and treated similarly. While there was no significant correlation between nitrate levels and head measurements, Figures 7.1-7.3 tend to indicate ideal soil nitrate to be about 20 ppm.

Phosphorus (Figures 7.4-7.6)

Phosphorus was very poorly correlated with head size and no clear indication of ideal levels was apparent over the 30-60 ppm range.

Potassium (Figures 7.7-7.9)

Potassium was similarly poorly correlated with head size harvest measurements. No clear indication of improved head size occurred in the 320-460 ppm range.

Magnesium (Figures 7.10-7.12)

While not significant, there was a weak trend towards increased head size when Mg levels increased from about 2800 ppm to about 3250 ppm.

Calcium (Figures 7.13-7.15)

Increasing Ca levels from 3000 ppm to about 4000 ppm significantly increased both head weight and width, although the correlation was not particularly strong. Head weight was the most significantly affected head characteristic (R^2 = 0.64); head width somewhat less so (R^2 = 0.53). While stem width was not significantly affected (R^2 = 0.47) the trend was the same.

Sulfur (Figures 7.16-7.18)

Sulfur was poorly correlated with head size harvest measurements. No clear indication of improved head size occurred in the 8-30 ppm range.

Manganese (Figures 7.19-7.21)

Mn was the only nutrient to show significantly improved head size across all three harvest measurements. Increasing Mn levels from 30 ppm to about 40 ppm significantly increased all three head-size indicators. Head weight was the most significantly affected head characteristic (R^2 = 0.68); head width (R^2 = 0.58) and stem width (R^2 = 0.51) somewhat less so. Based on the head weight results alone, there is a compelling case for seeing 30-40 ppm as a critical minimum threshold requirement for Mn.

Boron (Figures 7.22-7.24)

Boron was poorly correlated with head size harvest measurements. No clear indication of improved head size occurred above 1.5 ppm. If anything, Boron appeared marginally toxic above this level.

Copper (Figures 7.25-7.27)

Copper was poorly correlated with head size harvest measurements. No clear indication of improved head size occurred in the 2-2.7 ppm range.

Iron (Figures 7.28-7.30)

Iron was very poorly correlated with head size harvest measurements. No clear indication of improved head size occurred in the 60-72 ppm range.

Zinc (Figures 7.31-7.33)

Zinc was among the most poorly correlated nutrients with head size harvest measurements. No clear indication of improved head size occurred in the 2-16 ppm range.

Sodium (Figures 7.34-7.36)

Sodium was poorly correlated with head size harvest measurements. No clear indication of a change in head size occurred in the 380-680 ppm range. If anything, sodium began to show a trend towards toxicity above about 500 ppm, as might reasonably be expected.

Aluminium (Figures 7.37-7.39)

Aluminium was poorly correlated with head size harvest measurements. No clear indication of differences in head size parameters was seen in the 11-20 ppm range.

Figure 7.1 shows the average harvest head weight (20 plants) associated with the nitrate level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head weight and nitrate level in this trial.

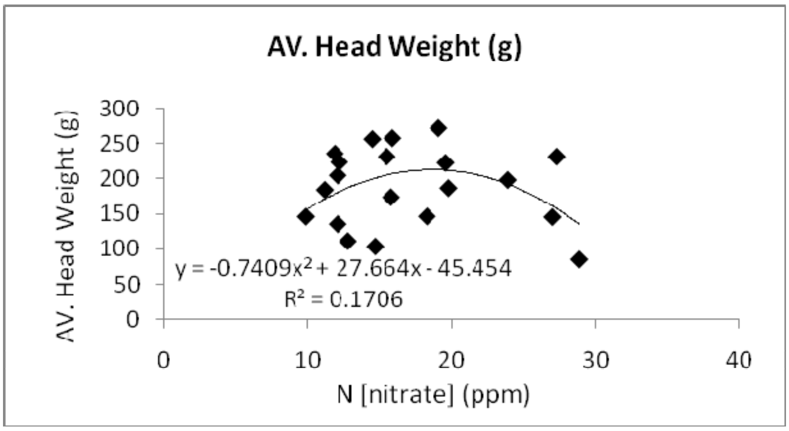

Figure 7.1. The effect of soil nitrate concentration on the average head weight of broccoli.

Figure 7.2 shows the average harvest head width (20 plants) associated with the nitrate level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head width and nitrate level in this trial.

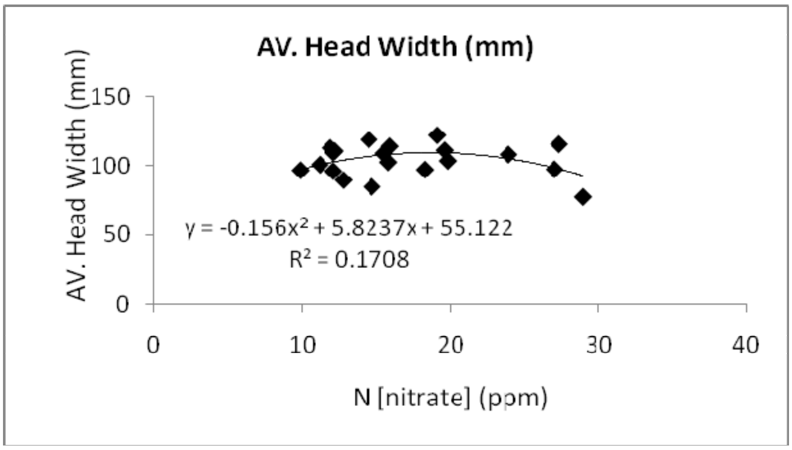

Figure 7.2. The effect of soil nitrate concentration on the average head width of broccoli.

Figure 7.3 shows the average stem width (20 plants) associated with the nitrate level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between stem width and nitrate level in this trial.

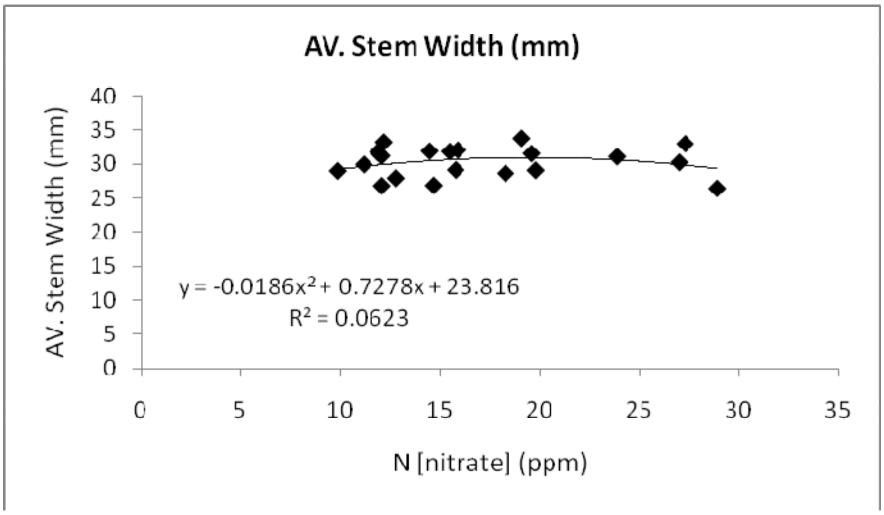

Figure 7.3. The effect of soil nitrate concentration on the average stem width of broccoli.

Figure 7.4 shows the average head weight (20 plants) associated with the phosphorus level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head weight and phosphorus level in this trial.

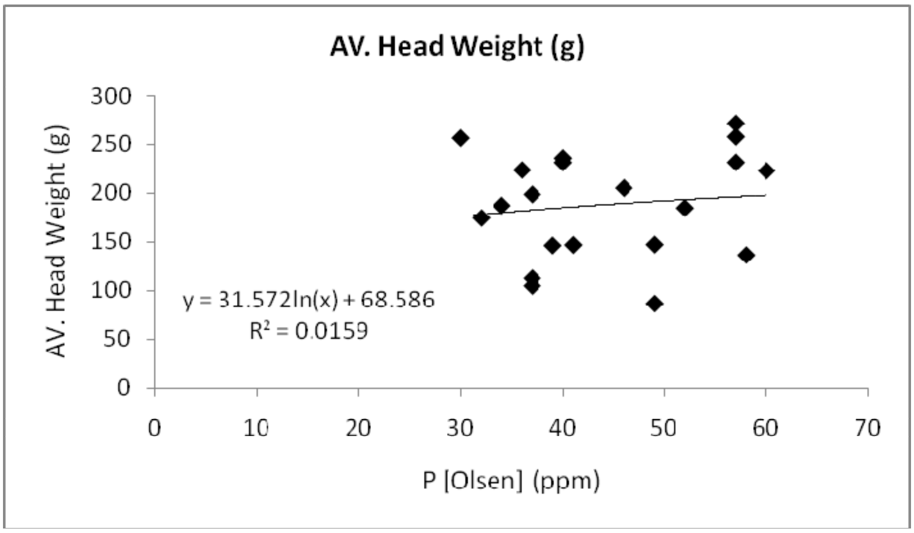

Figure 7.4. The effect of soil phosphorus concentration on the average head weight of broccoli.

Figure 7.5 shows the average head width (20 plants) associated with the phosphorus level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head width and phosphorus level in this trial.

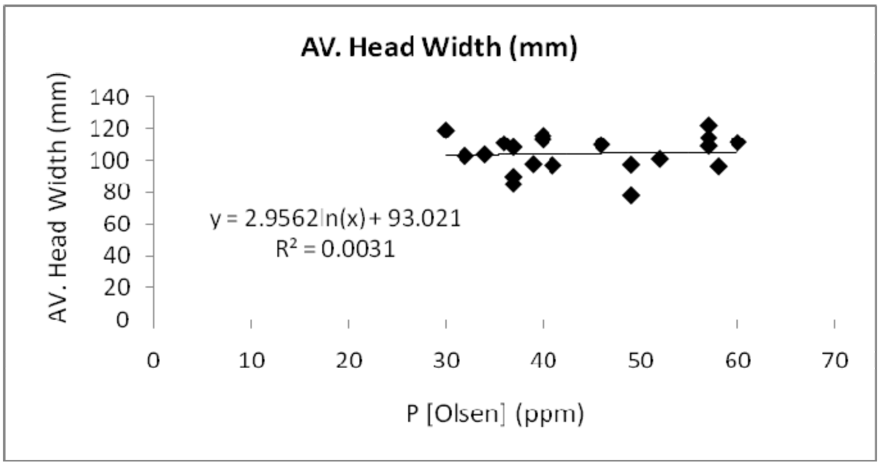

Figure 7.5. The effect of soil phosphorus concentration on the average head width of broccoli.

Figure 7.6 shows the average stem width (20 plants) associated with the phosphorus level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between stem width and phosphorus level in this trial.

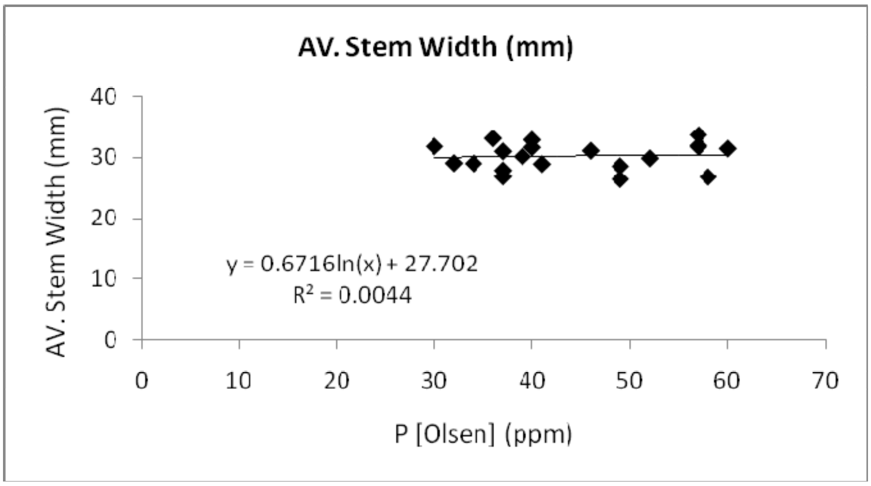

Figure 7.6. The effect of soil phosphorus concentration on the average stem width of broccoli.

Figure 7.7 shows the average harvest head weight (20 plants) associated with the potassium level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head weight and potassium level in this trial.

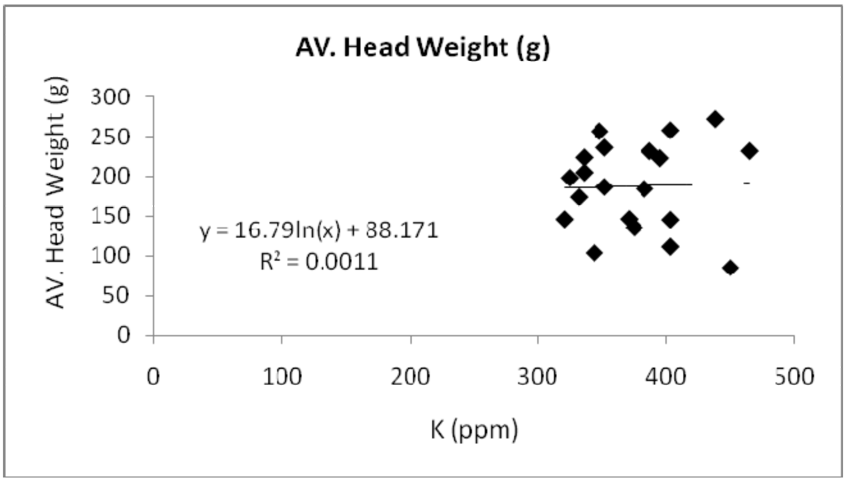

Figure 7.7. The effect of soil potassium concentration on the average head weight of broccoli.

Figure 7.8 shows the average harvest head width (20 plants) associated with the potassium level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head width and potassium level in this trial.

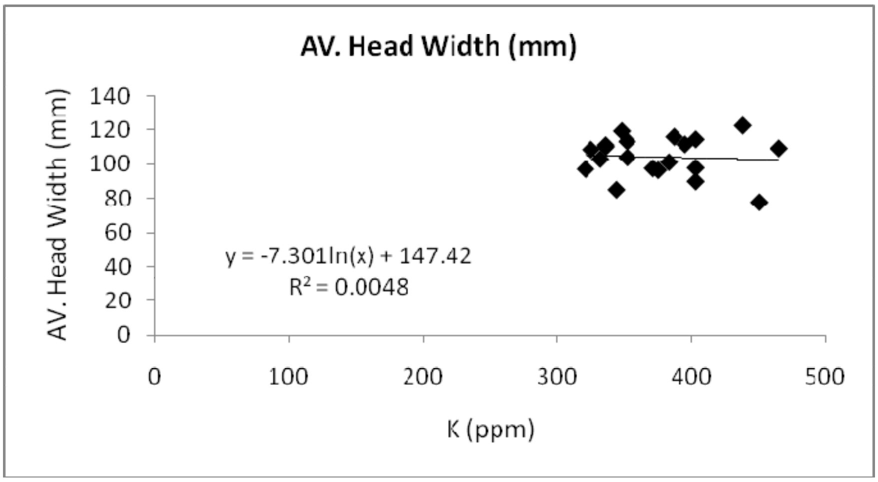

Figure 7.8. The effect of soil potassium concentration on the average head width of broccoli.

Figure 7.9 shows the average stem width (20 plants) associated with the potassium level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between stem width and potassium level in this trial.

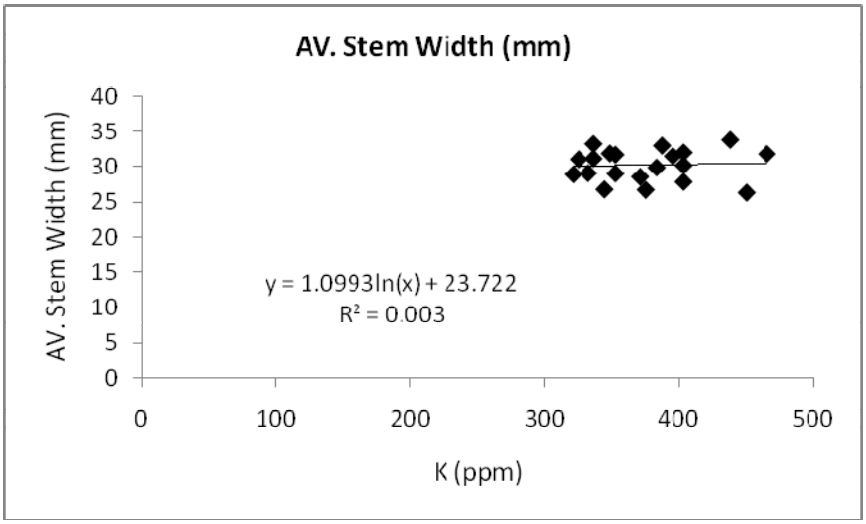

Figure 7.9. The effect of soil potassium concentration on the average stem width of broccoli.

Figure 7.10 shows the average harvest head weight (20 plants) associated with the magnesium level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head weight and magnesium level in this trial.

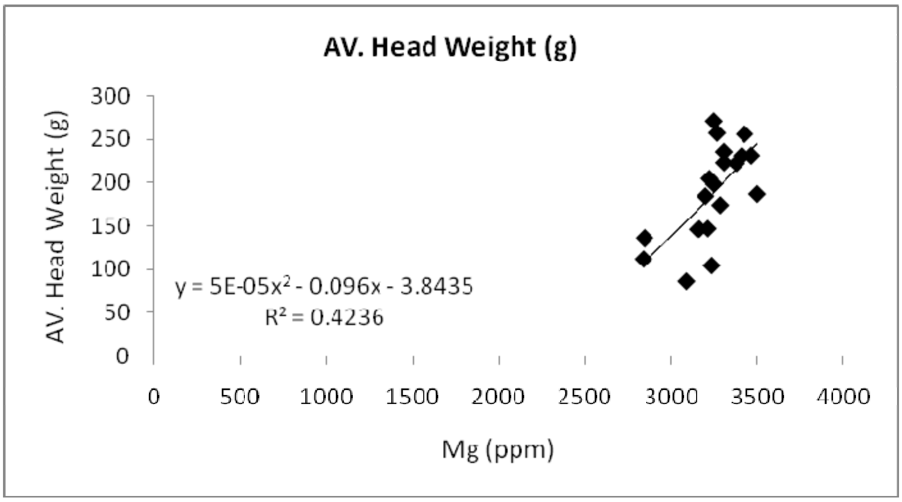

Figure 7.10. The effect of soil magnesium concentration on the average head weight of broccoli.

Figure 7.11 shows the average harvest head width (20 plants) associated with the magnesium level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head width and magnesium level in this trial.

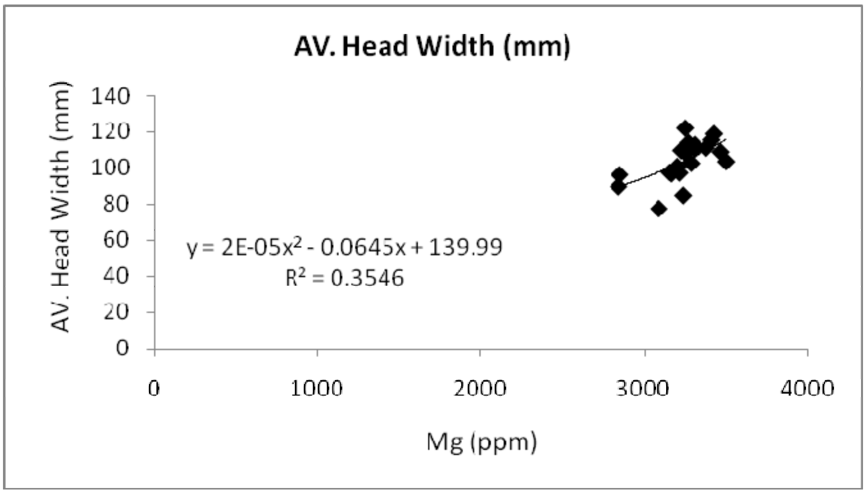

Figure 7.11. The effect of soil magnesium concentration on the average head width of broccoli.

Figure 7.12 shows the average stem width (20 plants) associated with the magnesium level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between stem width and magnesium level in this trial.

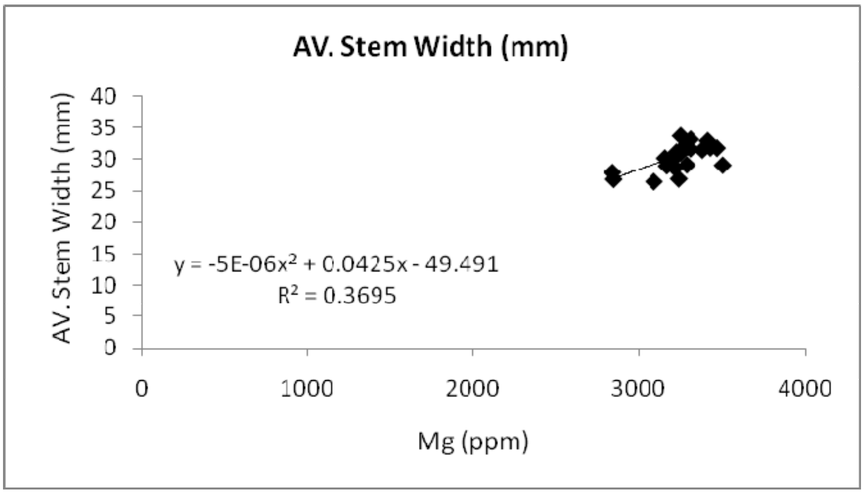

Figure 7.12. The effect of soil magnesium concentration on the average stem width of broccoli.

Figure 7.13 shows the average harvest head weight (20 plants) associated with the calcium level measured in a single soil sample, from 20 locations in the same crop. There was a significant correlation between head weight and calcium level in this trial.

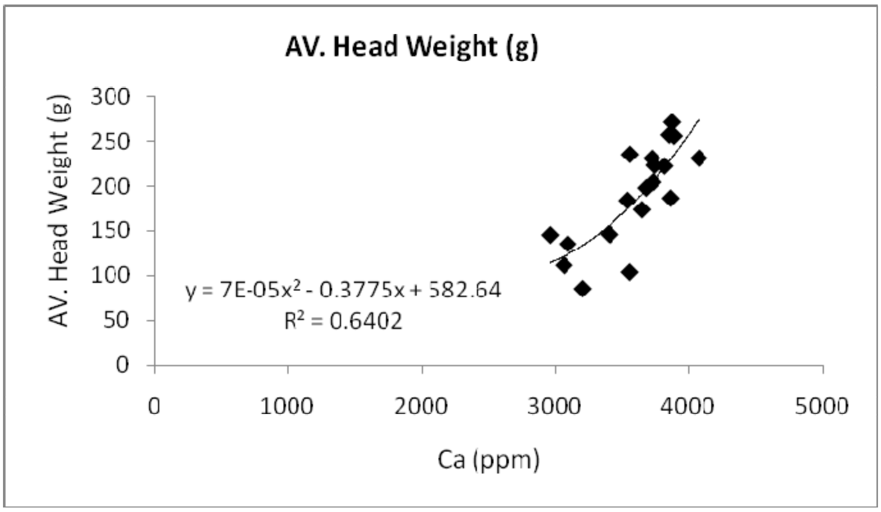

Figure 7.13. The effect of soil calcium concentration on the average head weight of broccoli.

Figure 7.14 shows the average harvest head width (20 plants) associated with the calcium level measured in a single soil sample, from 20 locations in the same crop. There was a significant correlation between head width and calcium level in this trial.

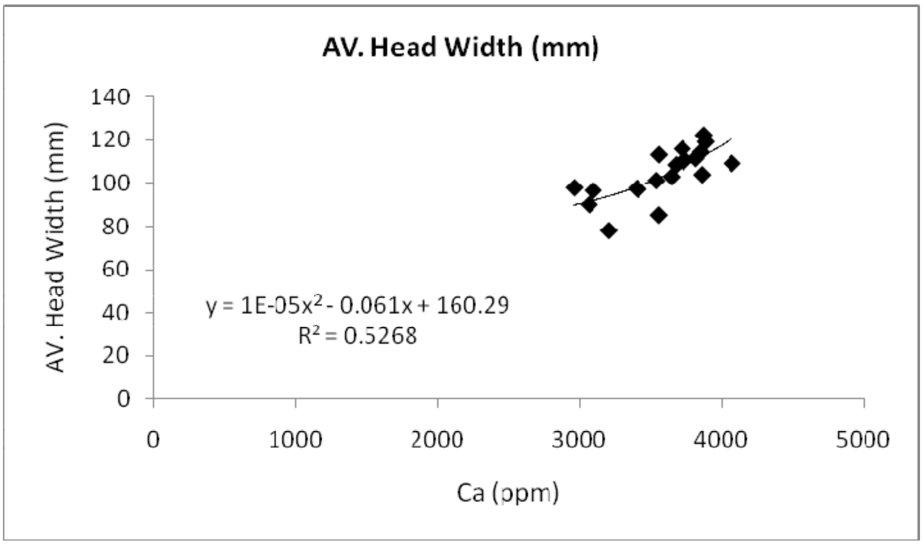

Figure 7.14. The effect of soil calcium concentration on the average head width of broccoli.

Figure 7.15 shows the average stem width (20 plants) associated with the calcium level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between stem width and calcium level in this trial.

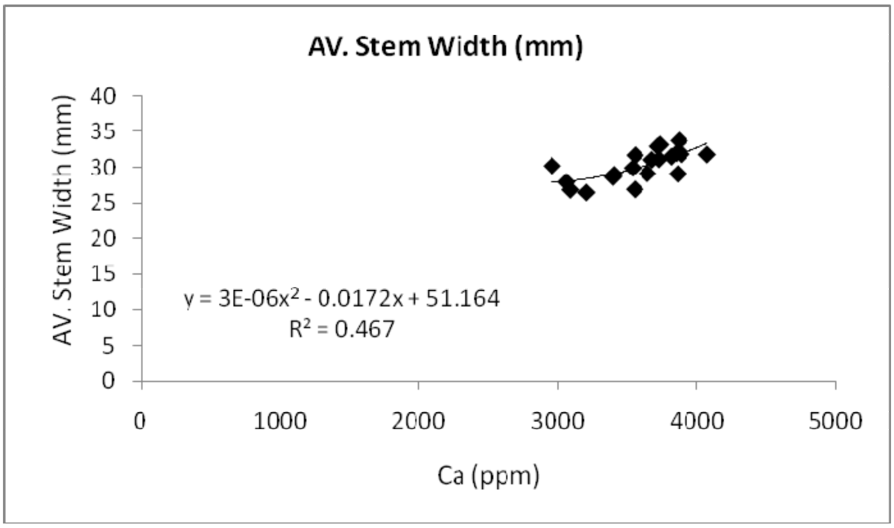

Figure 7.15. The effect of soil calcium concentration on the average stem width of broccoli.

Figure 7.16 shows the average harvest head weight (20 plants) associated with the sulfur level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head weight and sulfur level in this trial.

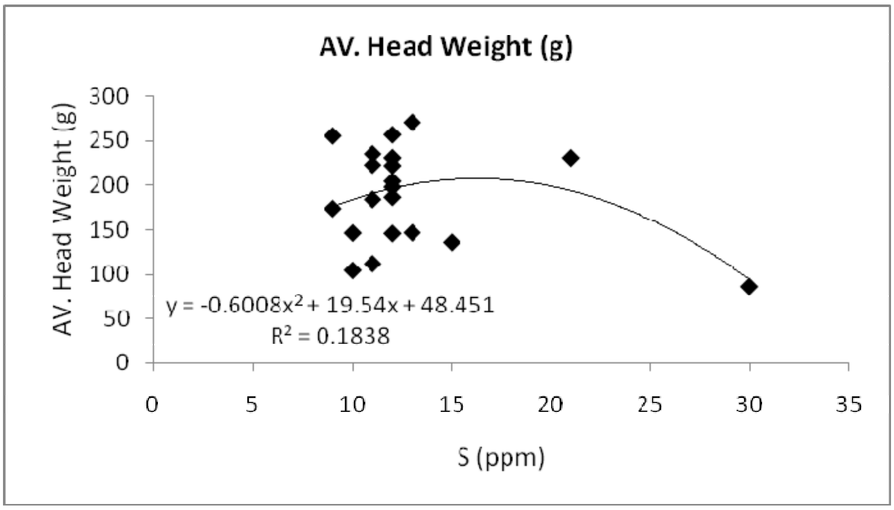

Figure 7.16. The effect of soil sulfur concentration on the average head weight of broccoli.

Figure 7.17 shows the average harvest head width (20 plants) associated with the sulfur level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head width and sulfur level in this trial.

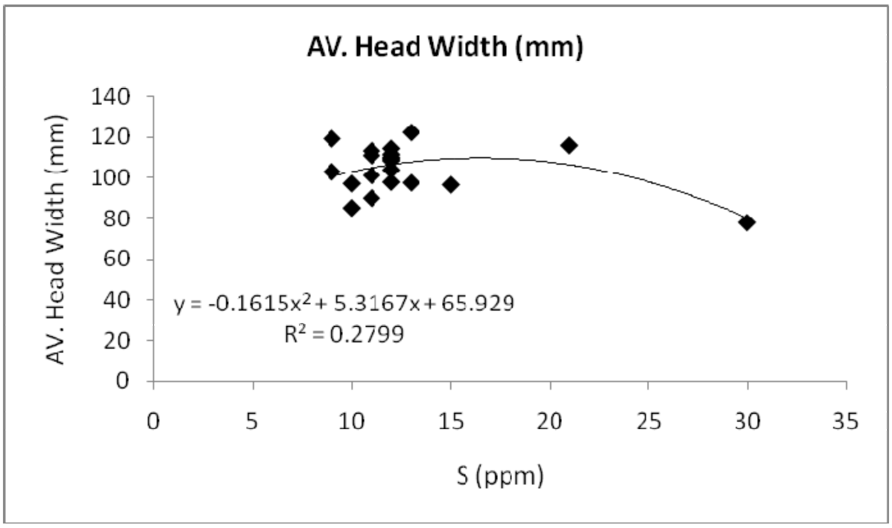

Figure 7.17. The effect of soil sulfur concentration on the average head width of broccoli.

Figure 7.18 shows the average stem width (20 plants) associated with the sulfur level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between stem width and sulfur level in this trial.

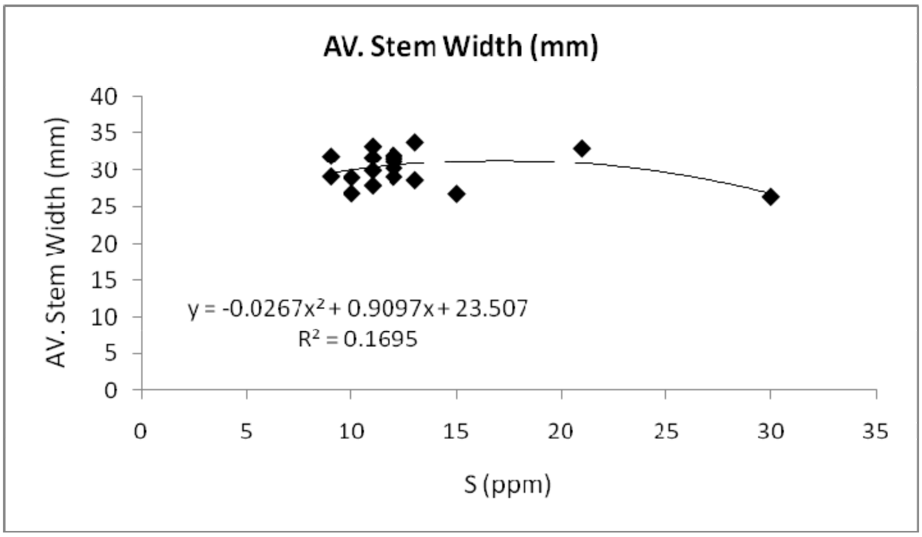

Figure 7.18. The effect of soil sulfur concentration on the average stem width of broccoli.

Figure 7.19 shows the average harvest head weight (20 plants) associated with the manganese level measured in a single soil sample, from 20 locations in the same crop. There was a significant correlation between head weight and manganese level in this trial.

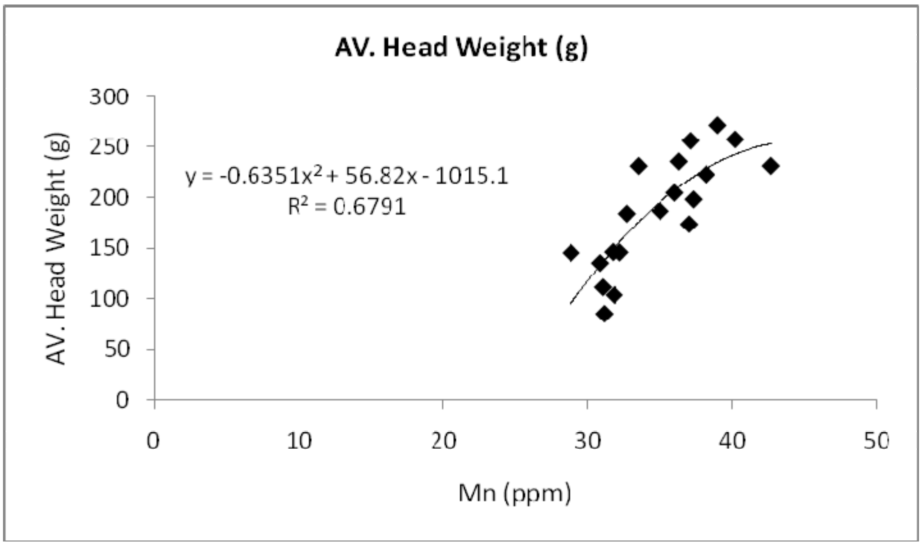

Figure 7.19. The effect of soil manganese concentration on the average head weight of broccoli.

Figure 7.20 shows the average harvest head width (20 plants) associated with the manganese level measured in a single soil sample, from 20 locations in the same crop. There was a significant correlation between head width and manganese level in this trial.

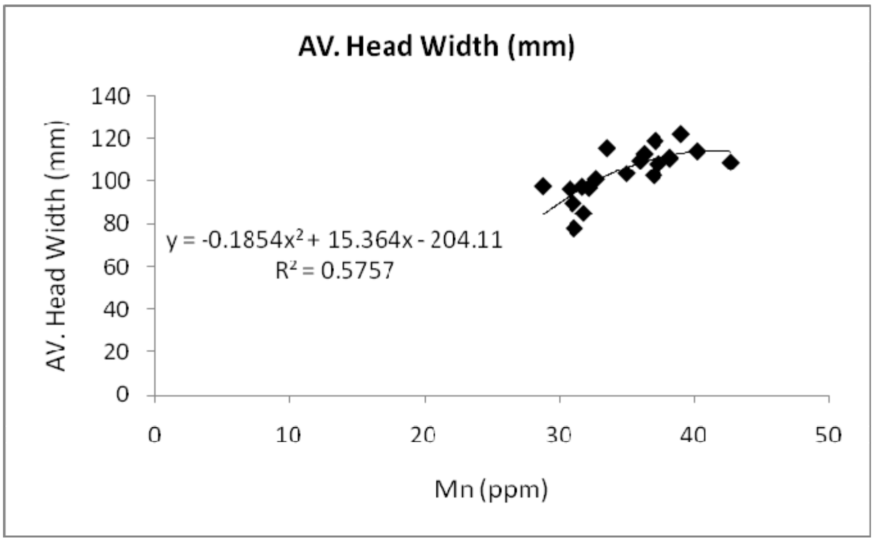

Figure 7.20. The effect of soil manganese concentration on the average head width of broccoli.

Figure 7.21 shows the average stem width (20 plants) associated with the manganese level measured in a single soil sample, from 20 locations in the same crop. There was a significant correlation between stem width and manganese level in this trial.

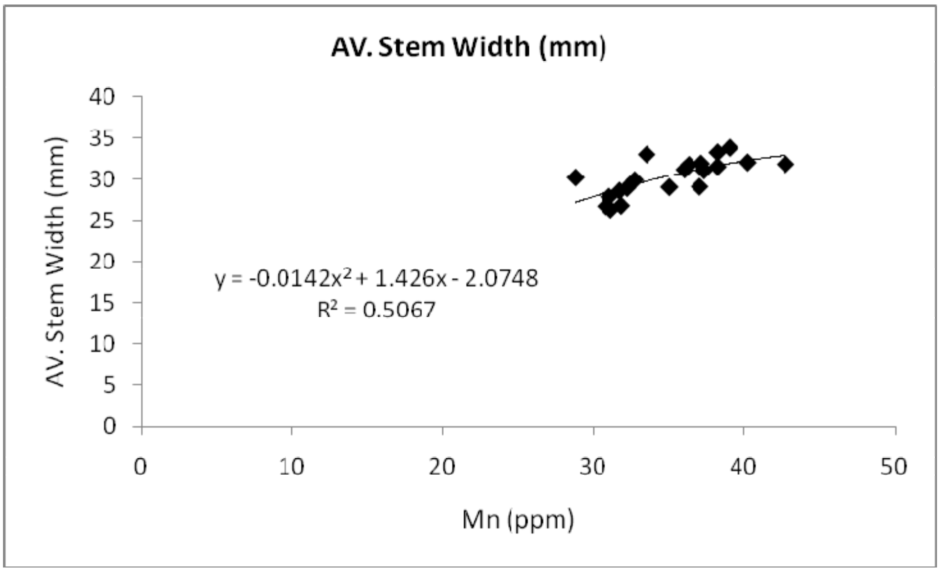

Figure 7.21. The effect of soil manganese concentration on the average stem width of broccoli.

Figure 7.22 shows the average harvest head weight (20 plants) associated with the boron level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head weight and boron level in this trial.

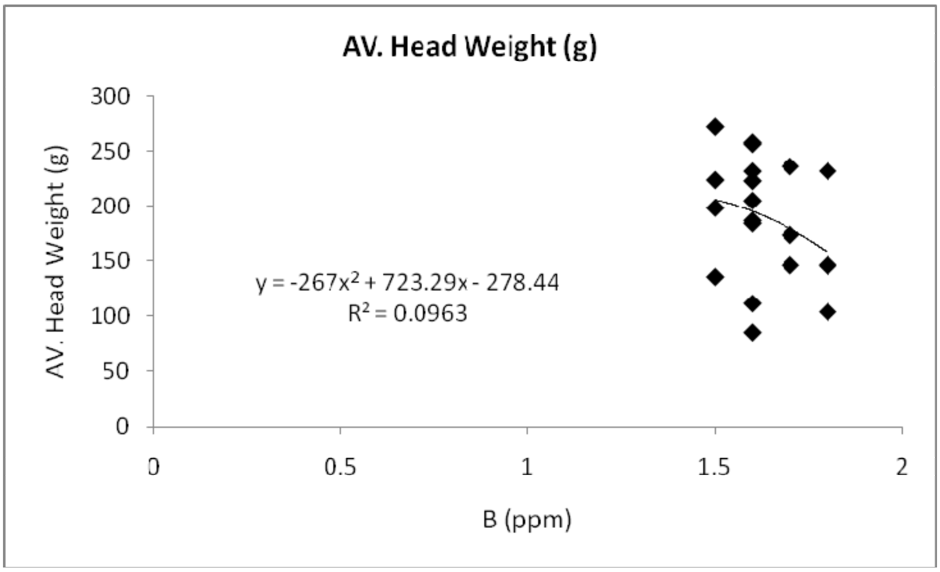

Figure 7.22. The effect of soil boron concentration on the average head weight of broccoli.

Figure 7.23 shows the average harvest head width (20 plants) associated with the boron level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head width and boron level in this trial.

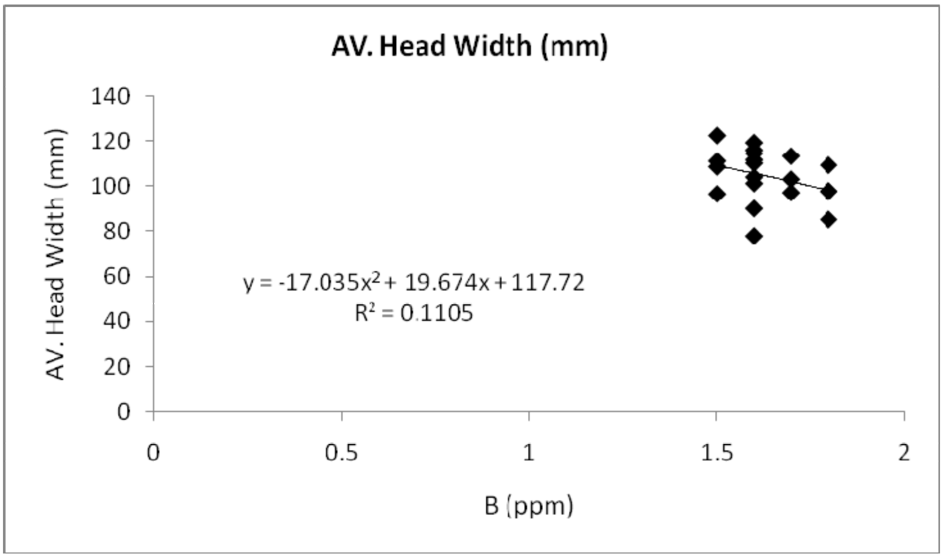

Figure 7.23. The effect of soil boron concentration on the average head width of broccoli.

Figure 7.24 shows the average stem width (20 plants) associated with the boron level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between stem width and boron level in this trial.

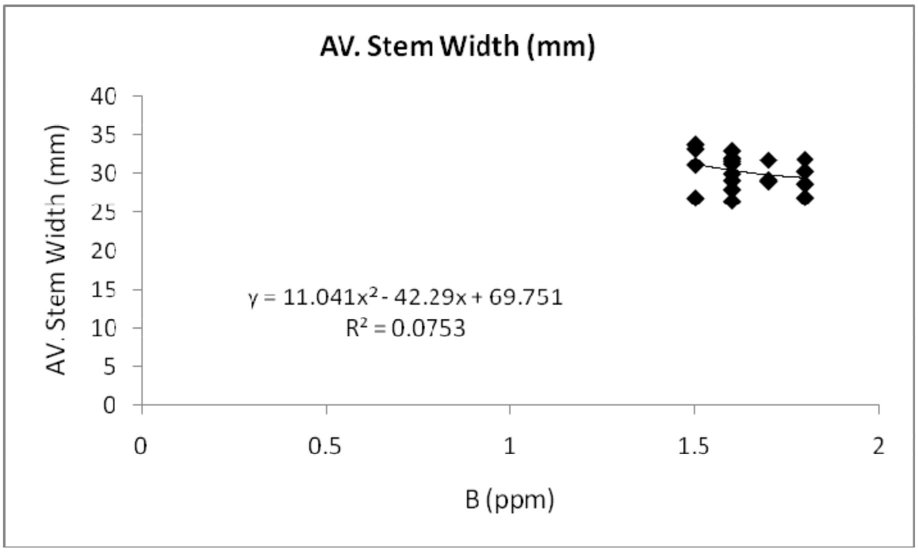

Figure 7.24. The effect of soil boron concentration on the average stem width of broccoli.

Figure 7.25 shows the average harvest head weight (20 plants) associated with the copper level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head weight and copper level in this trial.

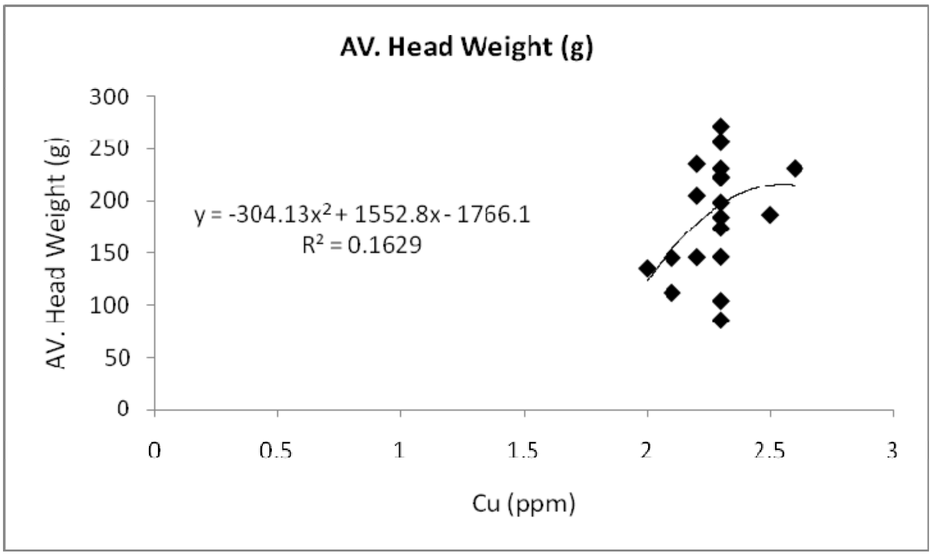

Figure 7.25. The effect of soil copper concentration on the average head weight of broccoli.

Figure 7.26 shows the average harvest head width (20 plants) associated with the copper level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head width and copper level in this trial.

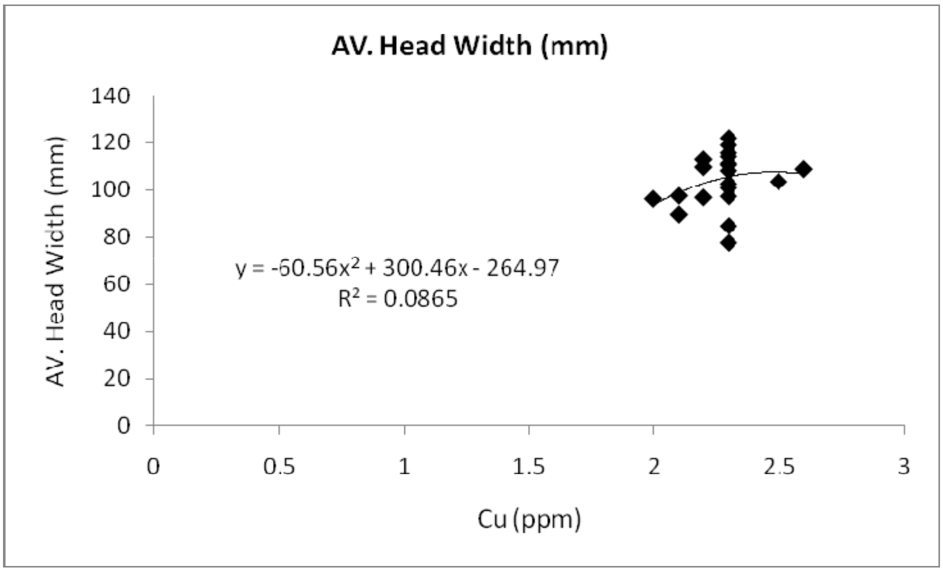

Figure 7.26. The effect of soil copper concentration on the average head width of broccoli.

Figure 7.27 shows the average stem width (20 plants) associated with the copper level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between stem width and copper level in this trial.

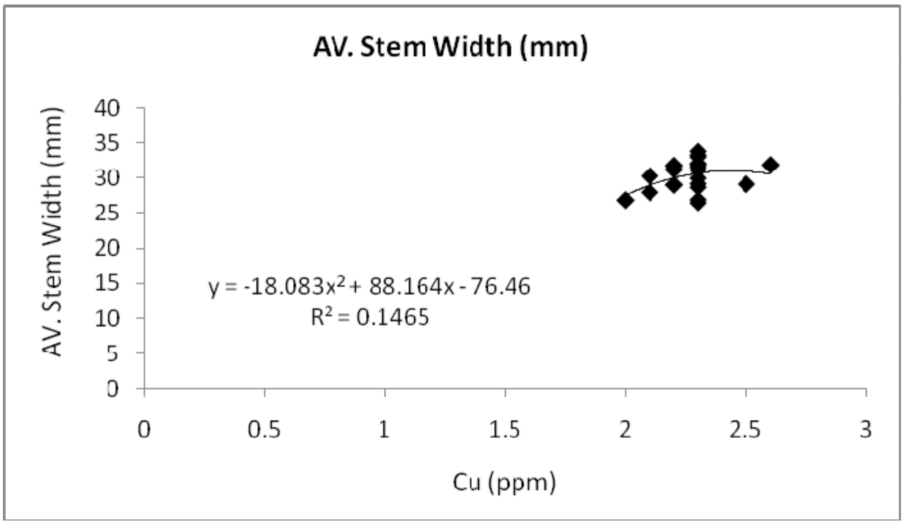

Figure 7.27. The effect of soil copper concentration on the average stem width of broccoli.

Figure 7.28 shows the average harvest head weight (20 plants) associated with the iron level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head weight and iron level in this trial.

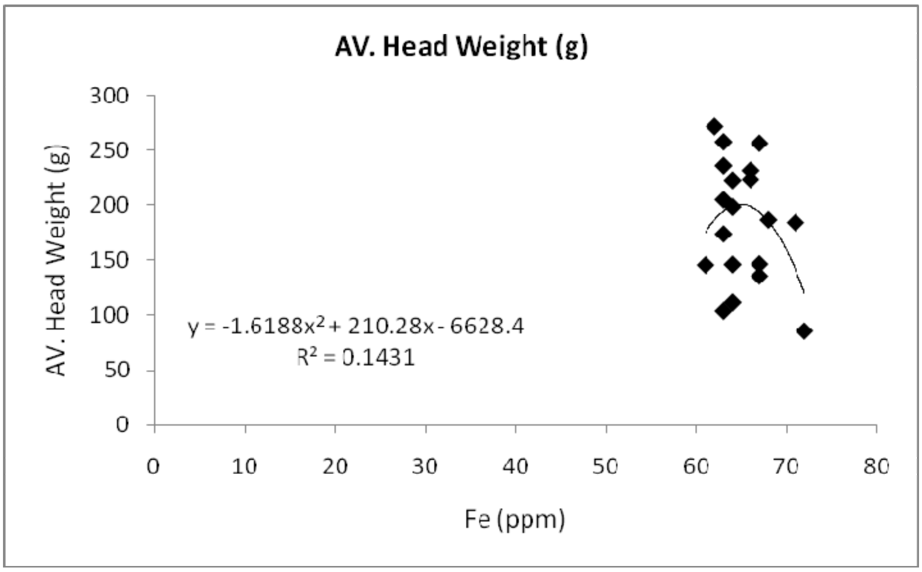

Figure 7.28. The effect of soil iron concentration on the average head weight of broccoli.

Figure 7.29 shows the average harvest head width (20 plants) associated with the iron level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head width and iron level in this trial.

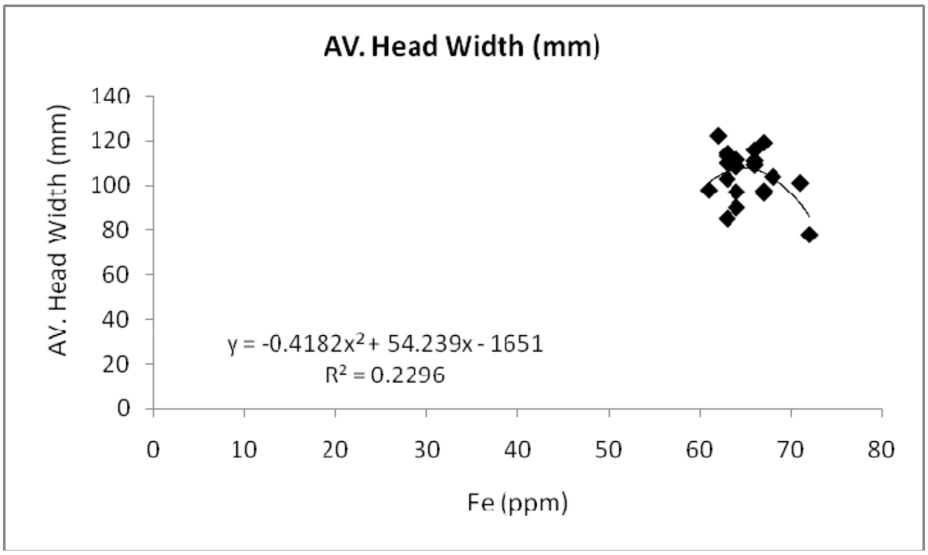

Figure 7.29. The effect of soil iron concentration on the average head width of broccoli.

Figure 7.30 shows the average stem width (20 plants) associated with the iron level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between stem width and iron level in this trial.

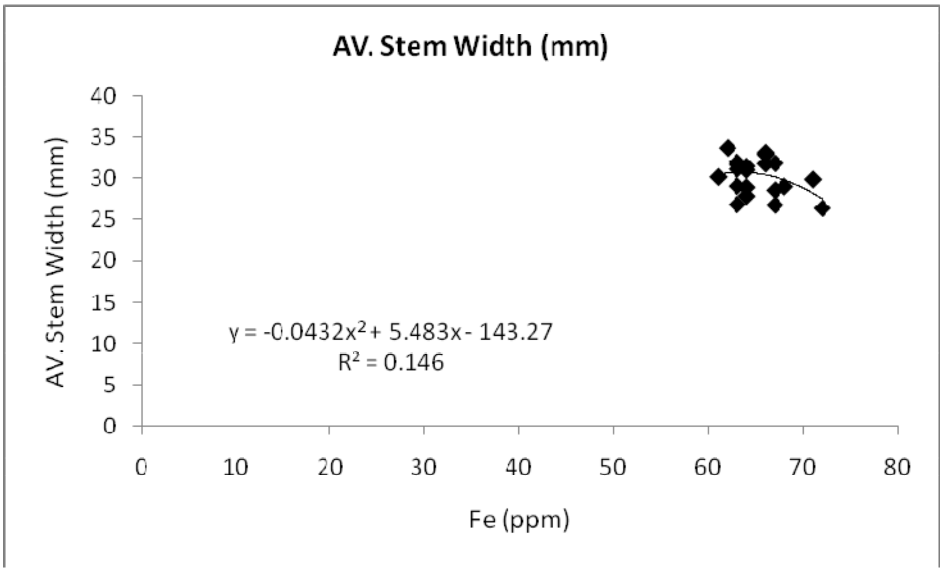

Figure 7.30. The effect of soil iron concentration on the average stem width of broccoli.

Figure 7.31 shows the average harvest head weight (20 plants) associated with the zinc level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head weight and zinc level in this trial.

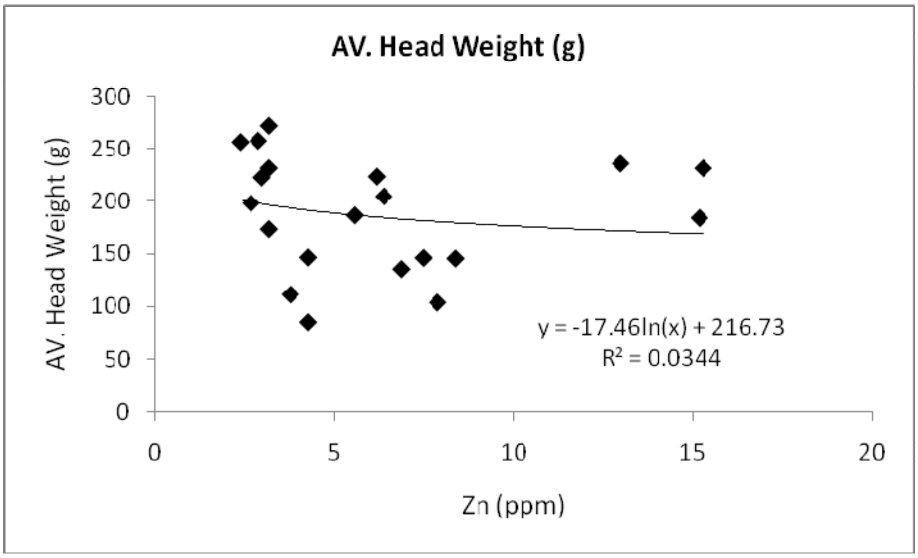

Figure 7.31. The effect of soil zinc concentration on the average head weight of broccoli.

Figure 7.32 shows the average harvest head width (20 plants) associated with the zinc level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head width and zinc level in this trial.

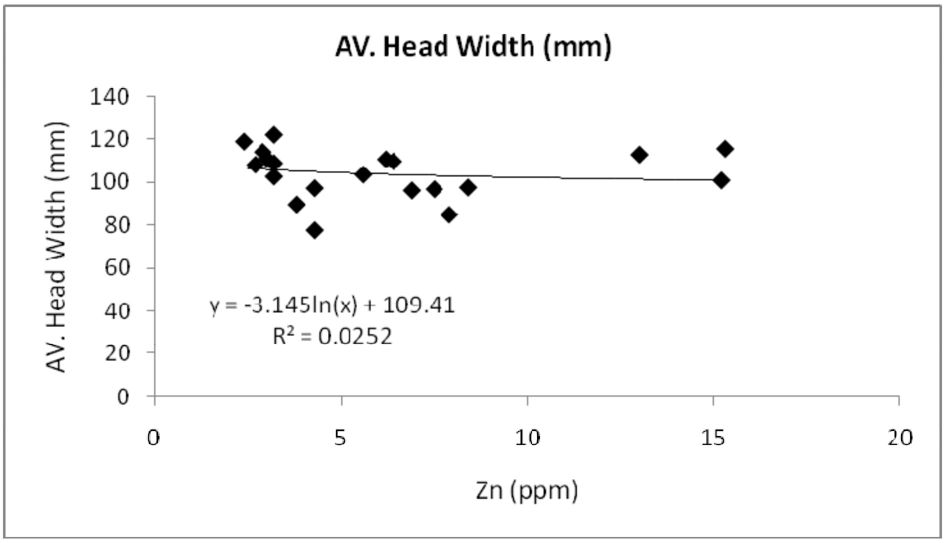

Figure 7.32. The effect of soil zinc concentration on the average head width of broccoli.

Figure 7.33 shows the average stem width (20 plants) associated with the zinc level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between stem width and zinc level in this trial.

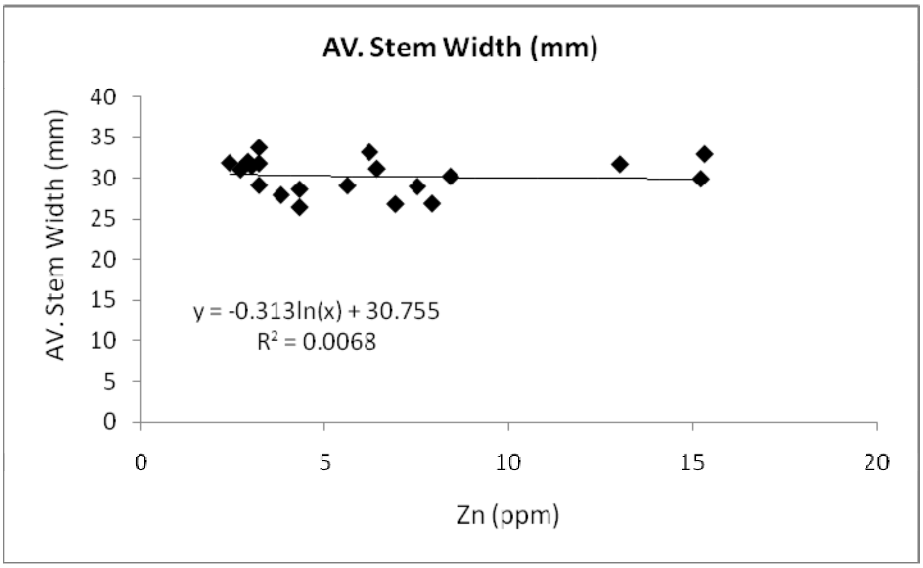

Figure 7.33. The effect of soil zinc concentration on the average stem width of broccoli.

Figure 7.34 shows the average harvest head weight (20 plants) associated with the sodium level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head weight and sodium level in this trial.

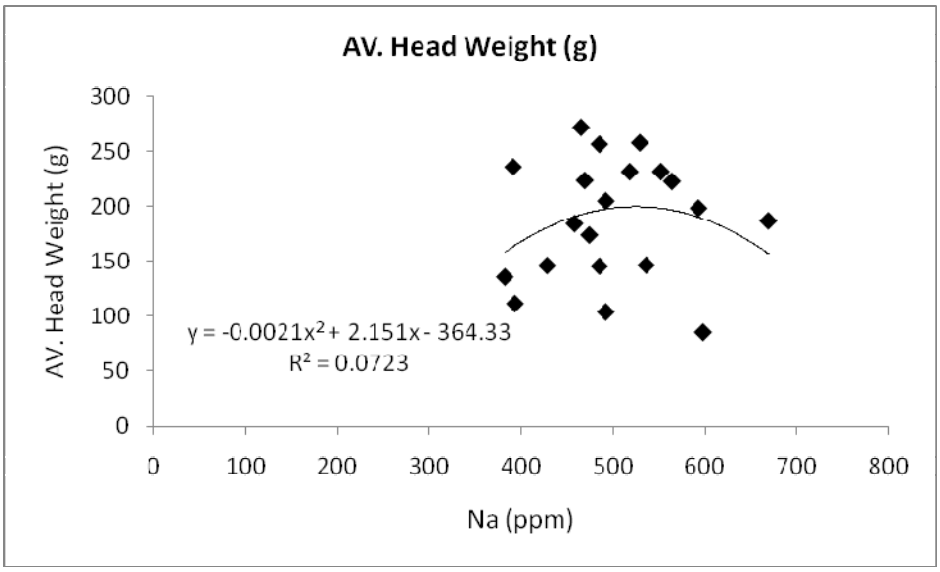

Figure 7.34. The effect of soil sodium concentration on the average head weight of broccoli.

Figure 7.35 shows the average harvest head width (20 plants) associated with the sodium level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head width and sodium level in this trial.

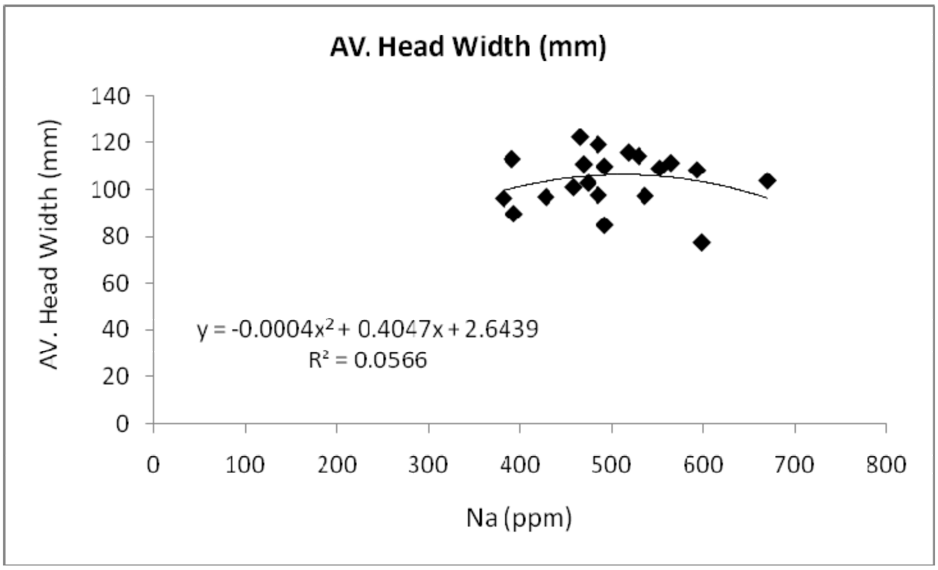

Figure 7.35. The effect of soil sodium concentration on the average head width of broccoli.

Figure 7.36 shows the average stem width (20 plants) associated with the sodium level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between stem width and sodium level in this trial.

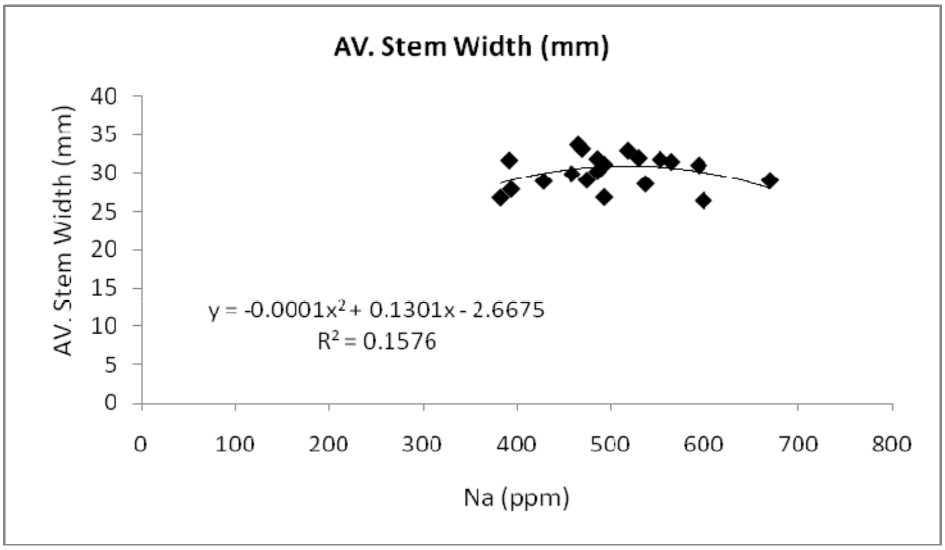

Figure 7.36. The effect of soil sodium concentration on the average stem width of broccoli.

Figure 7.37 shows the average harvest head weight (20 plants) associated with the aluminium level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head weight and aluminium level in this trial.

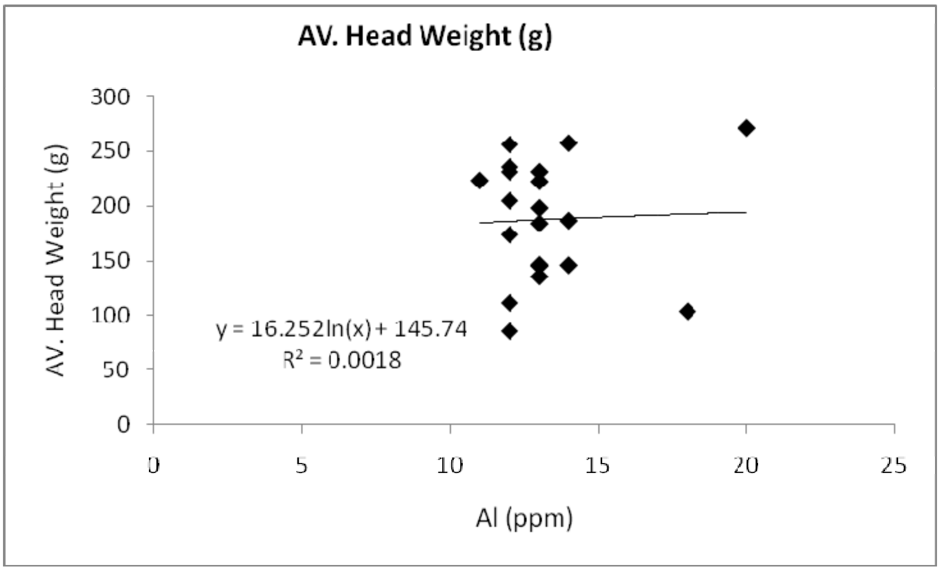

Figure 7.37. The effect of soil aluminium concentration on the average head weight of broccoli.

Figure 7.38 shows the average harvest head width (20 plants) associated with the aluminium level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between head width and aluminium level in this trial.

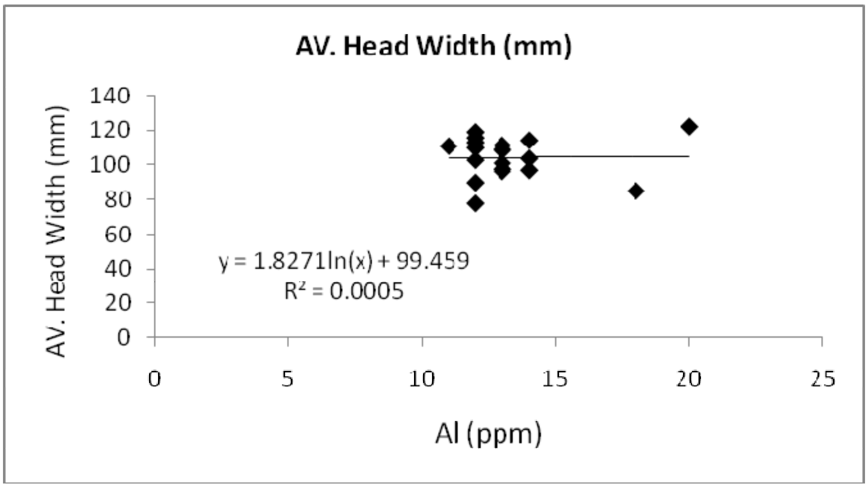

Figure 7.38. The effect of soil aluminium concentration on the average head width of broccoli.

Figure 7.39 shows the average stem width (20 plants) associated with the aluminium level measured in a single soil sample, from 20 locations in the same crop. There was no significant correlation between stem width and aluminium level in this trial.

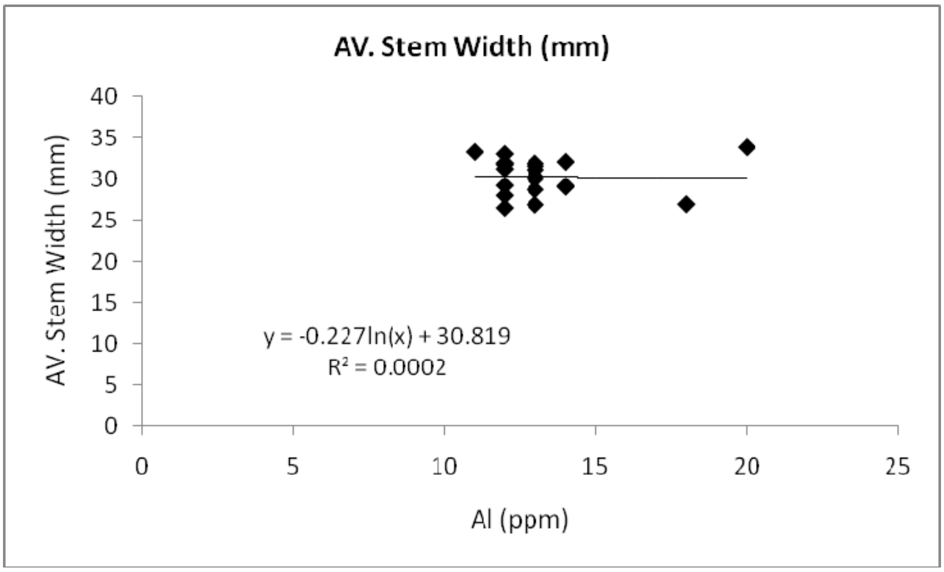

Figure 7.39. The effect of soil aluminium concentration on the average stem width of broccoli.

Conclusion

While the study initially aimed to examine the role of the three major elements, nitrogen, phosphorus and potassium on head size variability, a complete soil analysis allowed the inclusion of most secondary and minor elements as well.

Of all elements examined (N, P, K, Ca, Mg, Mn, S, Cu, Fe, Zn, B, Na & Al), only Ca and Mn were found to have a significant effect on head size across the normal range of levels found in a typical commercial planting in the Gatton production region. Based on any previous research conducted there is no real evidence that Ca or Mn are normally associated with improvements in head size.

8 Investigating the Optimum Irrigation Strategy for Mechanically Harvested Broccoli

Introduction

Furrow irrigation is the least water-use efficient irrigation method used in vegetable crop production. It does, however, have one significant advantage over the more water-use efficient trickle irrigation in that it wets the whole soil profile right across the bed and to the soil surface.

This feature is important for seed or seedling establishment because it means that furrow irrigation is able to supply the young plants with the soil moisture they need for early growth, irrespective of the plants' precise position in the bed. The other key advantage is that because the whole bed has been irrigated, there is a large reserve of soil moisture able to move by capillary into the root zone of the young seedlings to replace the water they use. Yet another advantage is the evaporative cooling effect if planting is carried out during hot weather. A larger area of wet surface soil provides a cooler microclimate around the seedling. This is achieved both through lowering the surface soil temperature immediately around the seedling and by lowering the air temperature around the seedling.

In contrast, trickle irrigation applies water to the root-zone of the plant in a much smaller volume of wetted soil around the trickle tube. In practice, it is often very difficult to uniformly wet the surface of the soil because the water has to move up from the buried trickle tube. This is especially so if the soil preparation is not perfect, i.e. clods remain or the bed surface is uneven. This problem is made worse if the trickle tube is not laid at an even depth and if the seedlings or seed are not planted exactly above the trickle-tube emitters.

In the case of broccoli, the harvester and farm machinery are all configured to plant two rows per bed. This means the trickle irrigation tube has to run down the centre of the bed and irrigate two rows of plants offset to either side, which further exacerbates the problem.

In higher value crops such as melons, tomatoes and capsicums, the problem of uneven water supply to young seedlings or seed under trickle irrigation is addressed by using plastic mulch. This helps to redistribute water more evenly across the bed, especially in the upper soil layers, and reduce evaporative losses. In machine-harvested broccoli the additional financial and environmental cost of laying and retrieving plastic would be prohibitive.

These issues result in poor establishment of crops such as broccoli and lettuce in bare soil using trickle irrigation. This has two main consequences. Firstly, many seeds or seedlings do not develop into mature plants. Secondly, varying soil moisture affects early crop growth rate and results in different sized heads at harvest.

Possible Solutions

One solution would be to install two trickle tubes per bed, i.e. one under each row of plants, but this would double the capital cost of irrigation and be uneconomic.

An innovative and cost-effective solution to this problem has been developed by Teixeira Farms in Santa Maria, California, to assist the establishment of lettuce and broccoli crops when irrigation water is supplied by trickle irrigation tape. This solution is to use portable sprinkler irrigation for the crop establishment phase (14-21 days from seeding/transplanting), which wets the whole bed and supplies water more evenly to the young plants. Then, after the establishment phase, the portable sprinkler irrigation is moved to the next planting and the crop is subsequently watered using trickle irrigation which has been installed in the soil prior to planting. The added advantage of using sprinkler irrigation temporarily for establishment is that can be used to incorporate pre-emergent herbicides such as Stomp® (pendimethalin). Pre-emergent herbicides must be applied before transplanting and incorporated with 12-25mm of irrigation within 24 hours. Trickle irrigation cannot be used to incorporate herbicides effectively or evenly. Only sprinklers, rainfall or mechanical incorporation gives satisfactory results.

Literature Review – Broccoli Irrigation Requirements

While some authors have suggested that maintaining moisture as close to 100% vol of ASW as possible should maximise yield for most crops by ensuring plant growth is not limited (Sharda and Singh 1993), the practical limitation to this is the reduced availability of oxygen under these conditions (Wiebe 1981). A study in Germany (Gutezeit 2006) showed that for both spring and autumn production, the highest marketable yield (head mass) was obtained by applying 14mm of water when soil moisture fell below 55% vol of ASW (available soil water) on sandy soils. In this, as well as in an earlier study by the same author (Gutezeit 2004), applying 14mm of water or more at 75% vol of ASW (overwatering) resulted in reduced head mass in both spring and autumn plantings. A study in Botswana (Imtiyaz *et al* 2000) found the highest mean marketable yield of broccoli, as well as the maximum irrigation production efficiency, occurred at 80% of pan evaporation replenishment.

Ludy *et al* (1997) found that greater irrigation frequency with overhead sprinklers has the potential for increased incidence of bacterial soft rot (*Erwinia carotovora* subsp. *carotovora*). This indicates another potential advantage to wider adoption of trickle irrigation for local conditions.

In a cabbage study in Ohio, USA, irrigation during head development was found to be essential for maximising head size and weight (Radovich *et al* 2005). In the absence of a specific broccoli study, it is likely that similar principles apply to other brassica head vegetables.

Trickle irrigation is increasingly being exploited and evaluated elsewhere in the world for broccoli production where water has become a scarce resource, such as Mexico (Jolalpa-Barrera *et al* 2004). Quite apart from the water conservation aspects of drip irrigation, it is increasingly being shown to be a more convenient and efficient means of applying fertiliser, particularly nitrogen. In the case of sub-surface drip irrigation, the convenience factor alone means very low doses can be applied as often as several times daily. However, optimum fertigation interval for sub-surface drip systems has not been well researched (Thompson *et al* 2003). Despite this, Thompson *et al* (2003) found in a study in Arizona that, providing adequate total N was applied to a crop, there was no difference in broccoli yield or quality, whether liquid N was applied every 1, 7, 14 or 28 days on a sandy loam or finer textured soil through sub-surface drip irrigation. The same study concluded that more frequent fertigation may be required on very coarse textured soils. It would appear Thompson and a dedicated team have undertaken a good deal of research since 2002, (some still to be published and some available directly from their University of Arizona website [Azdrip – Subsurface drip irrigation and research project, Department of Soil, Water and Environmental Science]), in the use of drip irrigation in arid zone, temperate vegetable production. One of the key issues experienced on this demonstration farm that is directly relevant to our local conditions is the difficulty in germinating directly-sown seed. Early attempts at direct seeding and watering up with subsurface drip irrigation caused excessive surface salinity and complete crop failure. Subsequent plantings were all successfully established by using sprinklers to irrigate for the first 2-3 weeks post-planting, before switching over to subsurface drip. This is essentially the same technique used in California (as described in the introduction to this section of the report), and the blueprint for any irrigation studies to be undertaken in this project.

Aim

To determine the extent to which the irrigation method used during and after crop establishment influences crop yield and variability.

Methods

A single trial was established, based on large single blocks for each treatment in a highly uniform paddock. Blocks in irrigation trials are by nature almost impossible to replicate in any meaningful way, so instead each treatment was quartered and sub-samples taken in a representative way. These were then evaluated as replicates. The double-barrelled treatment names pertain to the two phases used in any given regime. The first phase, establishment, indicates what irrigation method was used for the first 14 days. The second phase indicates the irrigation method used from after establishment until crop maturity and harvest. So, 'Overhead-Trickle', for example, tells us that overhead irrigation was used for the first 14 days during establishment, and then trickle was employed for the remainder of the trial up to harvest.

On 26 July 2009, the variety 'Evergreen' was sown as 4-week old seedlings into beds spaced 1.6m apart, in paired rows and spaced 60cm apart on each bed. The crop was harvested 83 days later, by hand. Ten adjacent plants from the north row and ten adjacent plants from the south row were cut by hand at each sampling point (replication).

Overhead Irrigation: Solid set risers were laid out in a grid pattern 9.0m apart applying approximately 8mm per hour.

Furrow Irrigation: Water was allowed to flood down the inter-rows (furrows) for approximately 24 hours before being shut off and allowed to drain through the profile to field capacity.

Trickle Irrigation: This consisted of single lines of 20mm drip-line laid down the centres of beds with pressure-compensating emitters every 30cm outputting 2.0 L/hour/emitter.

Each system ran until the root-zone reached field capacity, and it is fair to assume no treatment was hindered particularly by a lack of moisture compared to another. There were, however, efficiency gains in terms of total water volumes used per hectare, with trickle being more efficient than overhead, which was more efficient than furrow irrigation for each watering. Tensiometers were installed in all treatments at a depth of 150mm and irrigations were scheduled to occur when water tension reach 30 Kpa. This was to imitate standard practice. Actual volumes of water applied were adjusted by crop stage and environmental conditions. Six days prior to harvest, 37mm of rain fell. All other rain to fall during the course of the trial measured no more than 2mm in total.

Results & Discussion

Table 8.1. Harvest results summarised by treatment and row location

	Treatment name	Row	AV. Head weight	Std error Head weight	AV. Head width	Std error Head width	AV. Width group	Std Error Width group	AV. Stem length	Std Error Stem length
1	Overhead-Furrow	N	497	30.34	158	4.69	162	4.67	148	3.77
2	Furrow-Furrow	N	515	26.70	158	2.68	161	2.73	135	3.01
3	Overhead-Overhead	N	549	32.84	164	5.40	167	5.48	137	3.11
4	Overhead-Trickle	N	421	21.38	149	3.55	152	3.54	129	2.21
5	Trickle-Trickle	N	521	24.15	153	2.69	157	2.71	135	1.57
1	Overhead-Furrow	S	373	19.80	150	2.95	154	3.12	139	2.44
2	Furrow-Furrow	S	481	24.60	160	3.49	163	3.34	138	2.14
3	Overhead-Overhead	S	320	19.91	141	4.06	144	4.16	130	3.01
4	Overhead-Trickle	S	261	18.48	131	4.20	133	4.38	121	2.83
5	Trickle-Trickle	S	288	14.59	139	2.76	143	3.13	130	1.63

Average Head Weight (Figure 8.1 & Tables 8.1, 8.2, 8.3 & 8.4)

The most prominent feature from Fig. 8.1 is the more profound effect on head weights of row location rather than irrigation regime (treatment). More specifically, average head weights varied more between treatments in southern rows than treatments in northern rows. Head weights were always greater (generally, significantly so,) in northern rows than southern rows.

Standard errors were generally proportional to head weights, indicating no particular treatment resulted in more uniform head weights than others.

When results from both rows were combined, only Furrow-Furrow irrigation resulted in significantly heavier heads than Overhead-Trickle (Table 8.2). No other differences were significant.

Treatments were most clearly separated when only the south rows were compared (Table 8.3). Furrow-Furrow yielded significantly heavier heads than all other treatments. Overhead-Furrow watering yielded significantly heavier heads than Trickle-Trickle or Overhead-Trickle.

Treatments were not significantly different when only the northern rows were compared.

The relative closeness of results from northern and southern rows in the Furrow-Furrow regime compared with other treatments suggests this treatment may have had better access to moisture at critical times than other treatments (Fig. 8.1).

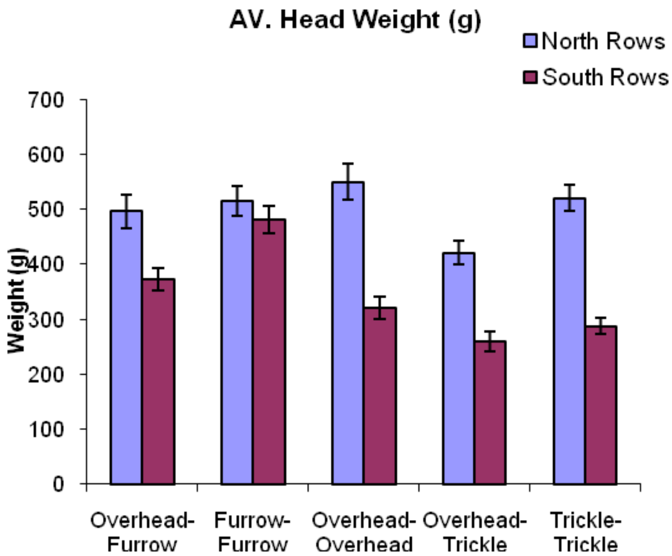

Figure 8.1. Average Head Weight & Standard Error by treatment and row location (from Table 8.1)

Table 8.2. AV. Head Weight (by Treatment - N and S rows combined)

<table>
<tr><th>Irrigation Regime</th><th>No.</th><th colspan="3">Head Weight (g)</th></tr>
<tr><td>Overhead-Trickle</td><td>4</td><td>341</td><td>|</td><td></td></tr>
<tr><td>Trickle-Trickle</td><td>5</td><td>404</td><td>|</td><td>|</td></tr>
<tr><td>Overhead-Overhead</td><td>3</td><td>435</td><td>|</td><td>|</td></tr>
<tr><td>Overhead-Furrow</td><td>1</td><td>435</td><td>|</td><td>|</td></tr>
<tr><td>Furrow-Furrow</td><td>2</td><td>498</td><td></td><td>|</td></tr>
<tr><td>Transformation</td><td></td><td colspan="3">None</td></tr>
</table>

Vertical bars aligned in the same column indicate means that are NOT SIGNIFICANTLY DIFFERENT (LSD, P=0.05). Means followed by "-" failed Bartlett's Chi-squared Test for Homogeneity of Variance and attempts to rectify this with transformations were NOT successful (P=0.05). Blue vertical bars indicate LSD results based on successfully transformed data BUT the numbers they follow are original.

Table 8.3. AV. Head Weight (by Treatment - S rows only)

<table>
<tr><th>Irrigation Regime</th><th>No.</th><th colspan="4">Head Weight (g)</th></tr>
<tr><td>Overhead-Trickle</td><td>4</td><td>261</td><td>|</td><td></td><td></td></tr>
<tr><td>Trickle-Trickle</td><td>5</td><td>288</td><td>|</td><td></td><td></td></tr>
<tr><td>Overhead-Overhead</td><td>3</td><td>320</td><td>|</td><td>|</td><td></td></tr>
<tr><td>Overhead-Furrow</td><td>1</td><td>373</td><td></td><td>|</td><td></td></tr>
<tr><td>Furrow-Furrow</td><td>2</td><td>481</td><td></td><td></td><td>|</td></tr>
<tr><td>Transformation</td><td></td><td colspan="4">None</td></tr>
</table>

Vertical bars aligned in the same column indicate means that are NOT SIGNIFICANTLY DIFFERENT (LSD, P=0.05). Means followed by "-" failed Bartlett's Chi-squared Test for Homogeneity of Variance and attempts to rectify this with transformations were NOT successful (P=0.05). Blue vertical bars indicate LSD results based on successfully transformed data BUT the numbers they follow are original.

Table 8.4. AV. Head Weight (by Treatment - N rows only)

<table>
<tr><th>Irrigation Regime</th><th>No.</th><th colspan="2">Head Weight (g)</th></tr>
<tr><td>Overhead-Trickle</td><td>4</td><td>421</td><td>|</td></tr>
<tr><td>Overhead-Furrow</td><td>1</td><td>497</td><td>|</td></tr>
<tr><td>Furrow-Furrow</td><td>2</td><td>515</td><td>|</td></tr>
<tr><td>Trickle-Trickle</td><td>5</td><td>521</td><td>|</td></tr>
<tr><td>Overhead-Overhead</td><td>3</td><td>549</td><td>|</td></tr>
<tr><td>Transformation</td><td></td><td colspan="2">None</td></tr>
</table>

Vertical bars aligned in the same column indicate means that are NOT SIGNIFICANTLY DIFFERENT (LSD, P=0.05). Means followed by "-" failed Bartlett's Chi-squared Test for Homogeneity of Variance and attempts to rectify this with transformations were NOT successful (P=0.05). Blue vertical bars indicate LSD results based on successfully transformed data BUT the numbers they follow are original.

Average Head Width (Figure 8.2 & Tables 8.1, 8.5, 8.6 & 8.7)

As with head weights, the effect of row location appeared to have a greater effect on head width than irrigation regime (Fig. 8.2). However, the differences were less pronounced with widths than weights. Average head weights varied slightly more between treatments in southern rows than treatments in northern rows. Head widths were generally greater (mostly, significantly so) in northern rows than southern rows.
Furrow-Furrow irrigation resulted in the numerically highest head widths in both north and south rows. However, no differences were significant whether row effects were included or separated from each other.

Standard errors were loosely proportional to head weights, but did not generally vary greatly, indicating no particular treatment resulted in more uniform head widths than others.

As with head weights, the relative closeness of head width results from northern and southern rows in the Furrow-Furrow regime compared with other treatments suggests this treatment may have had better access to moisture at critical times than other treatments (Fig. 8.2).

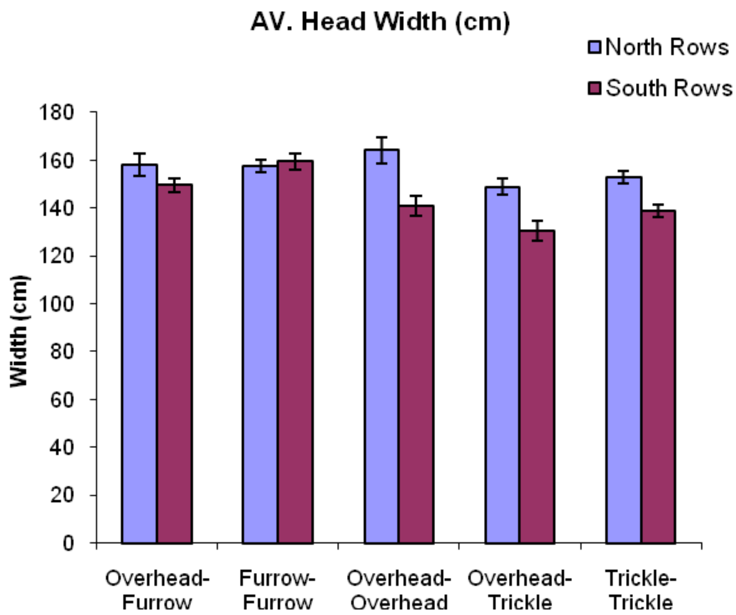

Figure 8.2. Average Head Width & Standard Error by treatment and row location (from Table 8.1)

Table 8.5. AV. Head Width (by Treatment - N and S rows combined)

Irrigation Regime	No.	Head Width (cm)
Overhead-Trickle	4	140 -
Trickle-Trickle	5	146 -
Overhead-Overhead	3	152 -
Overhead-Furrow	1	154 -
Furrow-Furrow	2	159 -
Transformation		All Failed

Vertical bars aligned in the same column indicate means that are NOT SIGNIFICANTLY DIFFERENT (LSD, P=0.05). Means followed by "-" failed Bartlett's Chi-squared Test for Homogeneity of Variance and attempts to rectify this with transformations were NOT successful (P=0.05). Blue vertical bars indicate LSD results based on successfully transformed data BUT the numbers they follow are original.

Table 8.6. AV. Head Width (by Treatment - S rows only)

Irrigation Regime	No.	Head Width (cm)
Overhead-Trickle	4	131 -
Trickle-Trickle	5	139 -
Overhead-Overhead	3	141 -
Overhead-Furrow	1	150 -
Furrow-Furrow	2	160 -
Transformation		All Failed

Vertical bars aligned in the same column indicate means that are NOT SIGNIFICANTLY DIFFERENT (LSD, P=0.05). Means followed by "-" failed Bartlett's Chi-squared Test for Homogeneity of Variance and attempts to rectify this with transformations were NOT successful (P=0.05). Blue vertical bars indicate LSD results based on successfully transformed data BUT the numbers they follow are original.

Table 8.7. AV. Head Width (by Treatment - N rows only)

Irrigation Regime	No.	Head Width (cm)
Overhead-Trickle	4	149 |
Trickle-Trickle	5	153 |
Furrow-Furrow	2	158 |
Overhead-Furrow	1	158 |
Overhead-Overhead	3	164 |
Transformation		None

Vertical bars aligned in the same column indicate means that are NOT SIGNIFICANTLY DIFFERENT (LSD, P=0.05). Means followed by "-" failed Bartlett's Chi-squared Test for Homogeneity of Variance and attempts to rectify this with transformations were NOT successful (P=0.05). Blue vertical bars indicate LSD results based on successfully transformed data BUT the numbers they follow are original.

Average Head Width Group (Figure 8.3 & Tables 8.1, 8.8, 8.9 & 8.10)

Head width groups were an attempt to classify heads by nearest commercial width grouping and as such are very similar to actual head widths already described. The only key change was in the southern row analysis where the results were significantly different (though the trend was identical). Here, the Furrow-Furrow treatment resulted in significantly wider heads than for all other treatments except the Overhead-Furrow treatment.

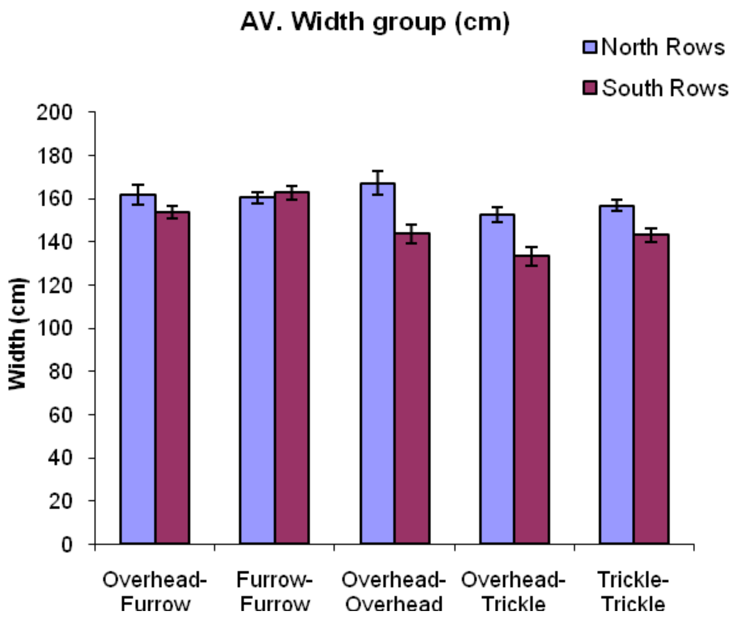

Figure 8.3. Average Head Width Group & Standard Error by treatment and row location (from Table 8.1)

Table 8.8. AV. Head Width Group (by Treatment - N and S rows combined)

Irrigation Regime	No.	Head Width Group (cm)
Overhead-Trickle	4	143 -
Trickle-Trickle	5	150 -
Overhead-Overhead	3	155 -
Overhead-Furrow	1	158 -
Furrow-Furrow	2	162 -
Transformation		All Failed

Vertical bars aligned in the same column indicate means that are NOT SIGNIFICANTLY DIFFERENT (LSD, P=0.05). Means followed by "-" failed Bartlett's Chi-squared Test for Homogeneity of Variance and attempts to rectify this with transformations were NOT successful (P=0.05). Blue vertical bars indicate LSD results based on successfully transformed data BUT the numbers they follow are original.

Table 8.9. AV. Head Width Group (by Treatment - S rows only)

Irrigation Regime	No.	Head Width Group (cm)
Overhead-Trickle	4	133 |
Trickle-Trickle	5	143 | |
Overhead-Overhead	3	144 | |
Overhead-Furrow	1	154 | |
Furrow-Furrow	2	163 |
Transformation		None

Vertical bars aligned in the same column indicate means that are NOT SIGNIFICANTLY DIFFERENT (LSD, P=0.05). Means followed by "-" failed Bartlett's Chi-squared Test for Homogeneity of Variance and attempts to rectify this with transformations were NOT successful (P=0.05). Blue vertical bars indicate LSD results based on successfully transformed data BUT the numbers they follow are original.

Table 8.10. AV. Head Width Group (by Treatment - N rows only)

Irrigation Regime	No.	Head Width Group (cm)
Overhead-Trickle	4	152 |
Trickle-Trickle	5	157 |
Furrow-Furrow	2	161 |
Overhead-Furrow	1	162 |
Overhead-Overhead	3	167 |
Transformation		None

Vertical bars aligned in the same column indicate means that are NOT SIGNIFICANTLY DIFFERENT (LSD, P=0.05). Means followed by "-" failed Bartlett's Chi-squared Test for Homogeneity of Variance and attempts to rectify this with transformations were NOT successful (P=0.05). Blue vertical bars indicate LSD results based on successfully transformed data BUT the numbers they follow are original.

Average Stem Length (Figure 8.4 & Tables 8.1, 8.11, 8.12 & 8.13)

Stem lengths did not vary as much as other parameters assessed. Differences between highest and lowest values were similar in both northern and southern rows. Head weights were generally greater in northern rows than southern rows.
Standard errors were all very small, indicating no particular treatment resulted in more uniform stem lengths than others.

When results from both rows were combined, Overhead-Furrow irrigation resulted in significantly heavier heads than for all other treatments except for Furrow-Furrow (Table 8.11). All treatments resulted in significantly longer stems than for Overhead-Trickle, except for Trickle-Trickle.

Less within-treatment variance resulted in greater statistical separation of southern row treatment results than northern row results, despite a similar magnitude in the separation. In the southern rows only, Furrow-Furrow and Overhead-Furrow performances were similar; both achieving significantly longer stems than Overhead-Trickle (Table 8.12).

The relative closeness of results from northern and southern rows in the Furrow-Furrow regime compared with other treatments suggests this treatment may have had better access to moisture at critical times than other treatments (Fig. 8.4).

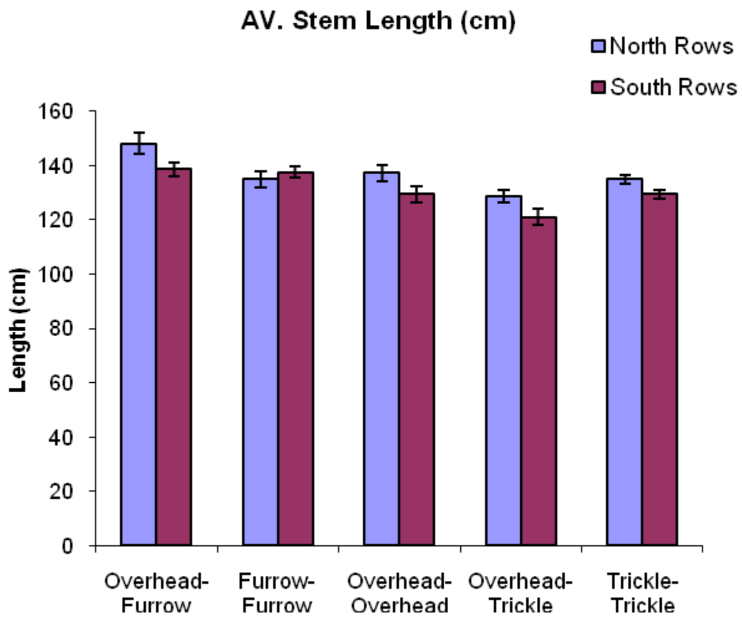

Figure 8.4. Average Stem Length & Standard Error by treatment and row location (from Table 8.1)

Table 8.11. AV. Stem Length (by Treatment - N & S rows combined)

Irrigation Regime	No.	Stem Length (cm)
Overhead-Trickle	4	125 I
Trickle-Trickle	5	132 I I
Overhead-Overhead	3	133 I
Furrow-Furrow	2	136 I I
Overhead-Furrow	1	143 I
Transformation		None

Vertical bars aligned in the same column indicate means that are NOT SIGNIFICANTLY DIFFERENT (LSD, P=0.05). Means followed by "-" failed Bartlett's Chi-squared Test for Homogeneity of Variance and attempts to rectify this with transformations were NOT successful (P=0.05). Blue vertical bars indicate LSD results based on successfully transformed data BUT the numbers they follow are original.

Table 8.12. AV. Stem Length (by Treatment - S rows only)

Irrigation Regime	No.	Stem Length (cm)
Overhead-Trickle	4	121 I
Trickle-Trickle	5	130 I I
Overhead-Overhead	3	130 I I
Furrow-Furrow	2	138 I
Overhead-Furrow	1	139 I
Transformation		None

Vertical bars aligned in the same column indicate means that are NOT SIGNIFICANTLY DIFFERENT (LSD, P=0.05). Means followed by "-" failed Bartlett's Chi-squared Test for Homogeneity of Variance and attempts to rectify this with transformations were NOT successful (P=0.05). Blue vertical bars indicate LSD results based on successfully transformed data BUT the numbers they follow are original.

Table 8.13. AV. Stem Length (by Treatment - N rows only)

Irrigation Regime	No.	Stem Length (cm)
Overhead-Trickle	4	129 I
Trickle-Trickle	5	135 I
Furrow-Furrow	2	135 I
Overhead-Overhead	3	137 I
Overhead-Furrow	1	148 I
Transformation		None

Vertical bars aligned in the same column indicate means that are NOT SIGNIFICANTLY DIFFERENT (LSD, P=0.05). Means followed by "-" failed Bartlett's Chi-squared Test for Homogeneity of Variance and attempts to rectify this with transformations were NOT successful (P=0.05). Blue vertical bars indicate LSD results based on successfully transformed data BUT the numbers they follow are original.

Conclusion

- Rows on the north side of beds nearly always resulted in a higher average head size (weights, widths and stems), than plants on the south side of beds, regardless of watering regime used.

- Only furrow watering resulted in similar sized heads in both north and south sides of beds, which suggests this traditional watering regime may still provide greater moisture during critical growth periods than other watering regimes. However, this is only conjecture and may simply be an aberration given the marked differences seen with the other four watering regimes.

- Results tend to suggest that total yields are not highly dependent on the establishment and post-establishment methods of irrigation used, provided plant access to water during critical times is not compromised.

9 Recommendations

This research project showed the potential for mechanically harvesting broccoli. The research showed that a key element for success is a uniform plant stand at harvest. This can be achieved with good plant establishment, land preparation and a high density planting.

1. The next step is to modify the mechanical harvester, to match the machine to the geometry of the heads produced in a dense planting. The cutting blades need to match the resulting plant height and head width. The development of the mechanical harvester could not be done in this project due to company constraints. Therefore, it is recommended that more research be done to adapt the current harvester to the heads produced from high density plantings.

2. More work is also needed to develop the harvester so that it causes less physical head damage. This will ensure a higher percentage of heads can be used for processing or sale on the fresh market.

10 Acknowledgements

The authors would like to thank Horticulture Australia, Matilda Fresh, Sakata Seed Company and South Pacific Seeds for providing the funds to make the project possible. In addition, we would especially like to thank the Sakata broccoli breeder Manabu Kawamura for his generous support and efforts in providing new broccoli breeding material for mechanical harvesting. We would also like to thank the staff of Matilda Farms for providing labour, land and resources to run field trials at Brookstead, Gunalda and Armidale, and finally Max Durham who allowed us to use his farm for some of the final trials of the project.

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Confidential Report for

Report on Year 1 Machine Harvest Trials at Brookstead 2007

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AHR Confidential Report

Report on Year 1 Machine Harvest Trials at Brookstead 2007

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22nd November 2007

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Introduction

A significant part component of this project will be the assessment of existing and new broccoli lines which will be bred by Sakata Seed company specifically for mechanical harvest.

The growth characteristics of Broccoli is highly sensitive to the length of the growing period and temperature, and it is therefore necessary to evaluate potential new varieties over the range of environments in which it will be grown, if a credible 12-month supply schedule is to be developed

Broccoli has been classified into four major classifications and several sub classifications (Kuwamura Manabu Sakata breeder pers. com) primarily driven by broccoli breeders who developed varieties that were adapted to a range of climatic conditions.

- **Extra-early:** warm, hot humid conditions in tropical and sub-tropical latitudes e.g. 'Green King' (Known-You)
- **Early:** warm conditions in mid to high latitudes environments e.g. 'Green Magic' (Sakata)
- **Mid-early**: e.g. 'Greenbelt'
- **Mid:** transitional varieties that perform in late autumn/early winter and spring/early summer e.g. Marathon
- **Mid-late**: 'Avenger' 7 days later than 'Marathon'
- **Late:** cool to cold season varieties that tolerate moderate to severe frosts and have some tolerance to water staining/bacterial soft rot e.g. 'Green Veil' (Sakata)

The extra-early types are characterised by very quick maturing particularly in sub tropical and tropical conditions and have been identified as inducing floral initiation at the appropriate leaf number at temperatures of 21-23^{0}C. An example of these types has been 'Green King' from Known-You Seed Company in Taiwan.

The early maturing varieties which have been characteristic of 'Green Magic' and 'Greenbelt' have been used in the mid-season transitional area and have been recorded to change from vegetative to reproductive initiation at temperatures around 17-18^{0}C.

The mid and mid-late maturing cool weather types has been characteristic of the variety 'Marathon' from Sakata Seeds. These varieties only required 5-7^{o}C to initiate their floral primordia at the appropriate leaf number.

The late maturing types which have only had a minor place in the Australian industry such as in Western Australia have been characterized by the Sakata variety 'Samurai' and these were recorded to initiate their floral primordia at 2-3^{0}C and have a very narrow harvest window in the late winter/early spring period.

With the majority of the Australian broccoli industry located in the southern states the cropping schedule by variety information for this region has been well documented. Now there is an increasing incidence of broccoli being grown in the winter time in southeast Queensland and the same type by optimum growing time has to be developed for varieties to cope with the climate for harvesting May to September.

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Materials and methods

The variety trials were set up at Matilda farms, at Brookstead, Queensland according to the following schedule.

All varieties were established as transplants and planted using the standard farm fertilizer rates and agronomic practices. The seedlings were irrigated as soon as possible after planting using furrow irrigation. The planting configuration was beds spaced at 0.9m between centres, 2 rows of plants per bed with 30cm between plants (60,000 plants per ha). There were also high density and low density plantings established at 90,000 and 30,000 plants per hectare respectively.

Seeding Schedule for Broccoli Project Variety Trials

No.	SPS Name	Other Name	Transplant date	Number planted	relative days to maturity
1	SPS 563-4		12/04/2007	Sow all 16 grams	110-115
2	SPS 494-3	Patron	12/04/2007	2,500	105
3	SPS 1151-5	Gypsy	12/04/2007	2,500	93
4	SPS 905-8 (Control)	Atomic	12/04/2007	2,500	90
5	SPS 627-6	Emerald Pride	12/04/2007	2,500	95
6		Aurora	12/04/2007	2,500	
7	SPS 1112-5	Bridge	12/04/2007	2,500	115

No.	SPS Name	Other Name	Transplant date	Number planted	relative days to maturity
1	SPS 1112-5	Bridge	2/05/2007	2,500	115
2	SPS 608-6		2/05/2007	2,500	110
3	SPS 494-3	Patron	2/05/2007	2,500	
4	Control	Mascot	2/05/2007	2,500	
5	Control	Evergreen	2/05/2007	2,500	

No.	SPS Name	Other Name	Transplant date	Number planted	relative days to maturity
1	SPS 568-6		16/05/2007	sow all 4 grams	115
2	SPS 1112-5	Bridge	16/05/2007	2500	115
3	SPS 608-6		16/05/2007	2500	110
4	Control	evergreen	16/05/2007	2500	

No.	SPS Name	Other Name	Transplant date	Number planted	relative days to maturity
1	SPS 1112-5	Bridge	31/05/2007	2500	115
2	SPS 608-6		31/05/2007	2500	110
3	Control	Bravo	31/05/2007	2500	

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Determination of Harvest time

For large plot mechanical harvest, the harvest time was determined as 50% marketable heads mature, or at a % mature agreed with Matilda.

Yield and Quality Assessments

(i) Mechanical Harvest

At least 1000 heads were harvested per plot irrespective of quality or stage of maturity from a data area selected out of the trial area. Of the harvested heads, 100 heads were sub-sampled and graded according to damage caused to the head and to the stem. The scale used was:

1 = undamaged and suitable for export
2 = slight damage and suitable for the domestic market grade 1
3 = more damage but still suitable for the domestic market grade 2
4 = more damage again, and only suitable for floreting
5= unmarketable

Other data collected:

1. *Area harvested:* The area harvested for trial 1 was 70m long x 4 beds (8 plant rows) wide (=1860 plants) and for trial 2, each area harvested was 50m long x 4 beds (8 plant rows) wide (=1300 plants).

2. *Yield*

3. *Harvest efficiency* – ie % of marketable heads at harvest. This will be achieved by harvesting 1000 heads including small, over-mature and damaged heads (take a subsample and count)

4. *Ratio of marketable heads*: classify and count (Crown / Processing / unmarketable head (small) / unmarketable (over mature head).

5. *Damage during mechanical harvest* - ratio of damaged head during mechanical harvest - number of marketable but damaged head / 1000 heads

6. Self life of a sub sample of heads form each category stored at 1 ^{o}C.

Note: the time taken for harvesting was not reported because it was so variable, and would not be a true representation of potential commercial harvest time.

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Results

Mechanical Harvest Trial 1

Small plot quality and yield assessments were carried out on all varieties but due to limitations with rain, it was only possible to mechanically harvest three varieties.

494-3

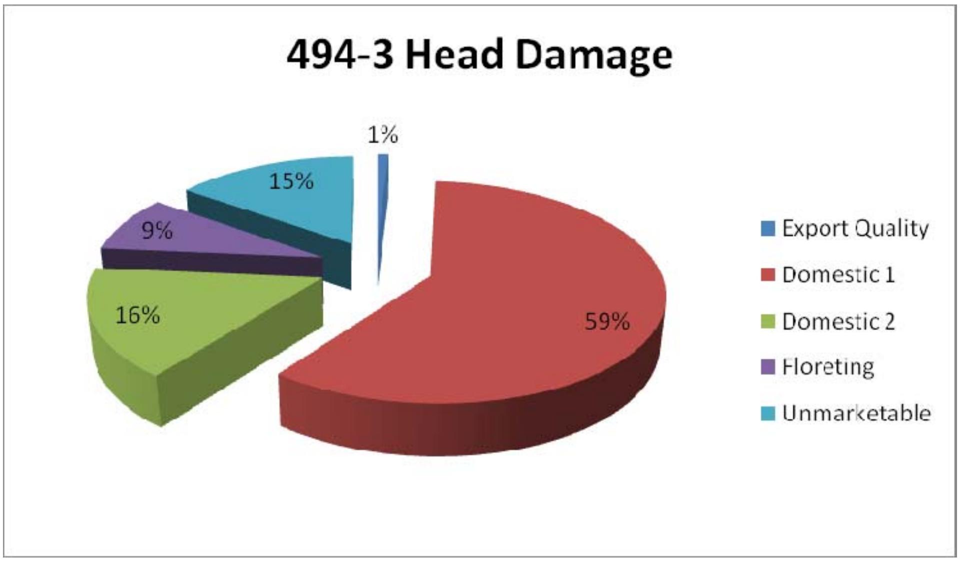

Figure 1. Variety 494-3 head damage after mechanical harvesting

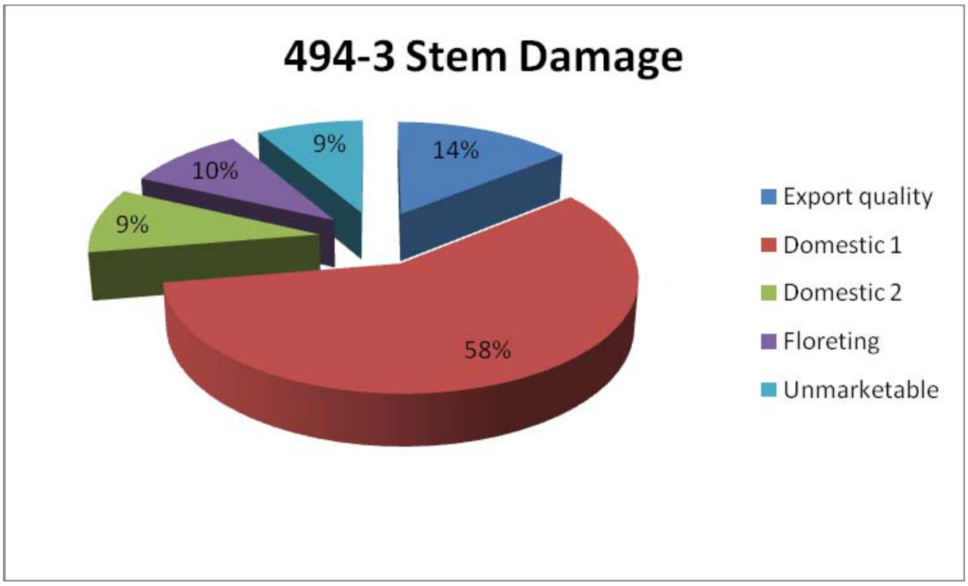

Figure 2. Variety 494-3 stem damage after mechanical harvesting

This variety was very resistant to damage caused by mechanical harvesting. While very little product was undamaged, around 60% was still suitable for grade domestic use. About 15% (head damage basis) was unmarketable due to excessive damage. The head damage was more of a limitation to quality than stem damage.

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Aurora

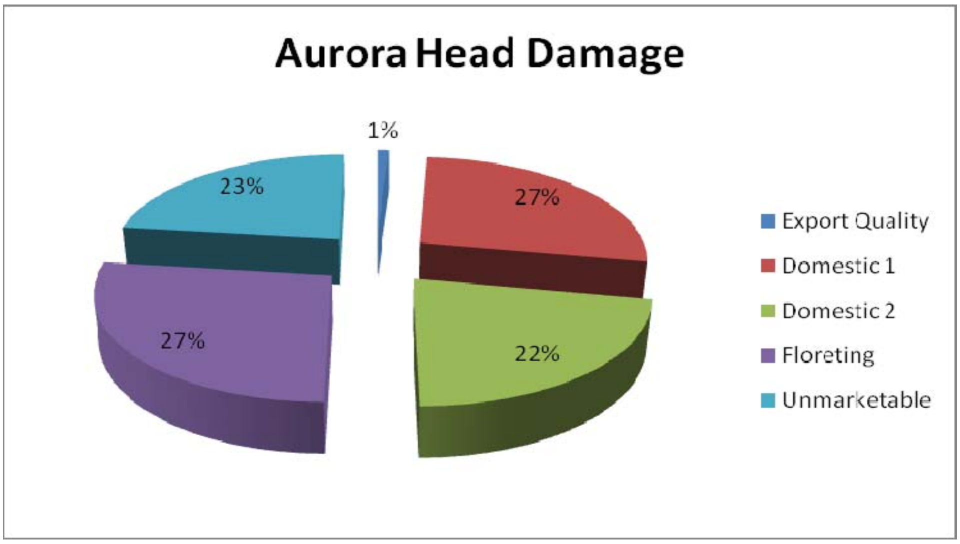

Figure 3. Variety Aurora head damage after mechanical harvesting

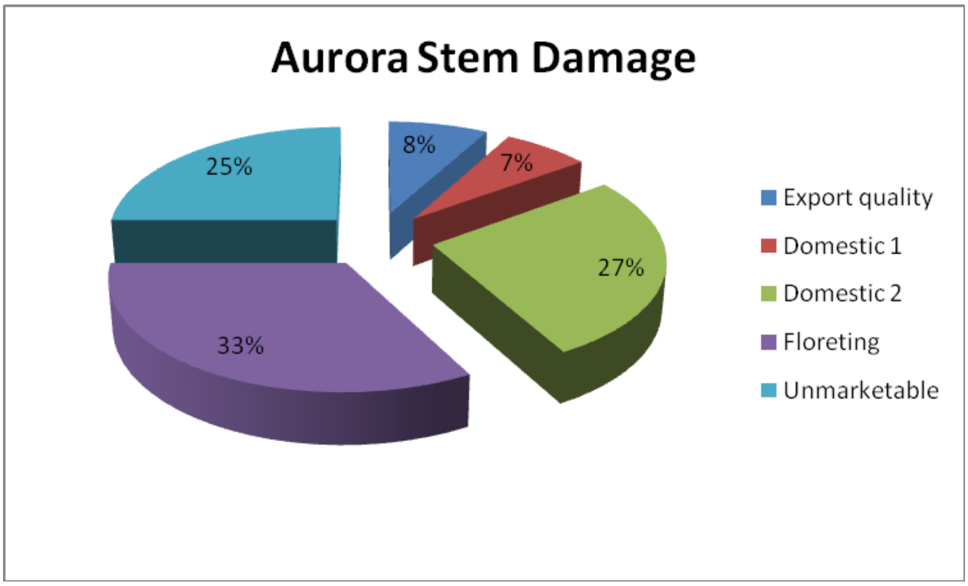

Figure 4. Variety Aurora stem damage after mechanical harvesting

Aurora was more susceptible to damage than 494-3. Again, only 1% of heads were undamaged and 27% were suitable for domestic grade 1 product. In the case of Aurora, stem damage was more of a limitation than for 494-3.

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Brumby

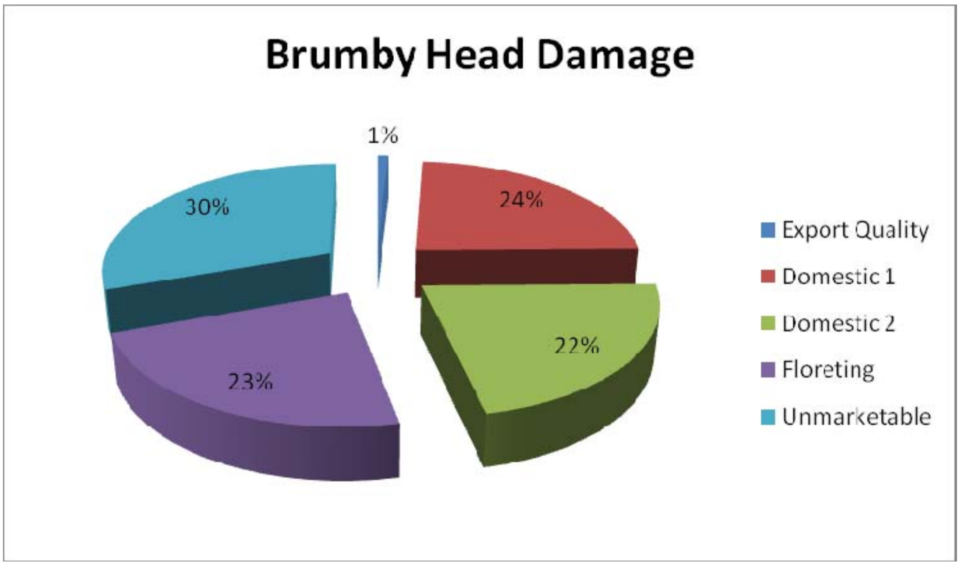

Figure 5. Variety Brumby head damage after mechanical harvesting

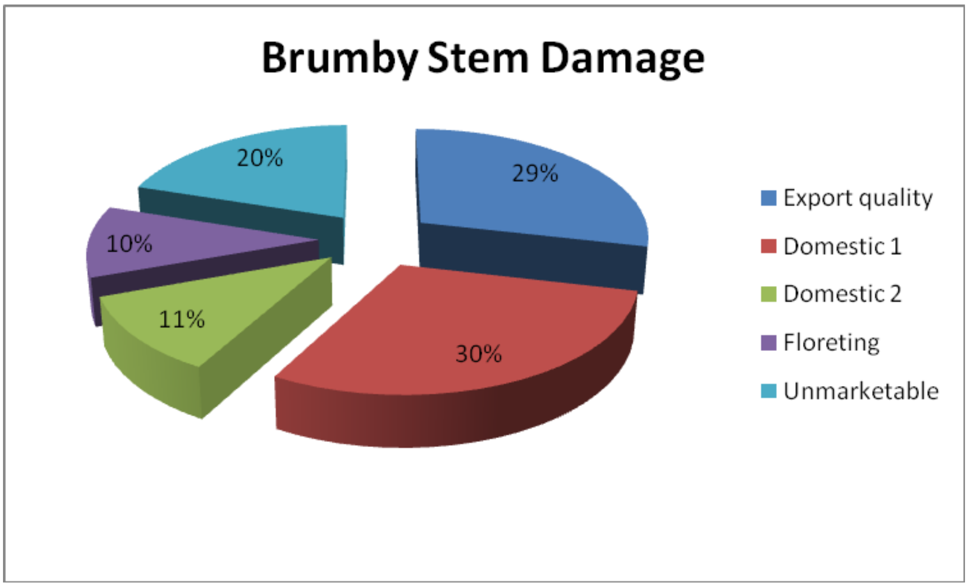

Figure 6. Variety Brumby stem damage after mechanical harvesting

The head damage response for Brumby was similar to that for Aurora. The stems of Brumby however were more resistant to damage with 29% remaining undamaged.

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Mechanical Harvest Trial 2

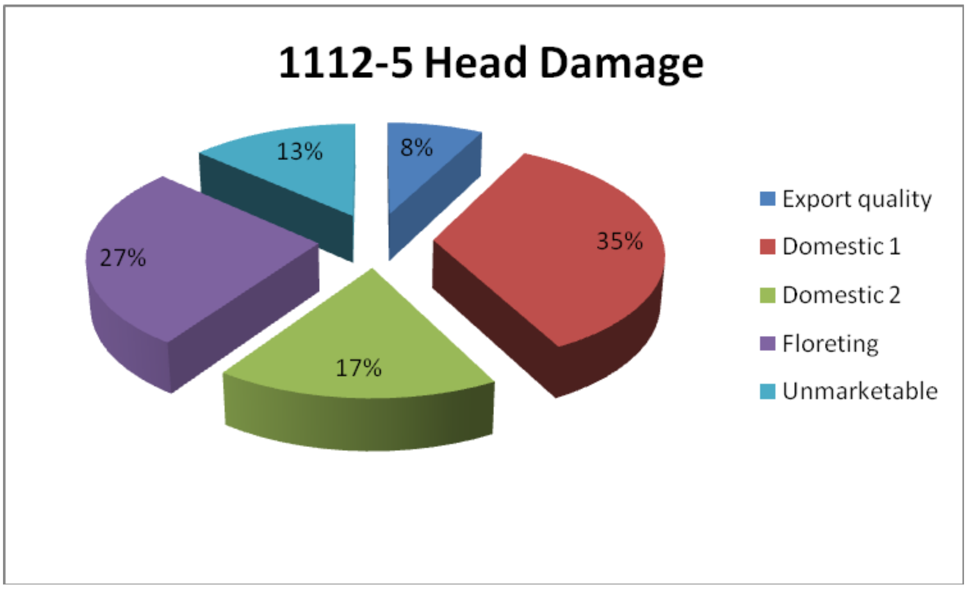

Figure 7. Variety 1112-5 head damage after mechanical harvesting

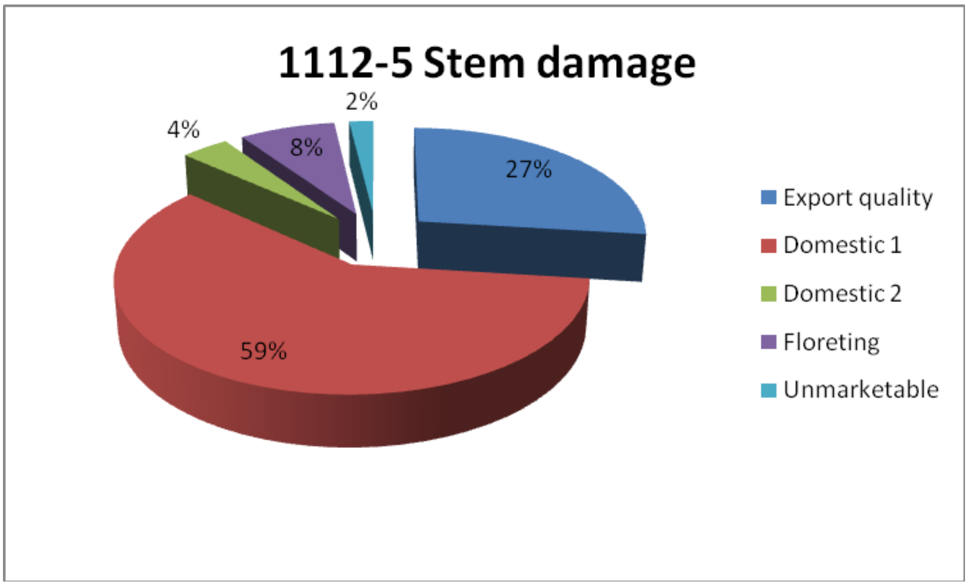

Figure 8. Variety 1112-5 stem damage after mechanical harvesting

The 1112-5 head is moderately sensitive to damage from the mechanical harvester with over half heads still marketable to the fresh market. The stems however of this variety are very resistant to damage.

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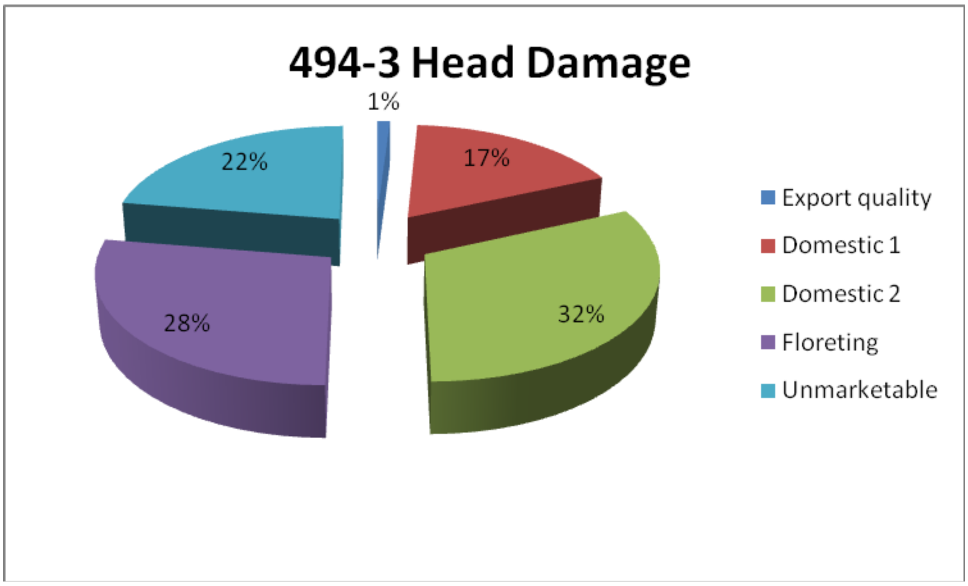

Figure 9. Variety 494-3 head damage after mechanical harvesting

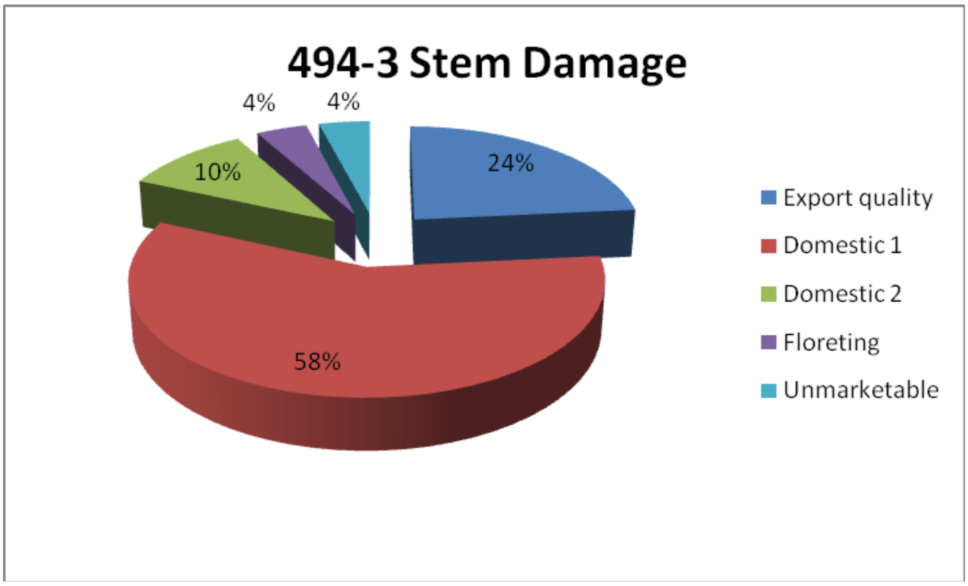

Figure 10. Variety 494-3 stem damage after mechanical harvesting

In this trail, 494-3 heads were not as resistamt to damage as in the first trial. The stems however are highly resistant.

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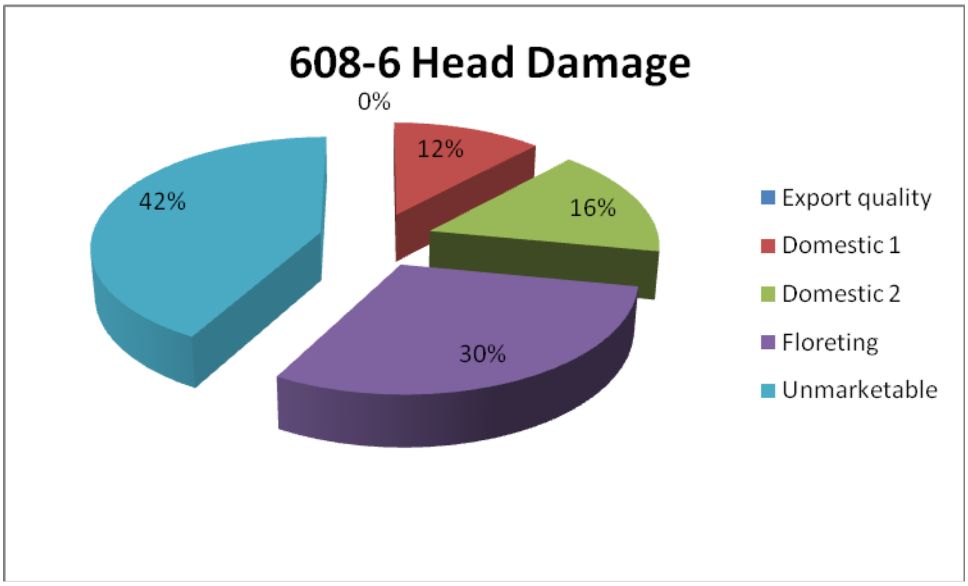

Figure 11. Variety 608-6 head damage after mechanical harvesting

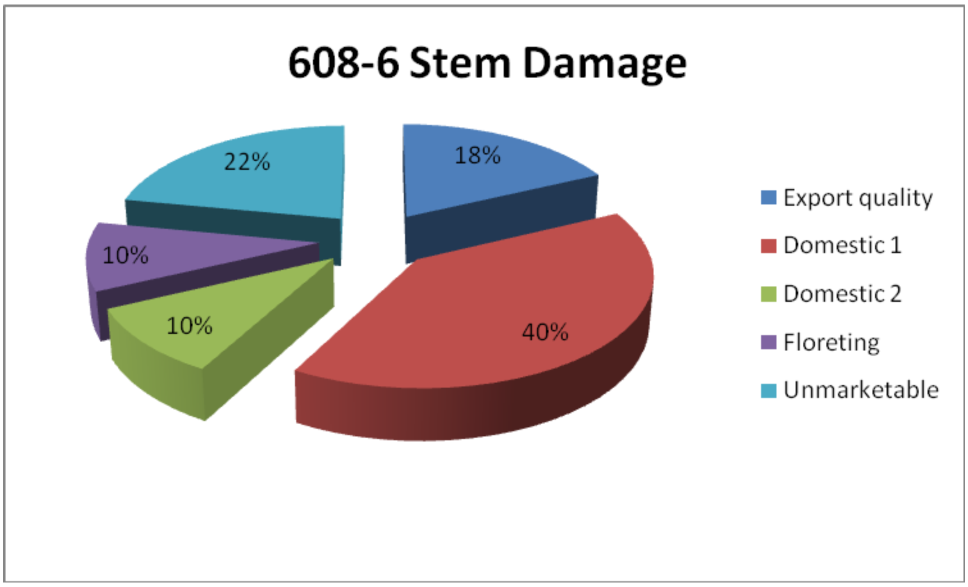

Figure 12. Variety 608-6 stem damage after mechanical harvesting

Variety 608-6 heads are highly susceptible to damage from the harvester with 72% either unmarketable or suitable for processing only.

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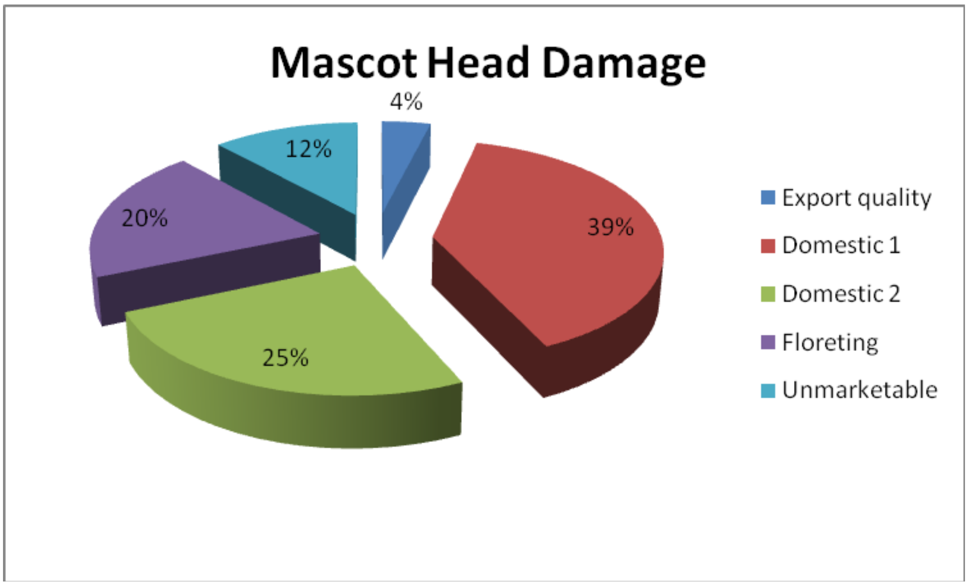

Figure 13. Variety Mascot head damage after mechanical harvesting

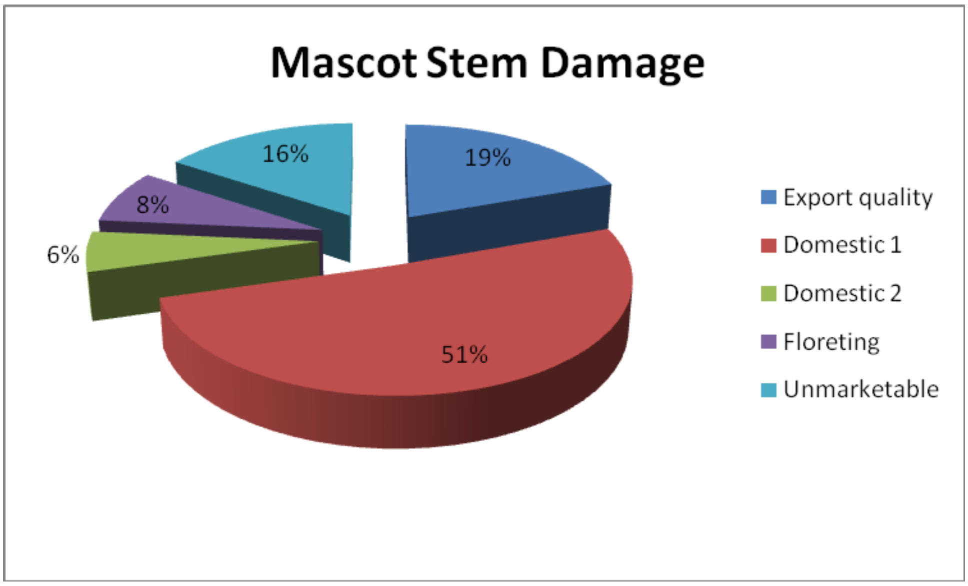

Figure 14. Variety Mascot stem damage after mechanical harvesting

Mascot heads were moderately resistant to mechanical damage.

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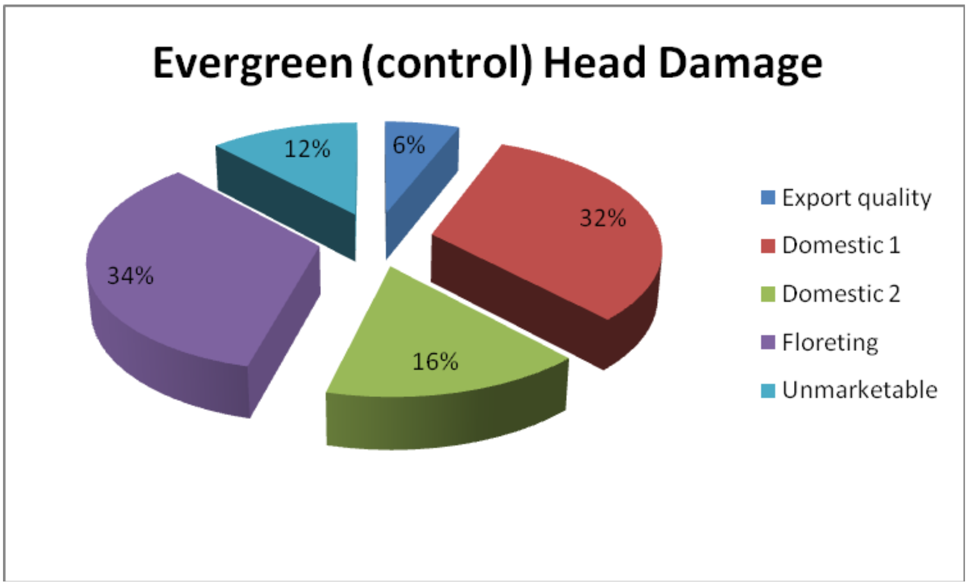

Figure 15. Variety Evergreen (control) head damage after mechanical harvesting

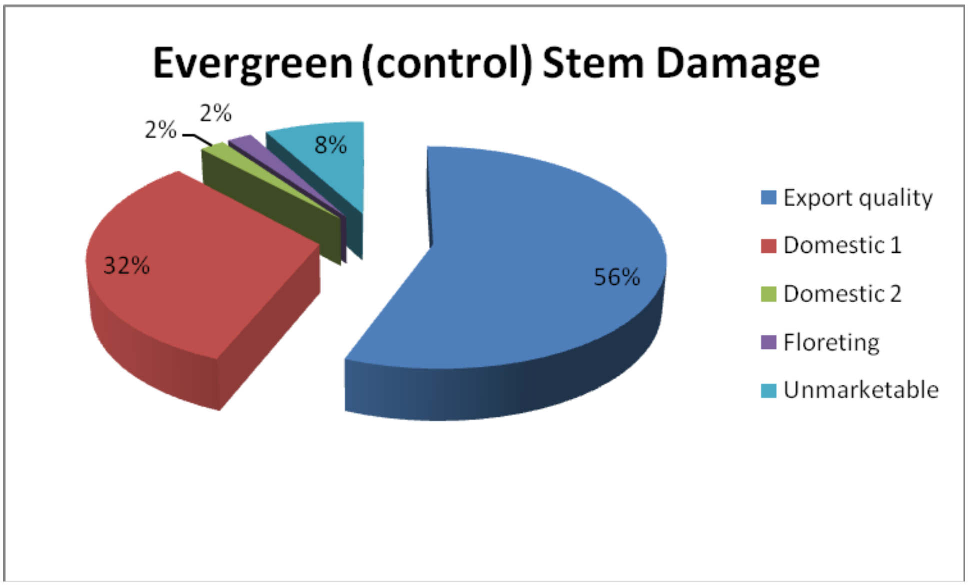

Figure 16. Variety Evergreen stem damage after mechanical harvesting

Evergreen heads were only moderratley resistant to mechaincal damage, but the stems were very highly resistant. The most resistamt of all the varieties tested so far.

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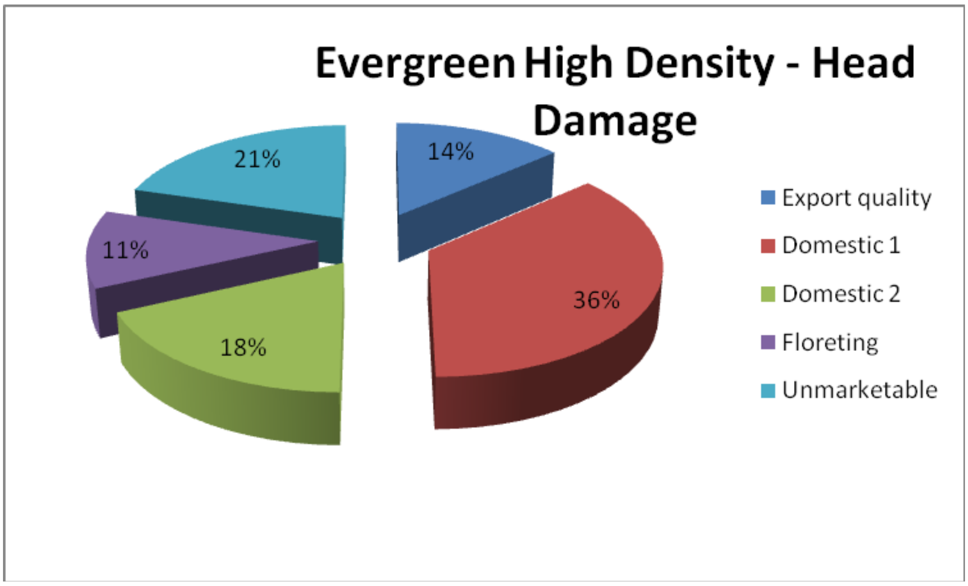

Figure 17. Variety Evergreen head damage after mechanical harvesting after planting at high planting density

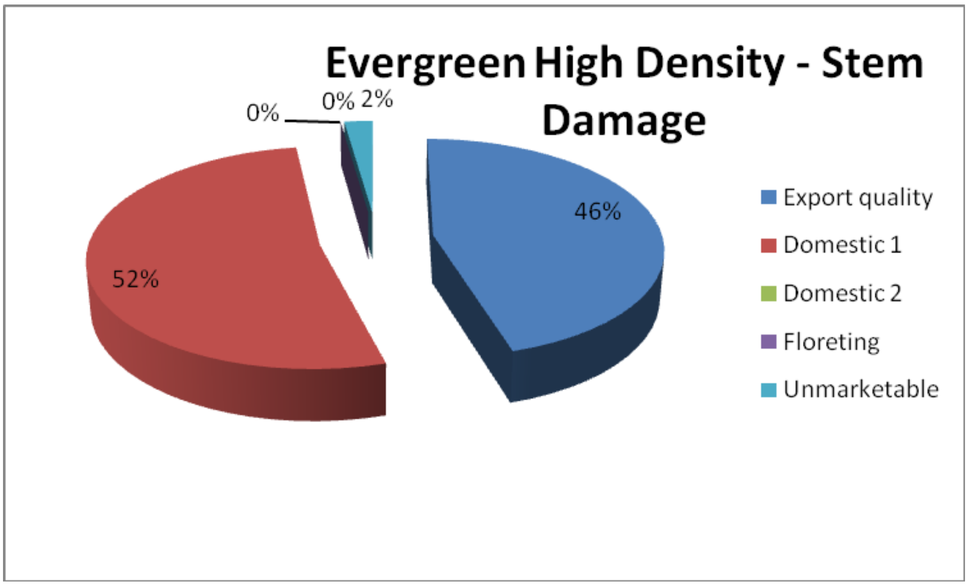

Figure 18. Variety Evergreen stem damage after mechanical harvesting after planting at high planting density

Incresaing the plant density from 60,000 plants per hectare to 90,000 inporved the head resistance to damage. The may be have been due to smaller heads which were produced as a result of the higher density (Fig, 21).

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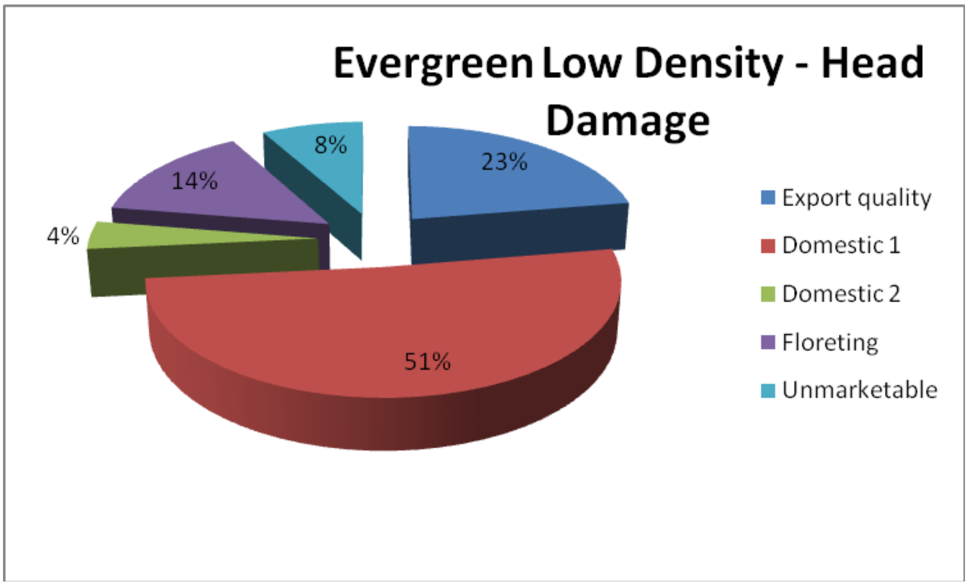

Figure 19. Variety Evergreen head damage after mechanical harvesting after planting at low planting density

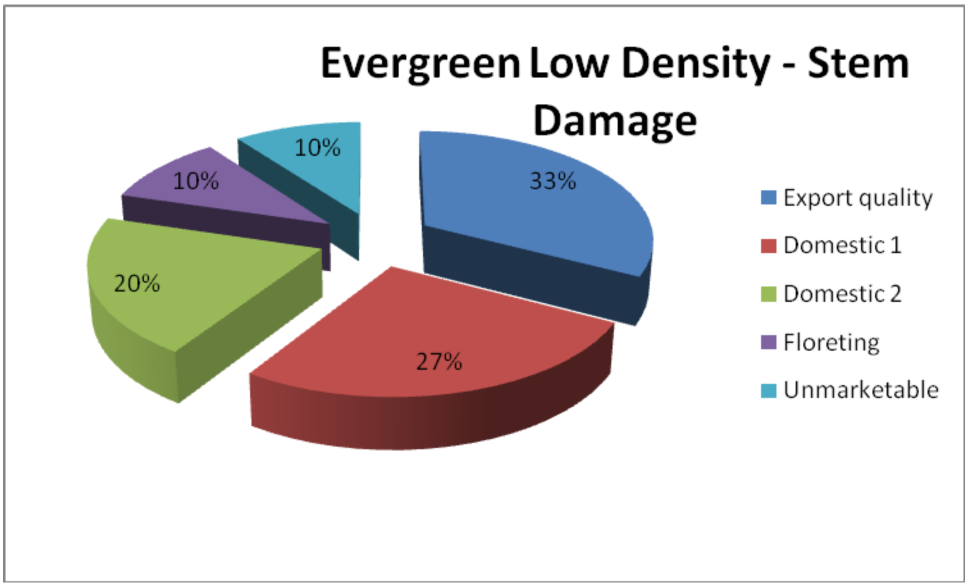

Figure 20. Variety Evergreen stem damage after mechanical harvesting after planting at low planting density

Growing plant at a lower planting density had a significant effect on improving the heads resistance to mechanical damage caused by the harvester (Figs 19 and 15). This may have been due to the heads being "tougher" because they were exposed to more light (less shading) than standard density plants.

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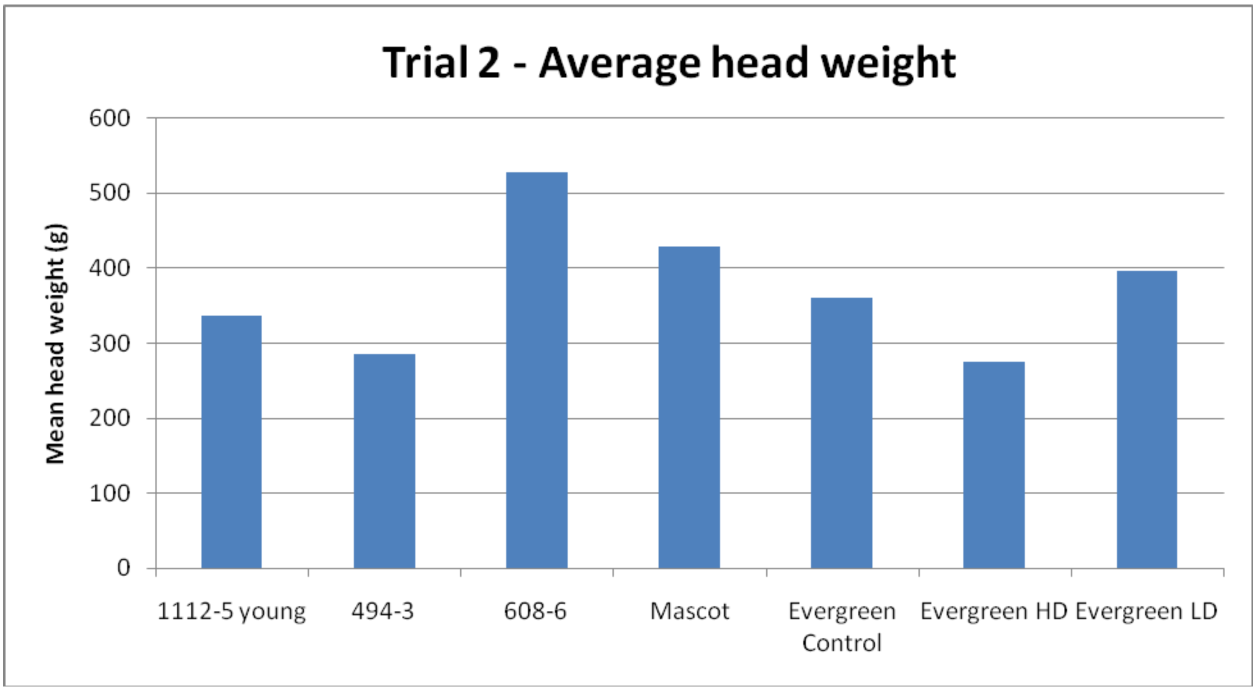

Figure 21. Average head weights of the machine harvested head samples.

The average heads weights suggest that larger heads may be more susceptible to mechanical damage. 608-6 was the worst, and had the largest heads. The larger heads in the wider spaced plants were probably tougher due to higher light exposure.

Relationship between Head Diameter and Head Weight

There was a good relationship between head weight and crown diameter for the three varieties. The relationship was logarithmic and the R2 values were all high, indicating a strong correlation. The relationship was similar for all varieties, but we have data for all 4 plantings from the small plot assessments, and these relationships could be plotted and examined if they are related to damage susceptibility.

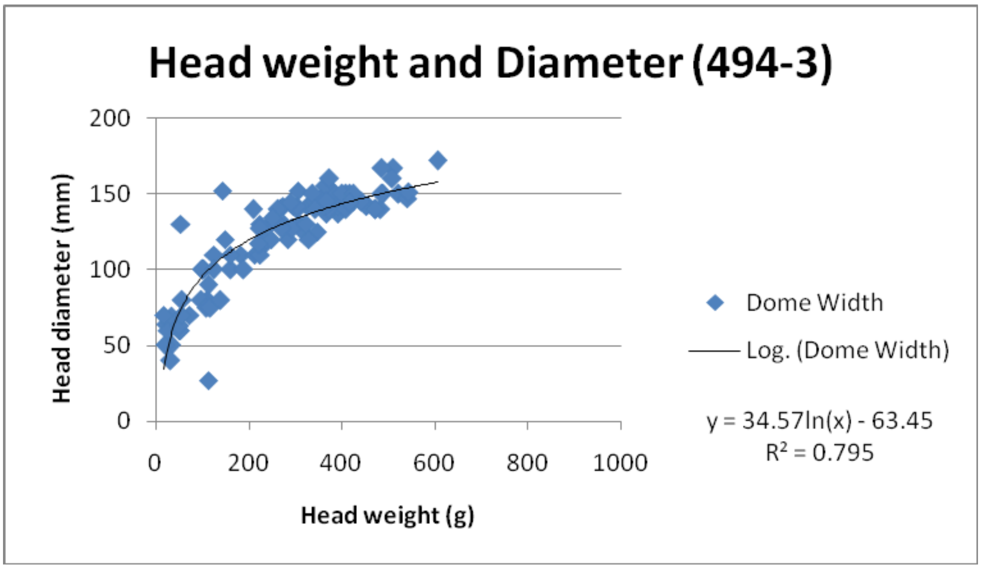

Fig 22 Head weight and Diameter for 494-3

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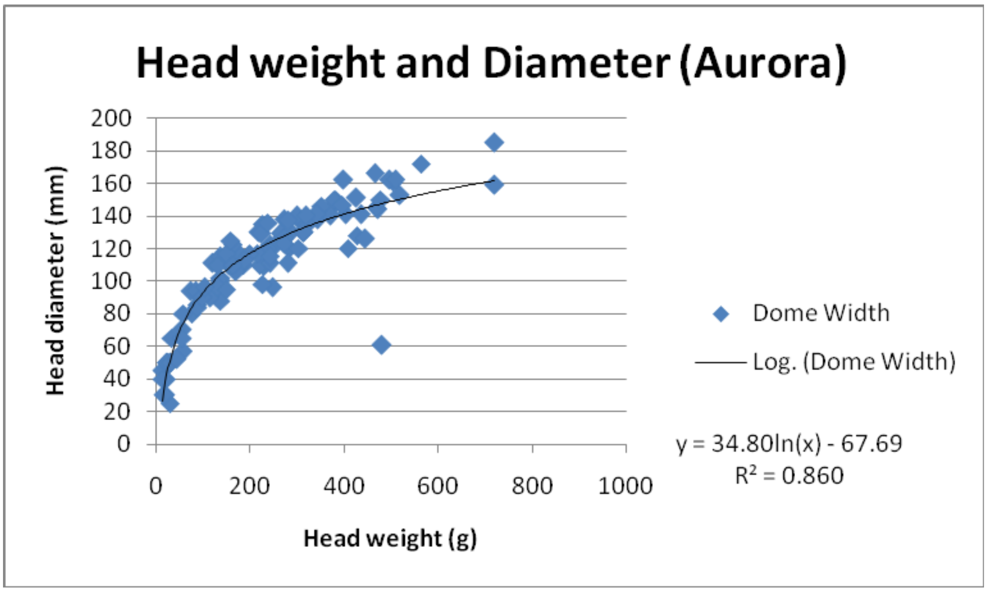

Fig 23 Head weight and Diameter for Aurora

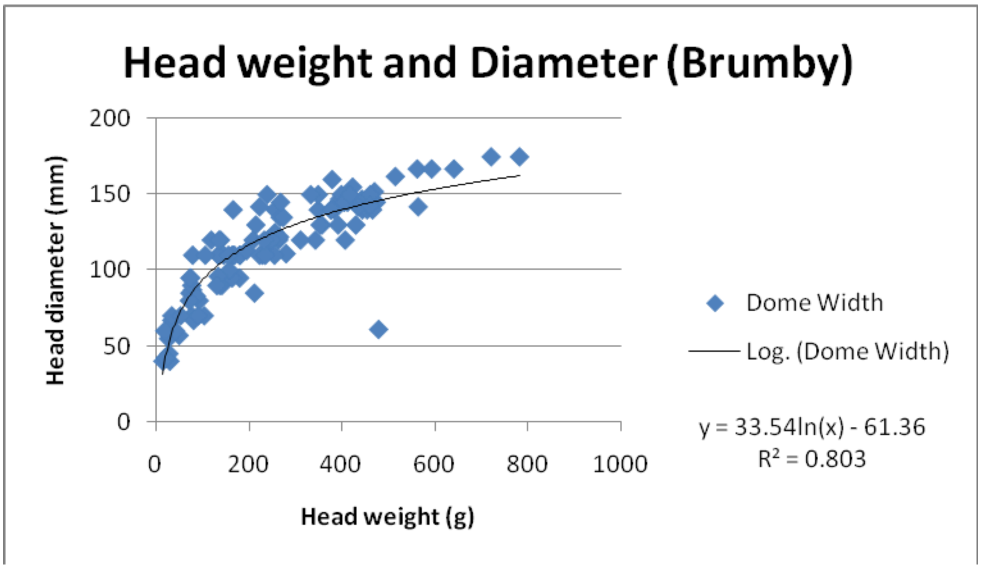

Fig 24 Head weight and Diameter for Brumby

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Small Plot Assessments

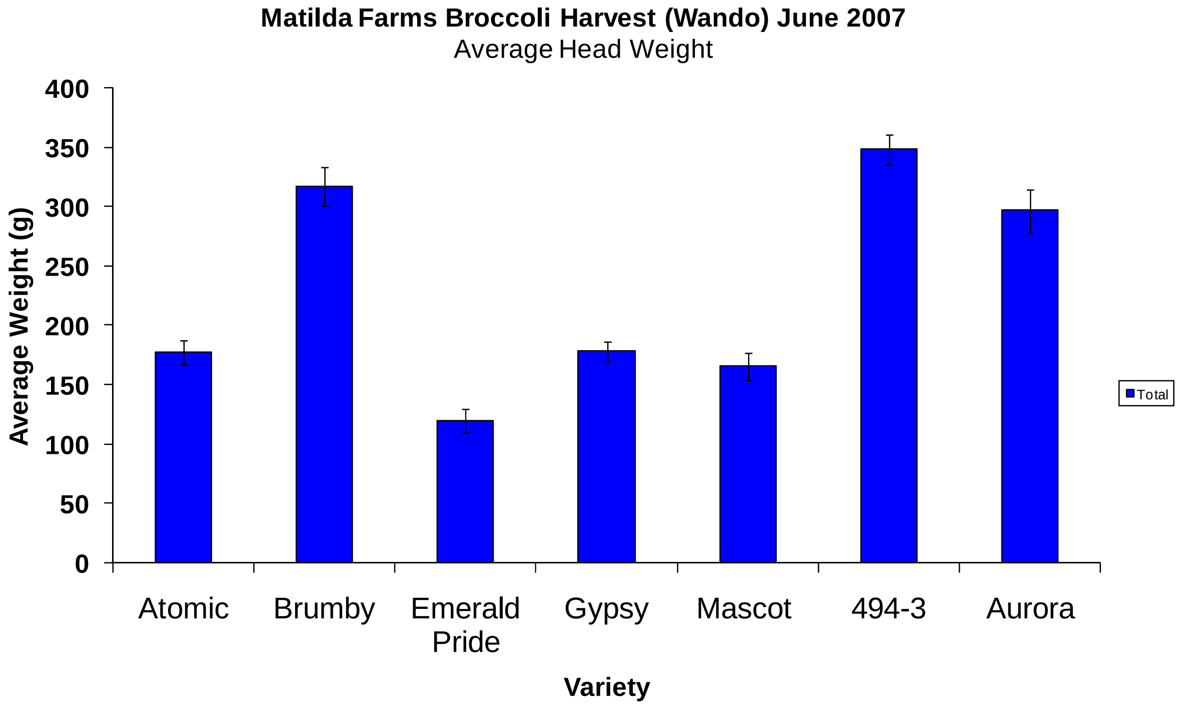

Figure 25. Average heads weights from Trial 1.

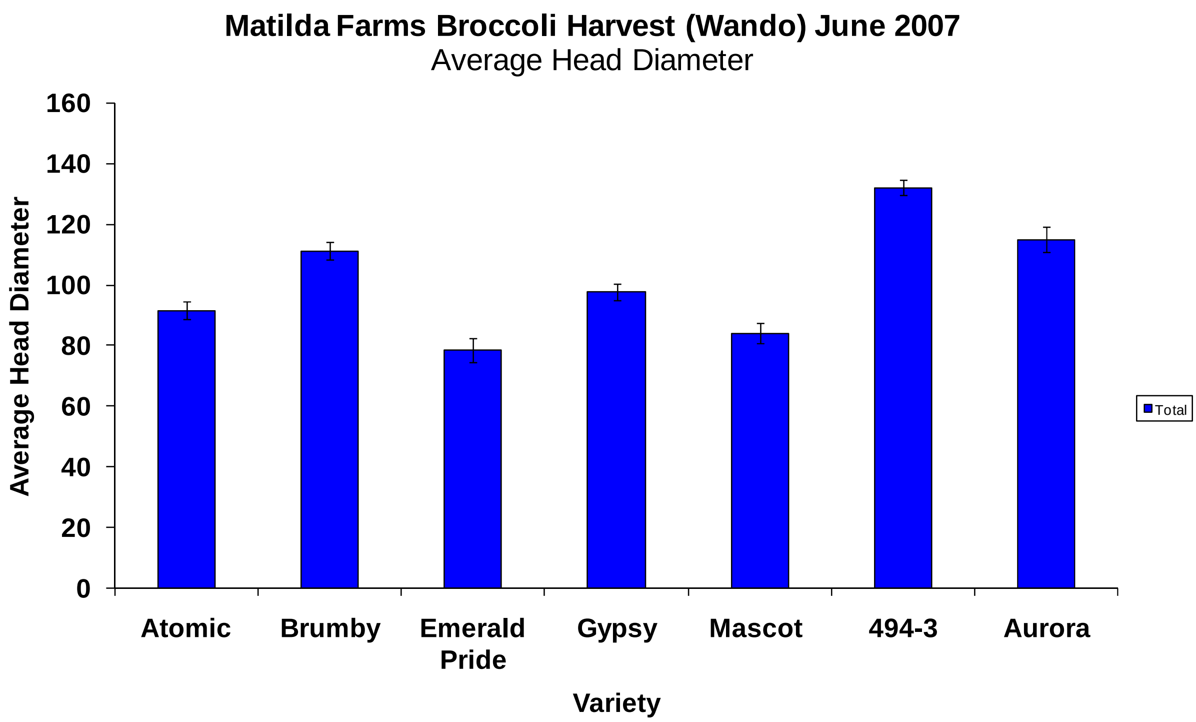

Figure 26 Average head diameter from Trial 1

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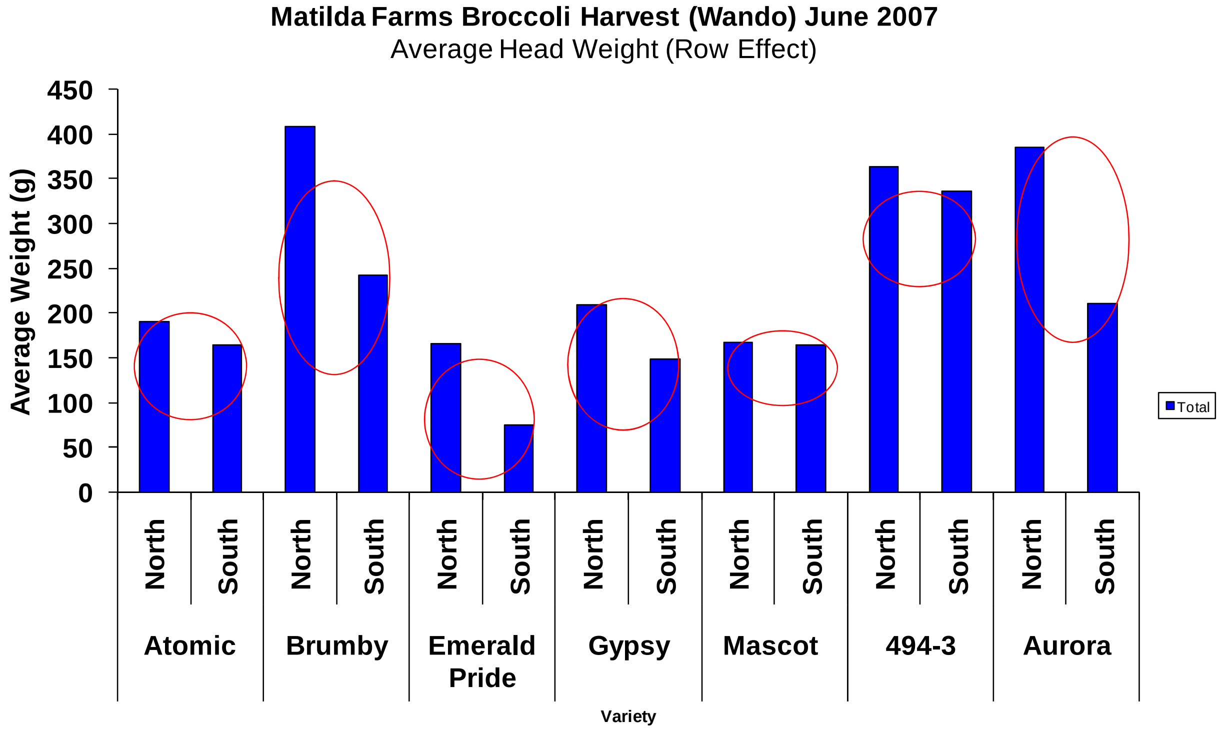

Figure 27 Effect of row orientation on the variation in head weights between varieties from planting 1

There is a very significant effect on plant growth rate and hence variability caused by the orientation of the plant row. Plants in the North-facing row are usually much larger than plants in the south-facing row. In this trial, and in subsequent trials over the season, the variety 494-3 did not show this row-to-row variation but still had large marketable heads. This trait would be an excellent one to preserve in a variety bred specifically for mechanical harvesting.

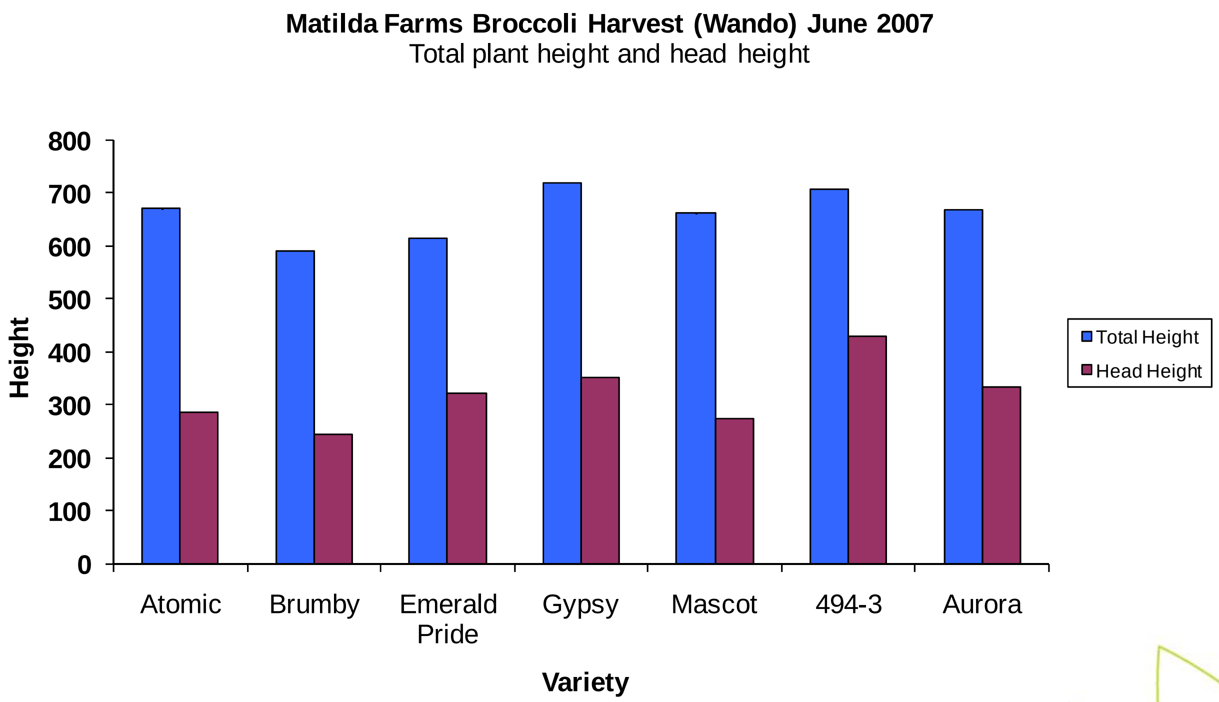

Figure 28 Plant height and head heights from trial 1

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Harvest Efficiency

The harvester took all the heads leaving no unharvested heads remaining in the field. Small heads may have been passed out the back of the harvester with the leaf trash.

Postharvest Assessments

Samples were taken from each of the mechanical harvest and stored at 2 ^{o}C. These heads were then rated for colour as an indication of postharvest longevity over a 3 week period after harvest. This data is yet to be analyzed and will be presented in a subsequent report.

Variety Trials 3 and 4

These trials were not able to be machine harvested due to heavy rain (we have pictures of the harvester bogged when attempting this. These trials were hand harvested and data collected. This, along with small plot data from trials 1 and 2, plus density, direct seeding and other trials will be presented in a separate report.

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Photos

494-3

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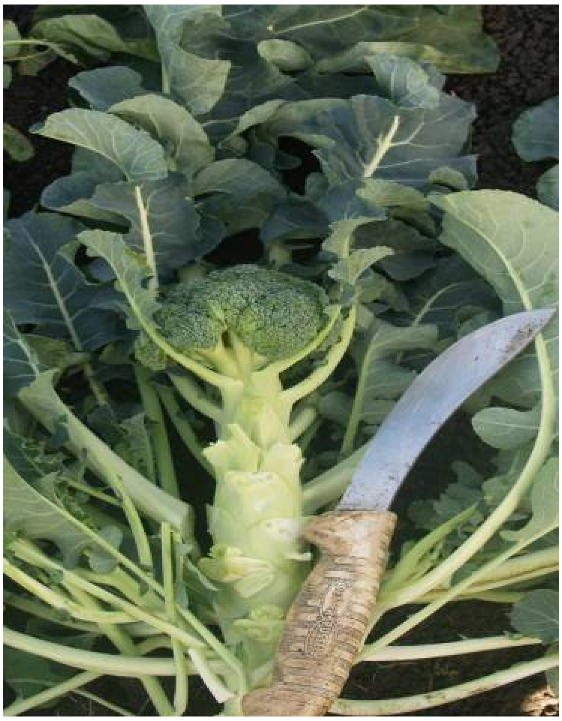
Brumby



`

Atomic

`

Aurora

`

Emerald Pride

`

Gypsy

`

Mascot

ahr applied horticultural research

PO Box 3114 Bundeena NSW 2230 Australia

phone +61 2 9527 0826 **fax** +61 2 9544 3782

Broccoli Project Review

22nd February 2008

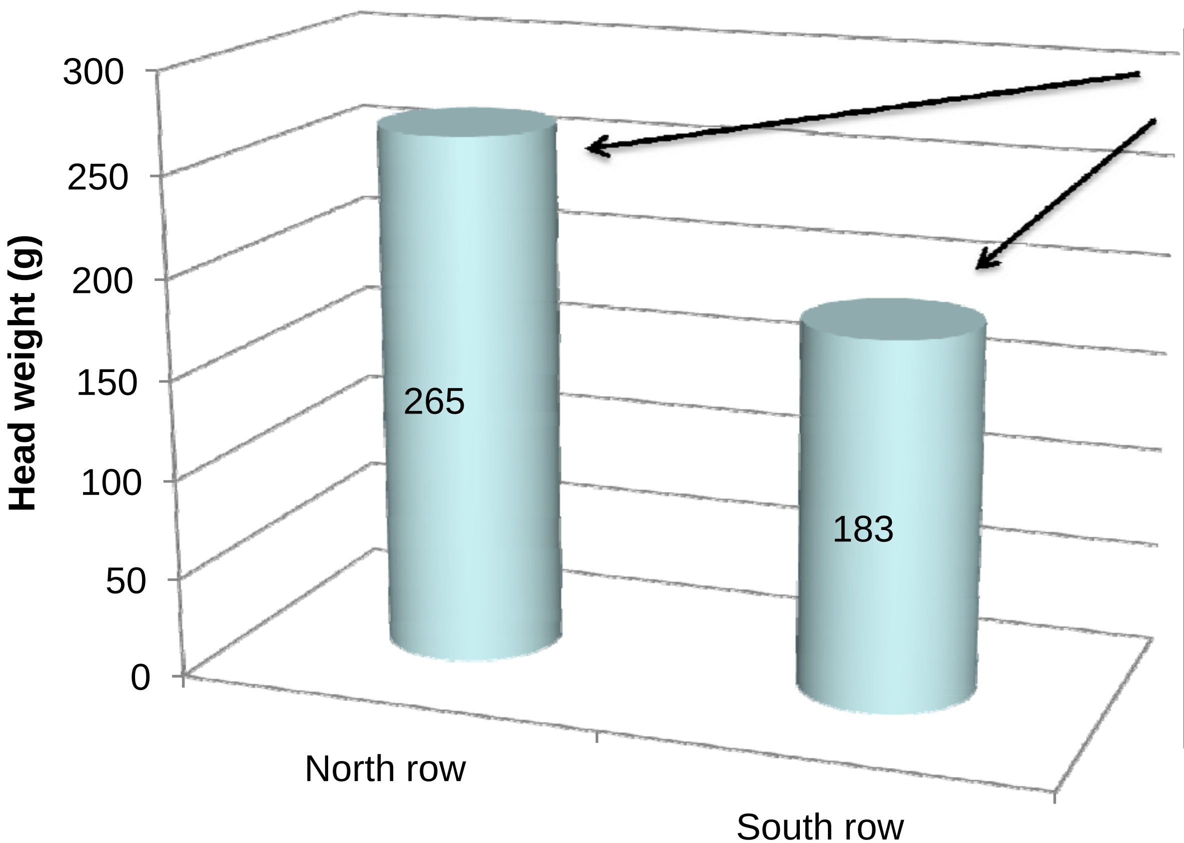
Toowoomba, Qld

Trials in 2007

- North/South Rows
- Density
- Seed encrusting
- Direct Seed v's transplant
- Variety

Effects of Row Orientation

Effect of row orientation on head weight

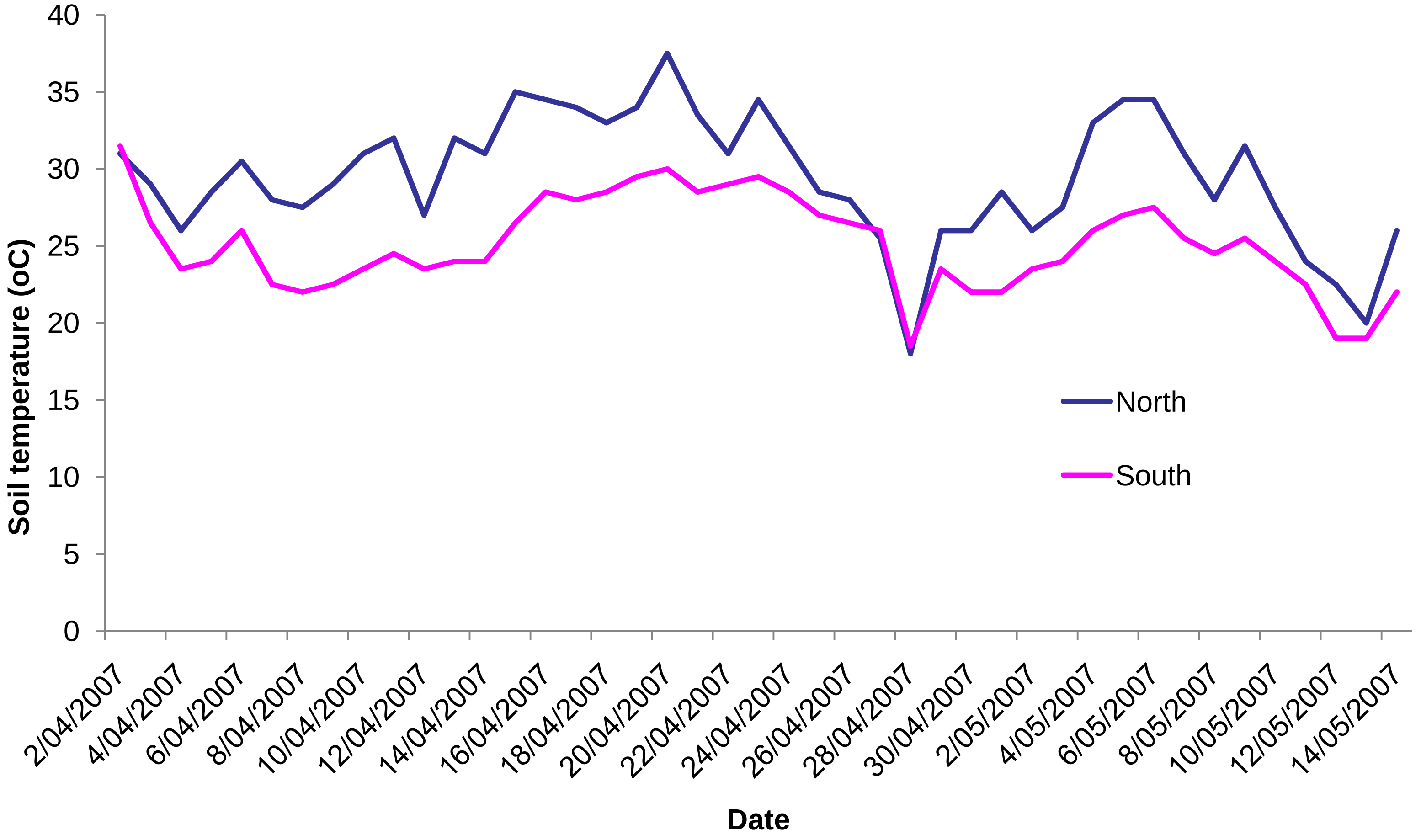


45% larger heads in North row compared to South.

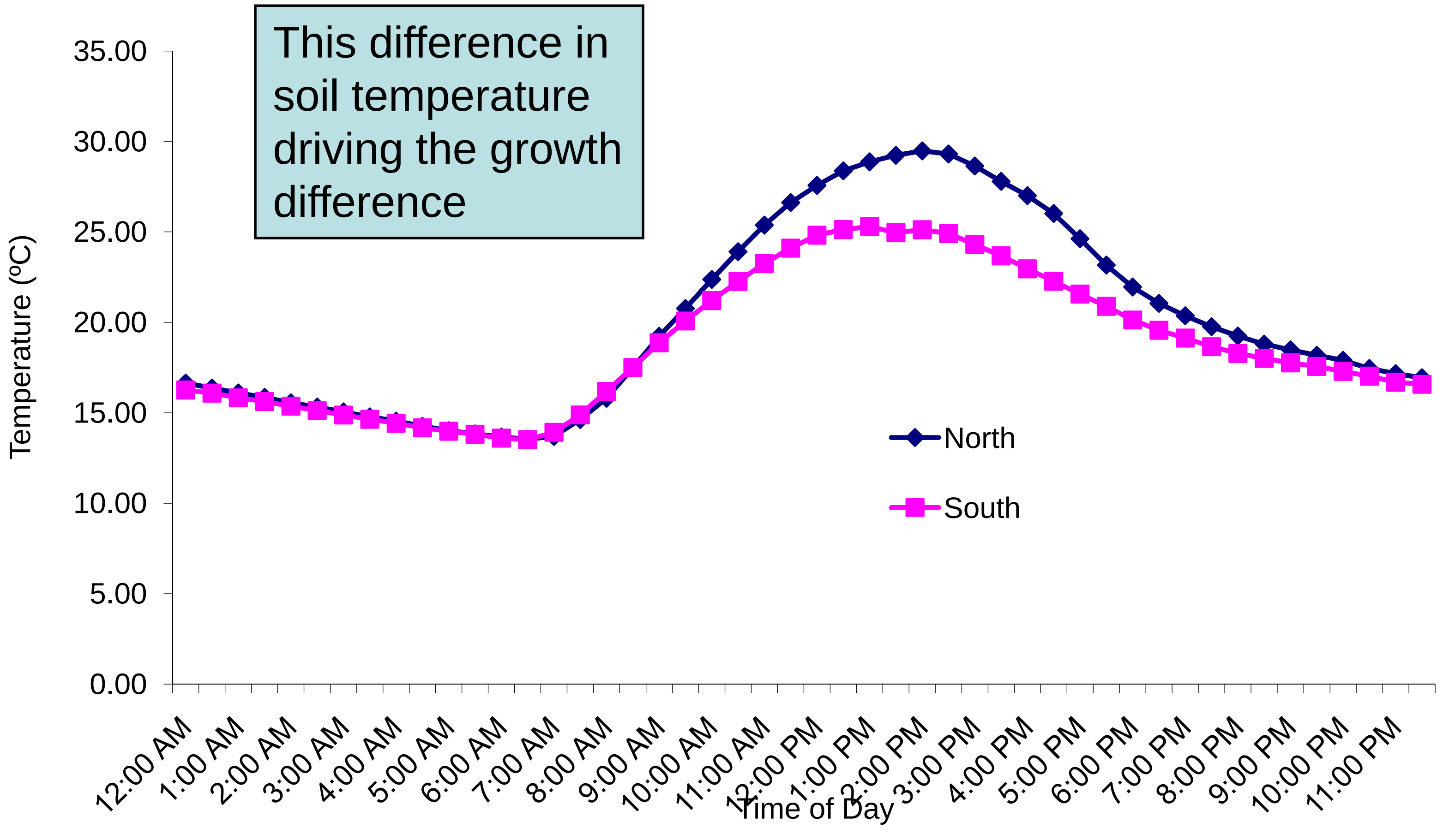
Suggests different growth rate

What is causing ?

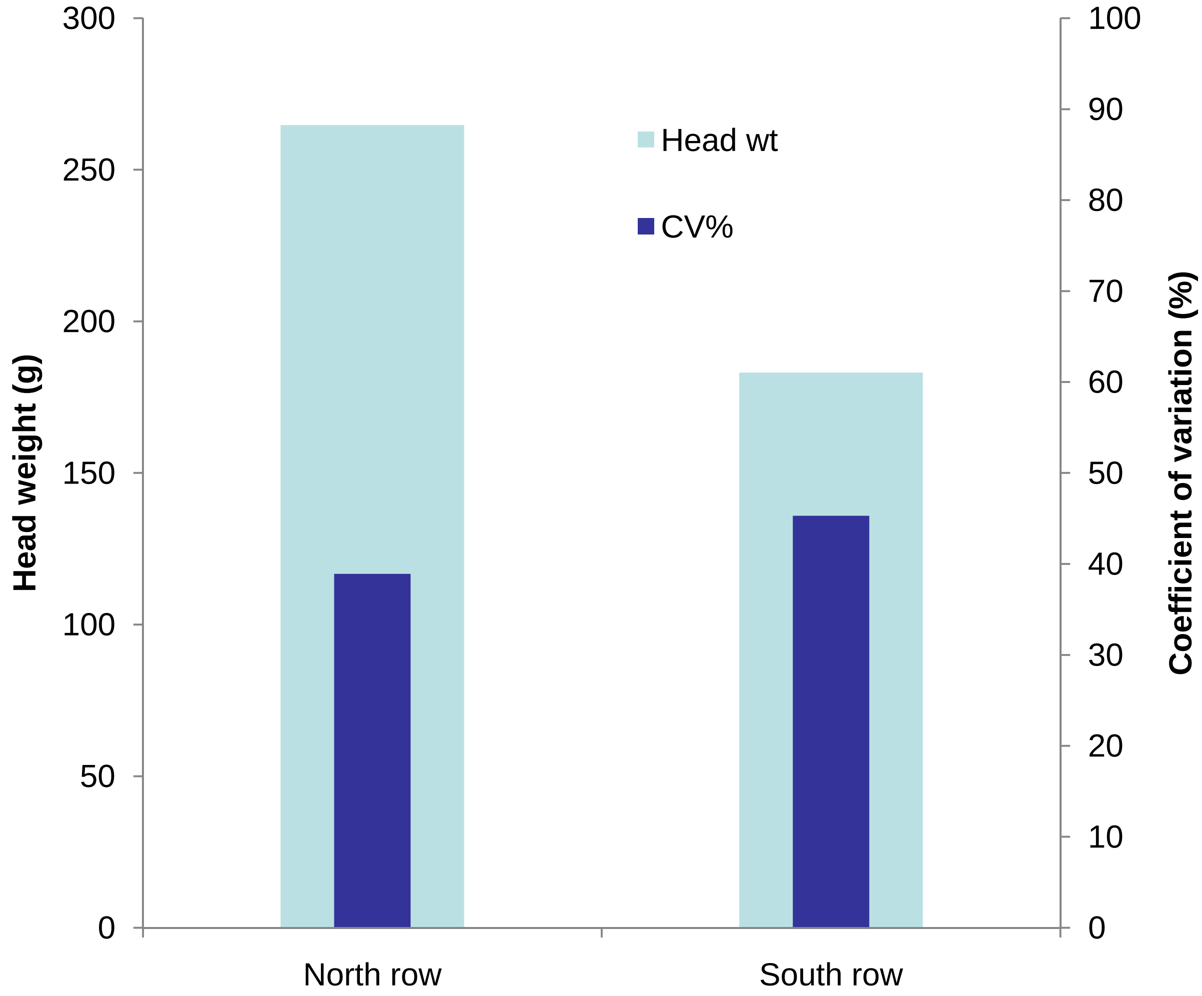
Daily maximum soil temperature April-May 2007 between North and South row



Soil temperatures during the day at 8mm depth



Row orientation: variability

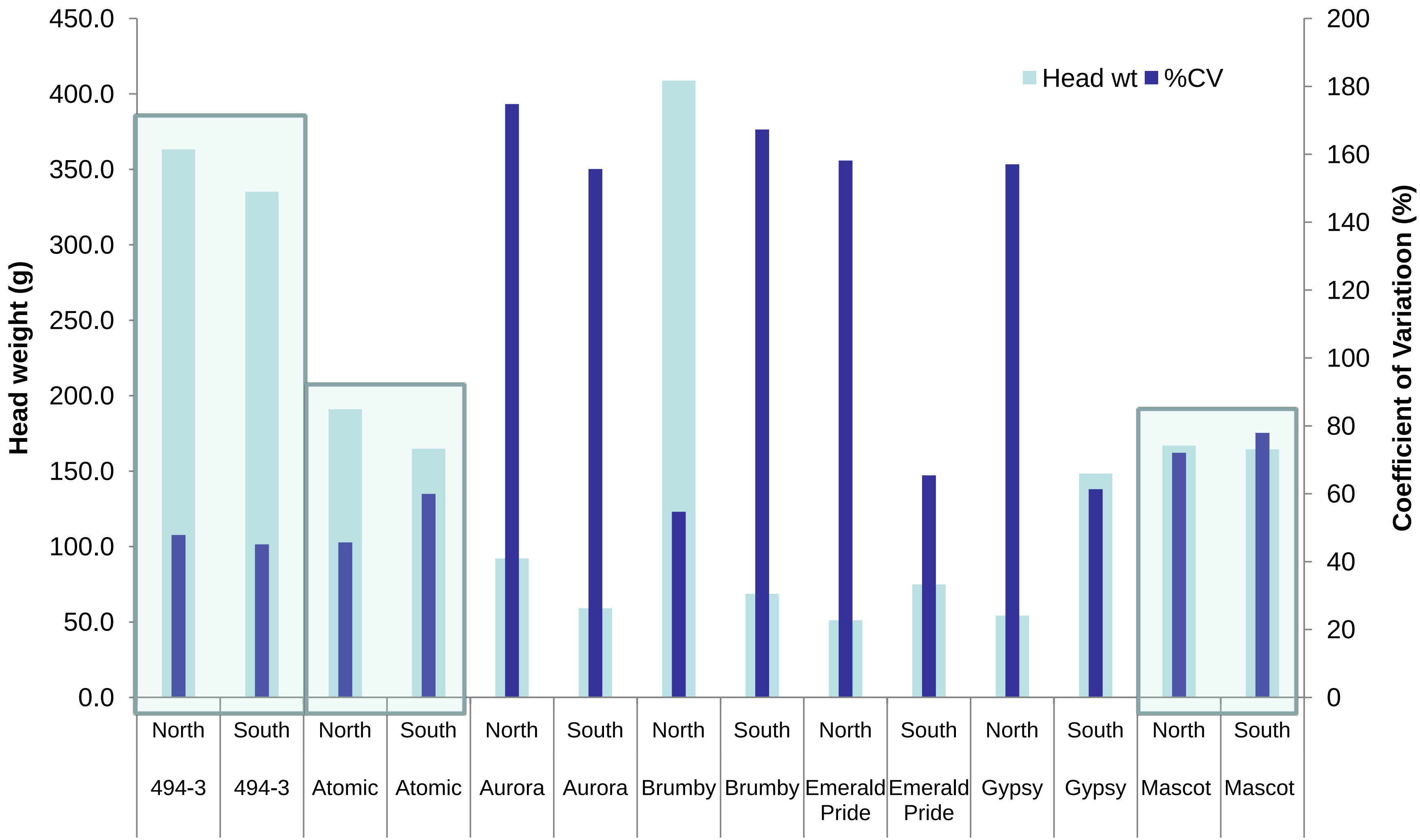


Coefficient of variation is a measure of variability

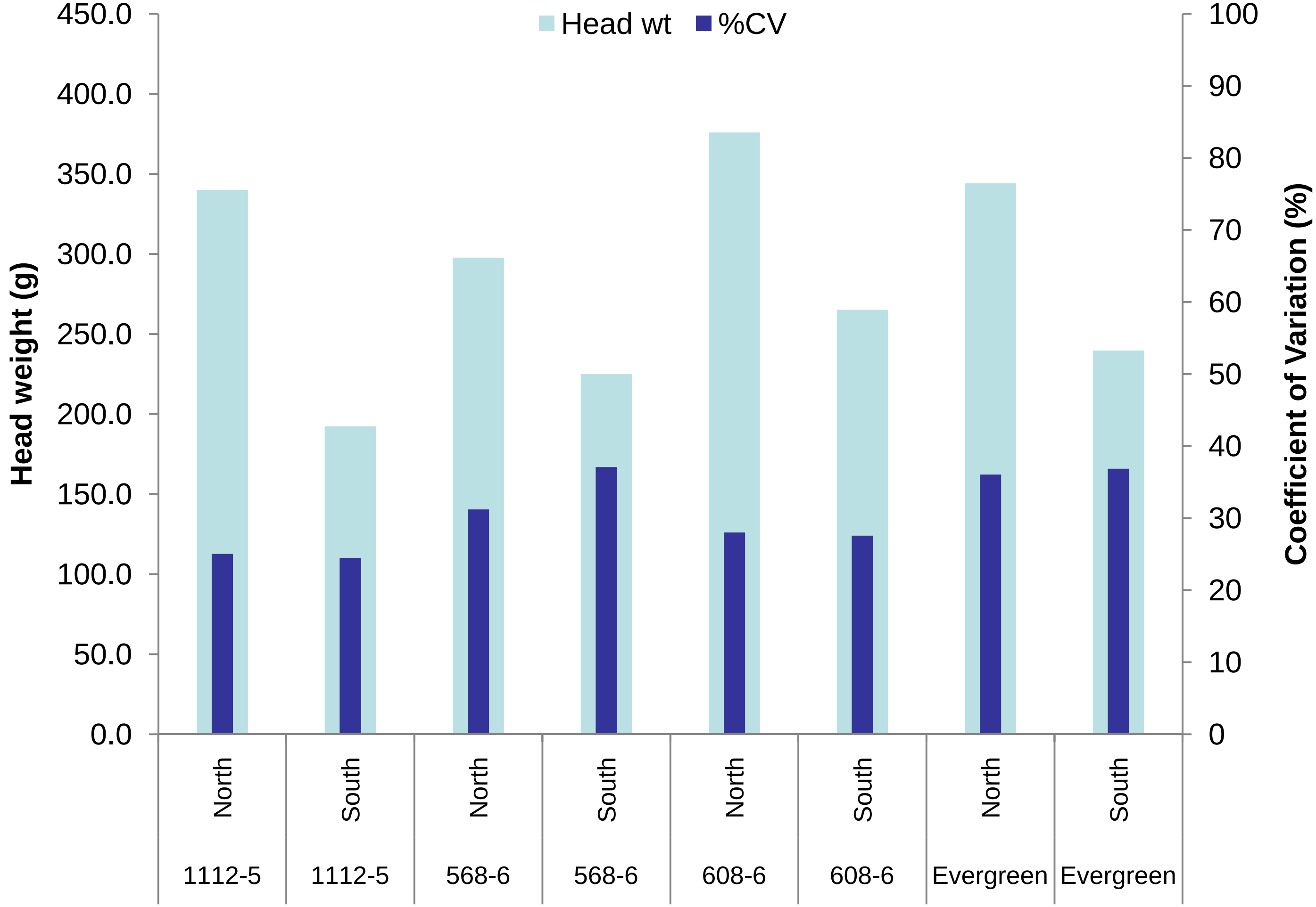
0% = uniform
100% = highly variable

South rows are more variable within the row

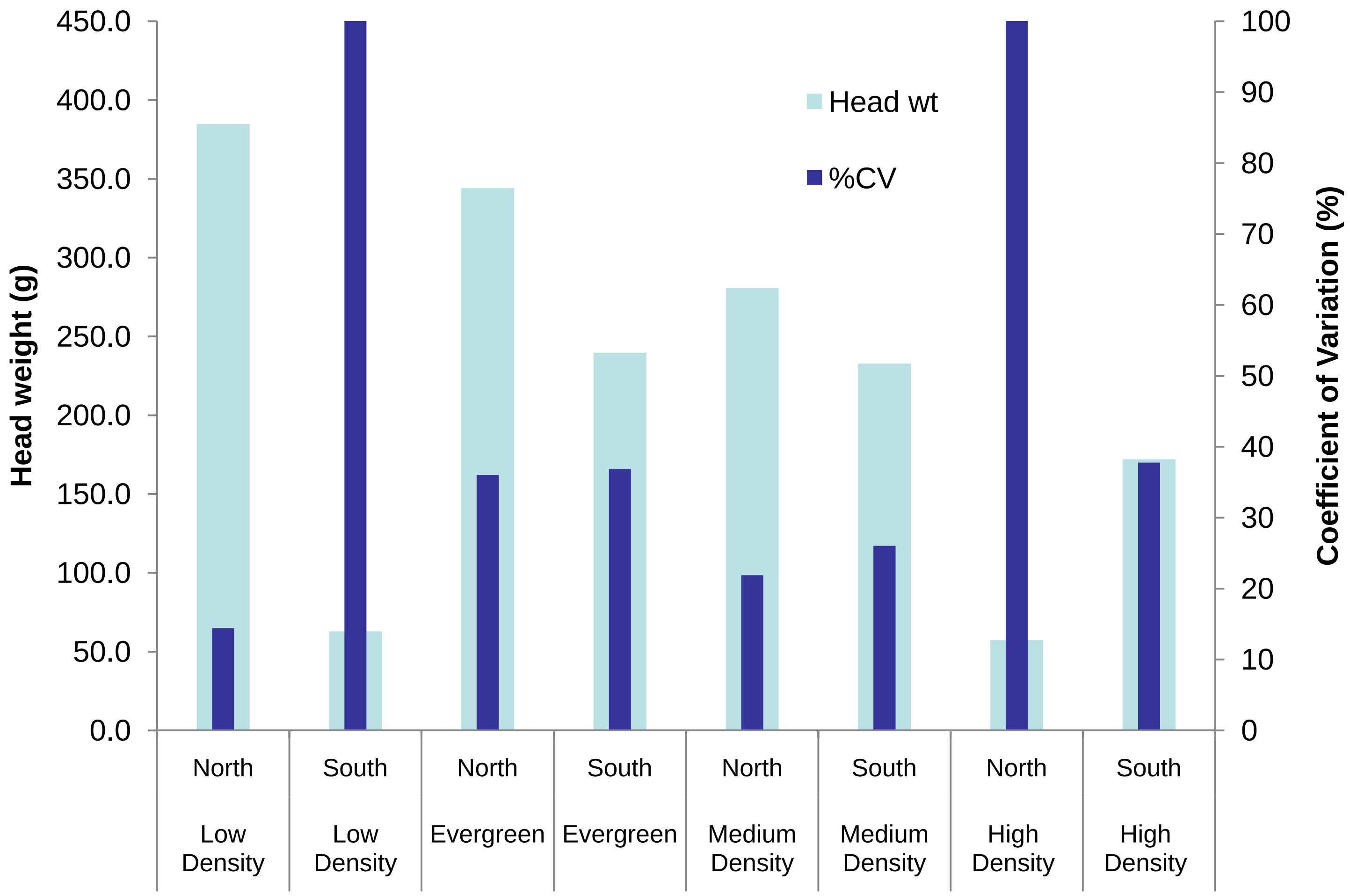
Effect of Row orientation x varieties (Planting 1)



Effect of Row orientation x varieties (Planting 3)



Effect of Row orientation x Planting Density: planting 3



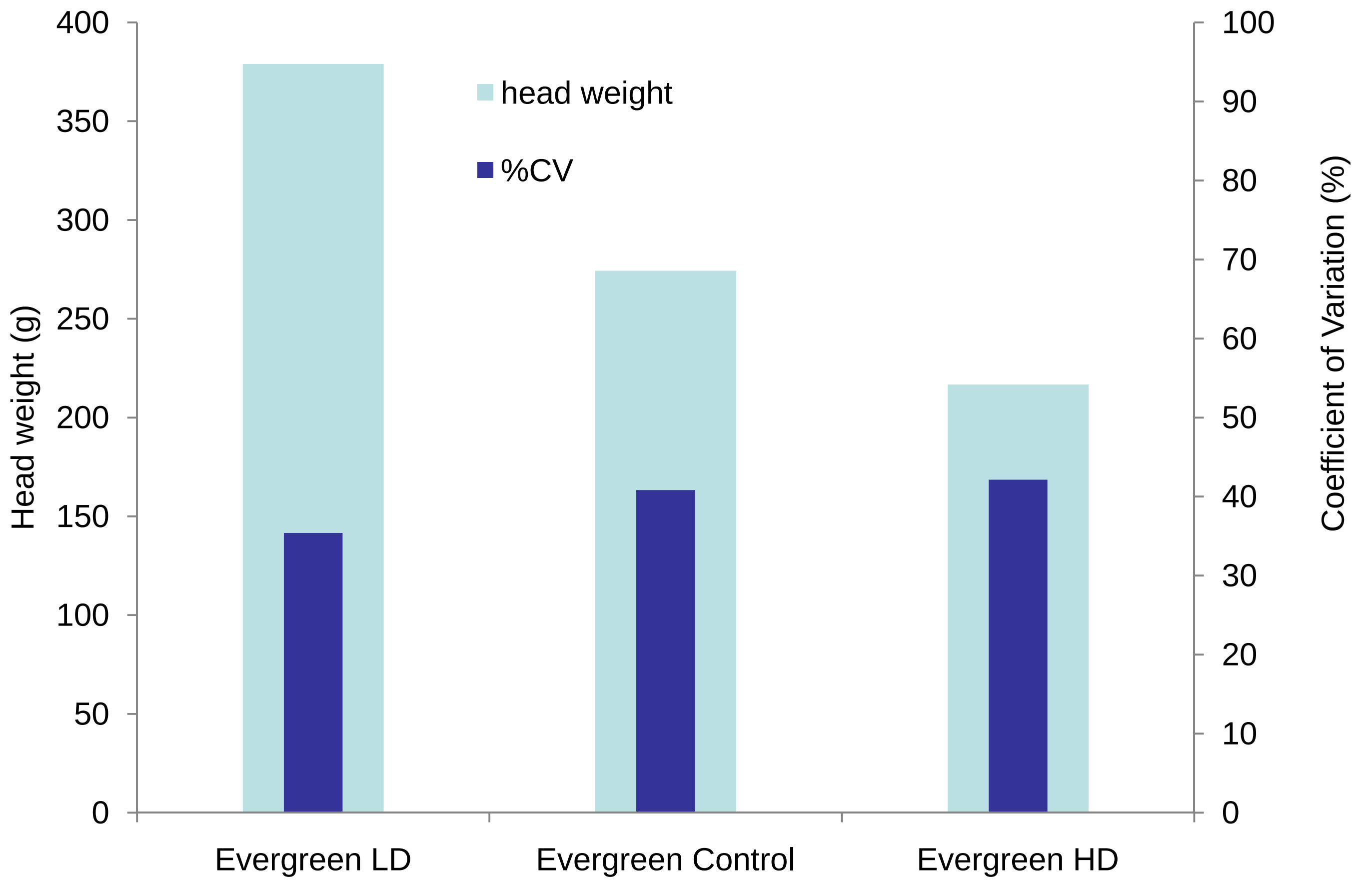
Planting Density

45,000 / 60,000 / 90.000 plants/ha

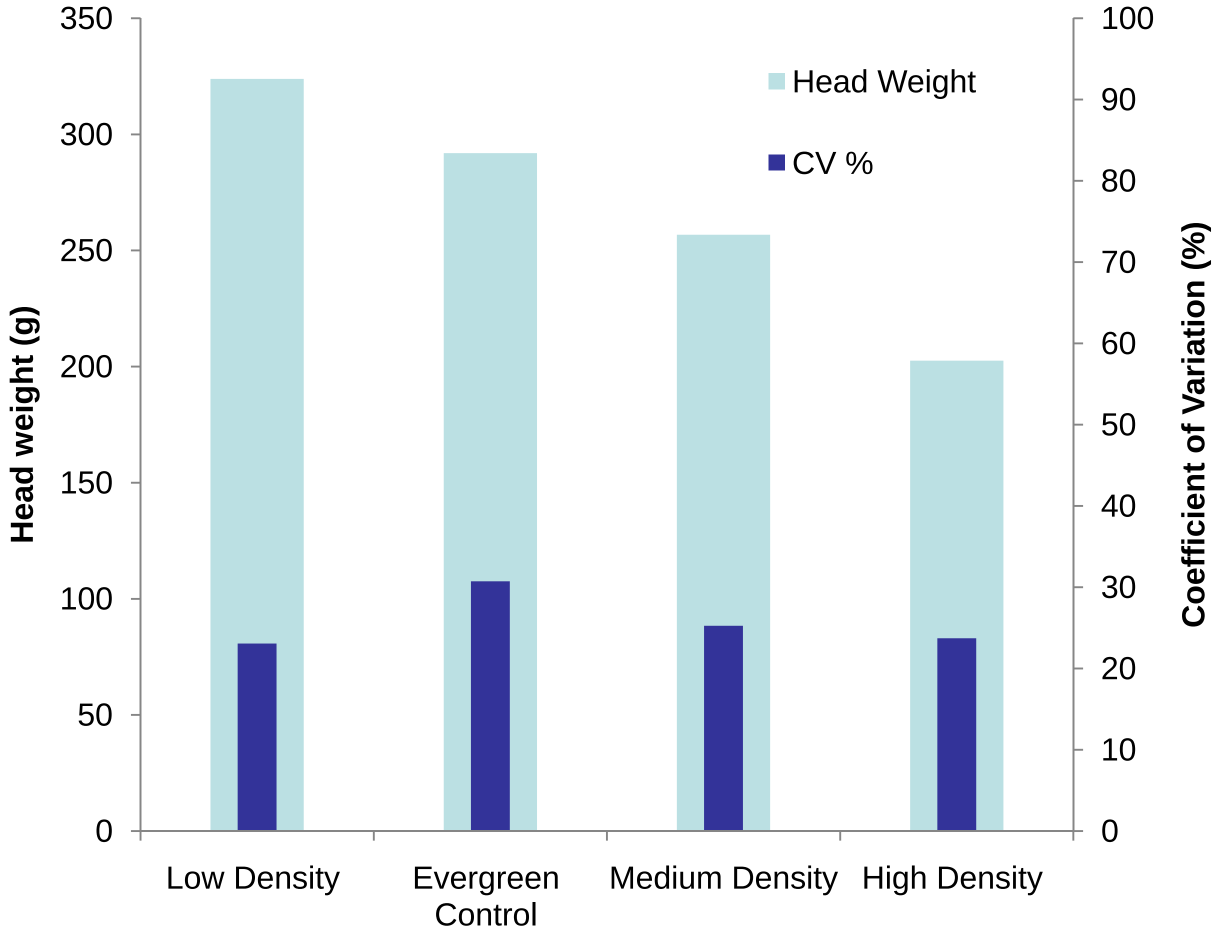
Head uniformity

Mechanical harvesting

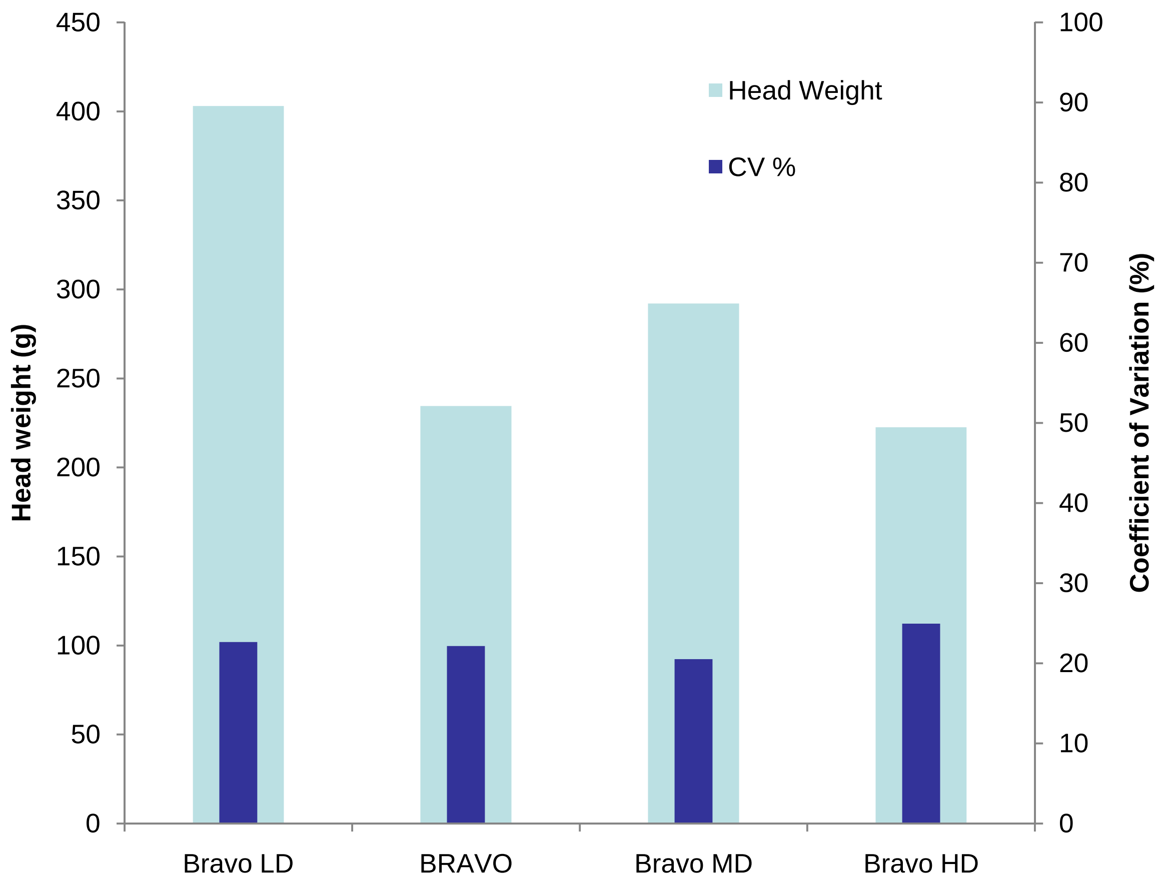
Density – planting 2 (5th May)



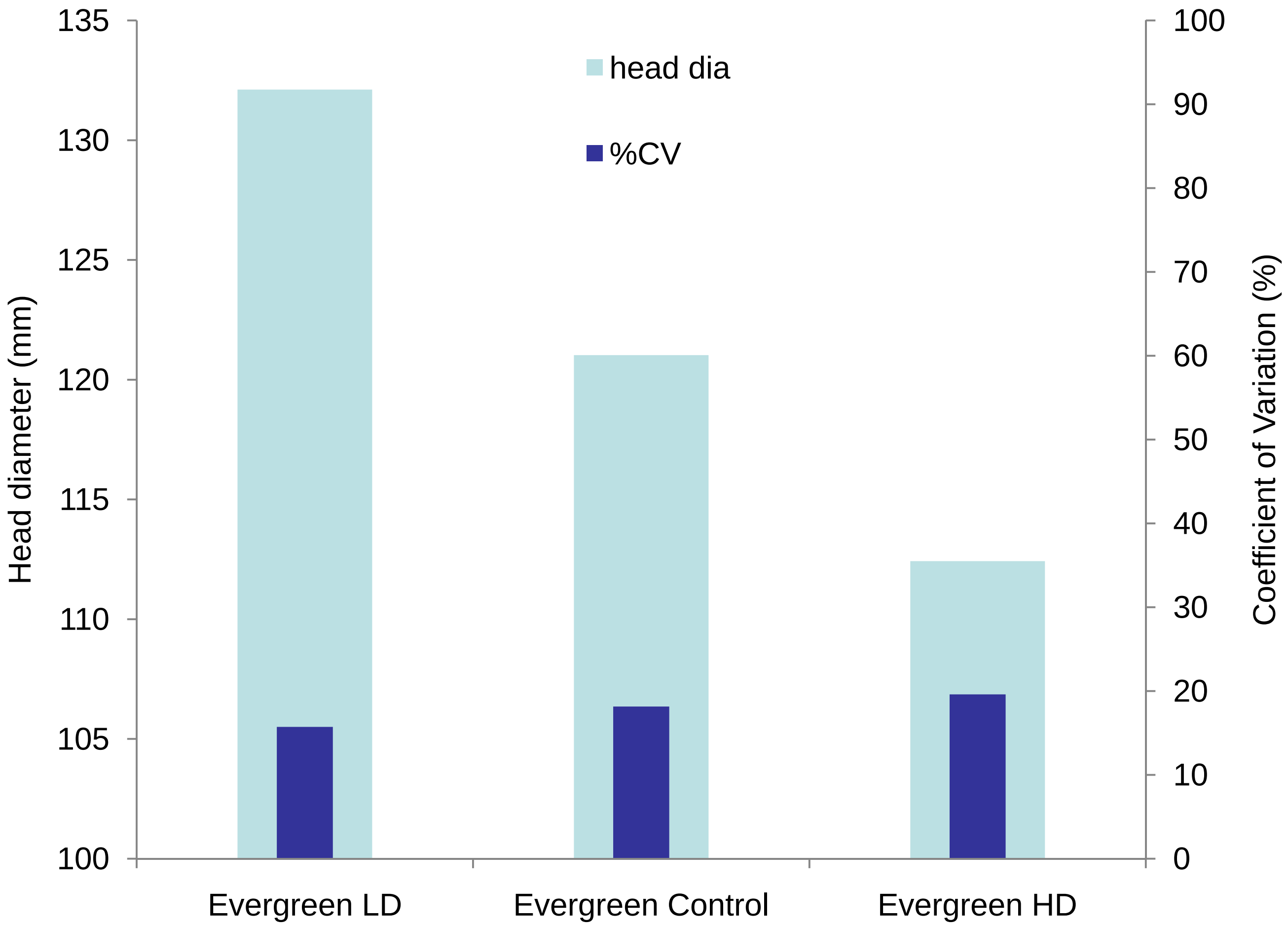
Density – planting 3 (16th May)



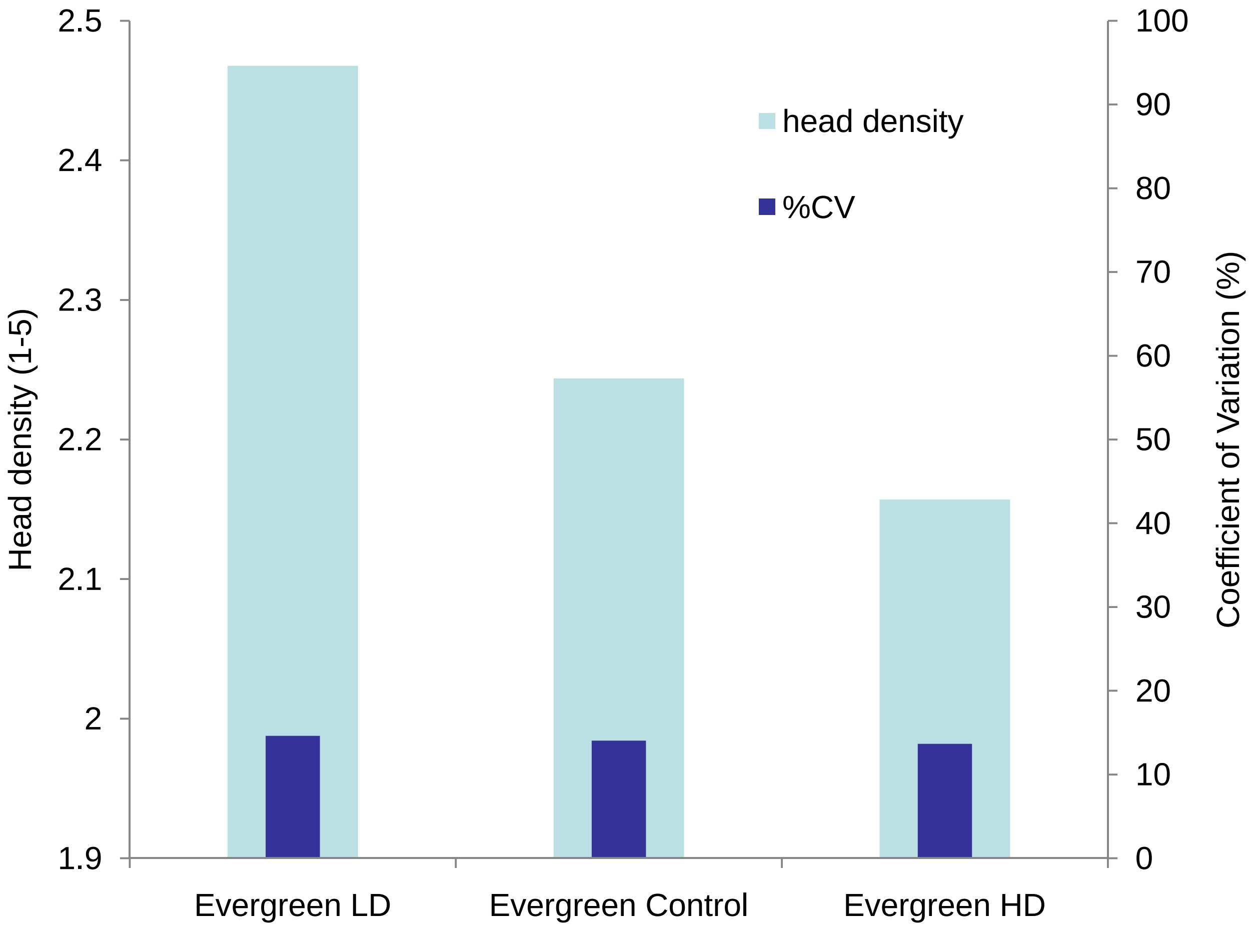
Density – planting 4 (31st May)



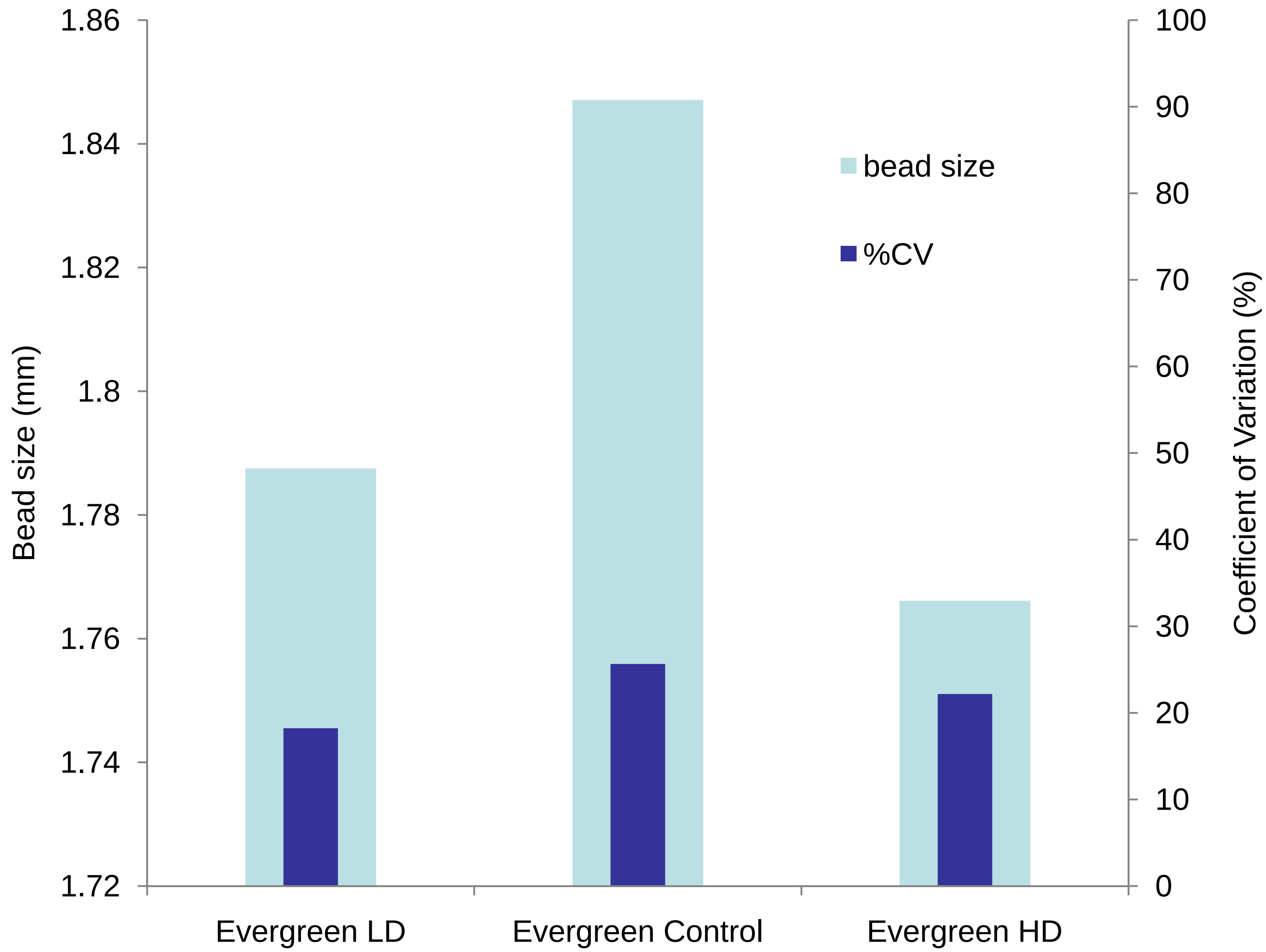
Density and head diameter



Head Density

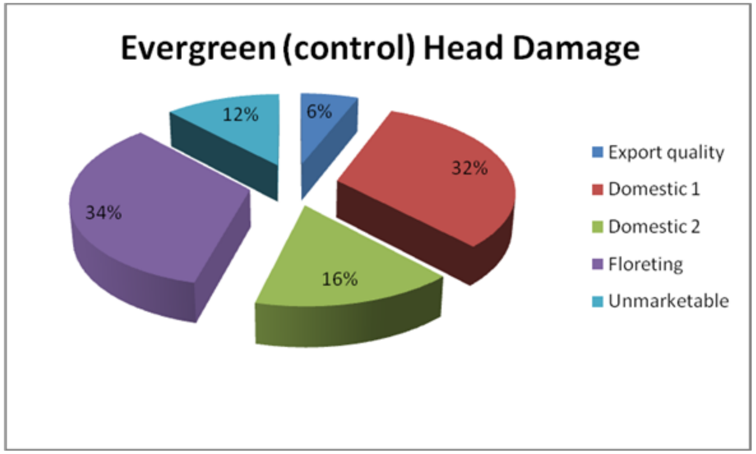


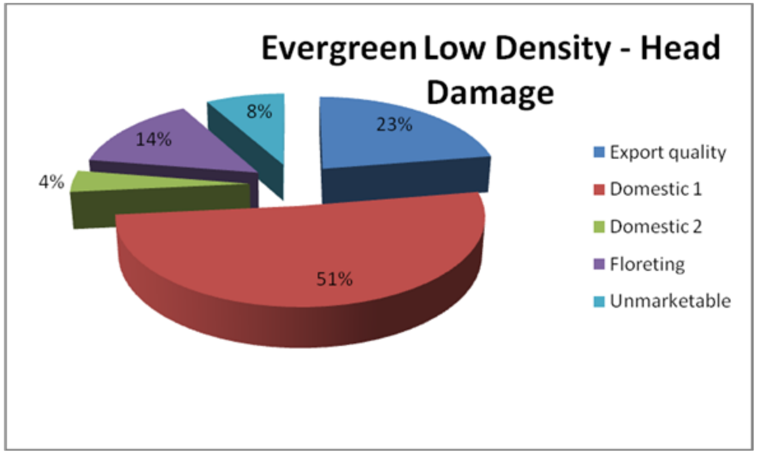
Bead Size

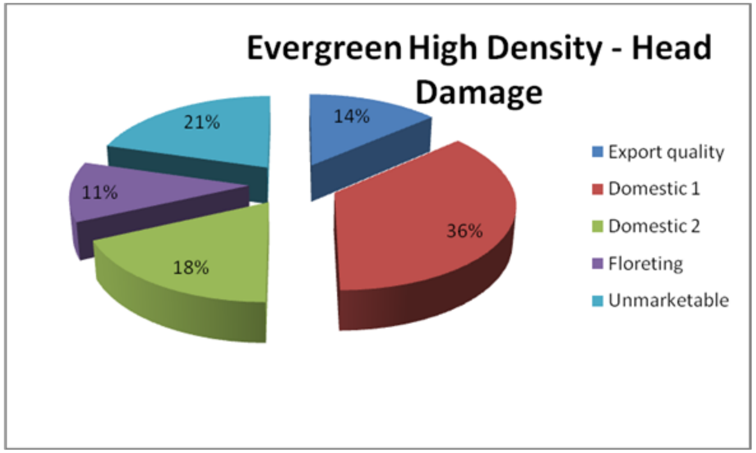


Bead size (mm)
1.86
1.84
1.82
1.8
1.78
1.76
1.74
1.72
Coefficient of Variation (%)
100
90
80
70
60
50
40
30
20
10
0
bead size
%CV
Evergreen LD
Evergreen Control
Evergreen HD

Density and Mechanical harvest



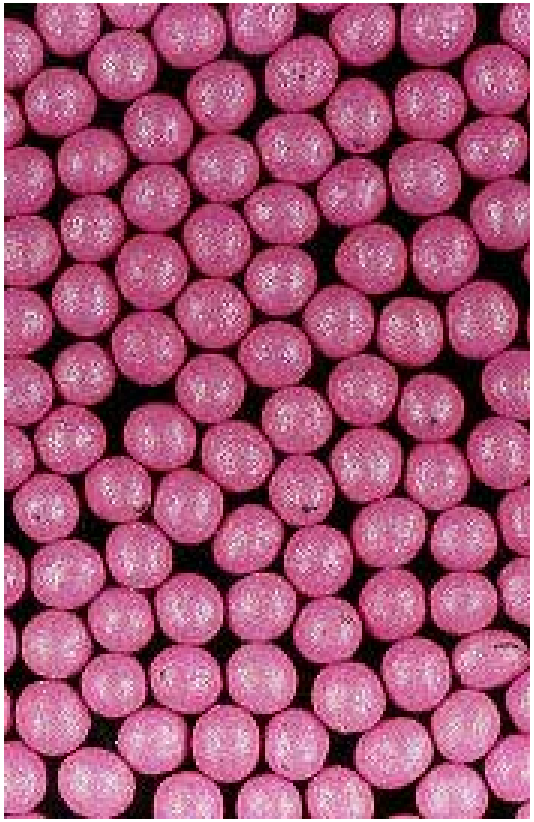




Lower planting density improved head resistance to mechanical damage .May have been due to the heads being “tougher” because they were exposed to more light (less shading) than standard density plants.

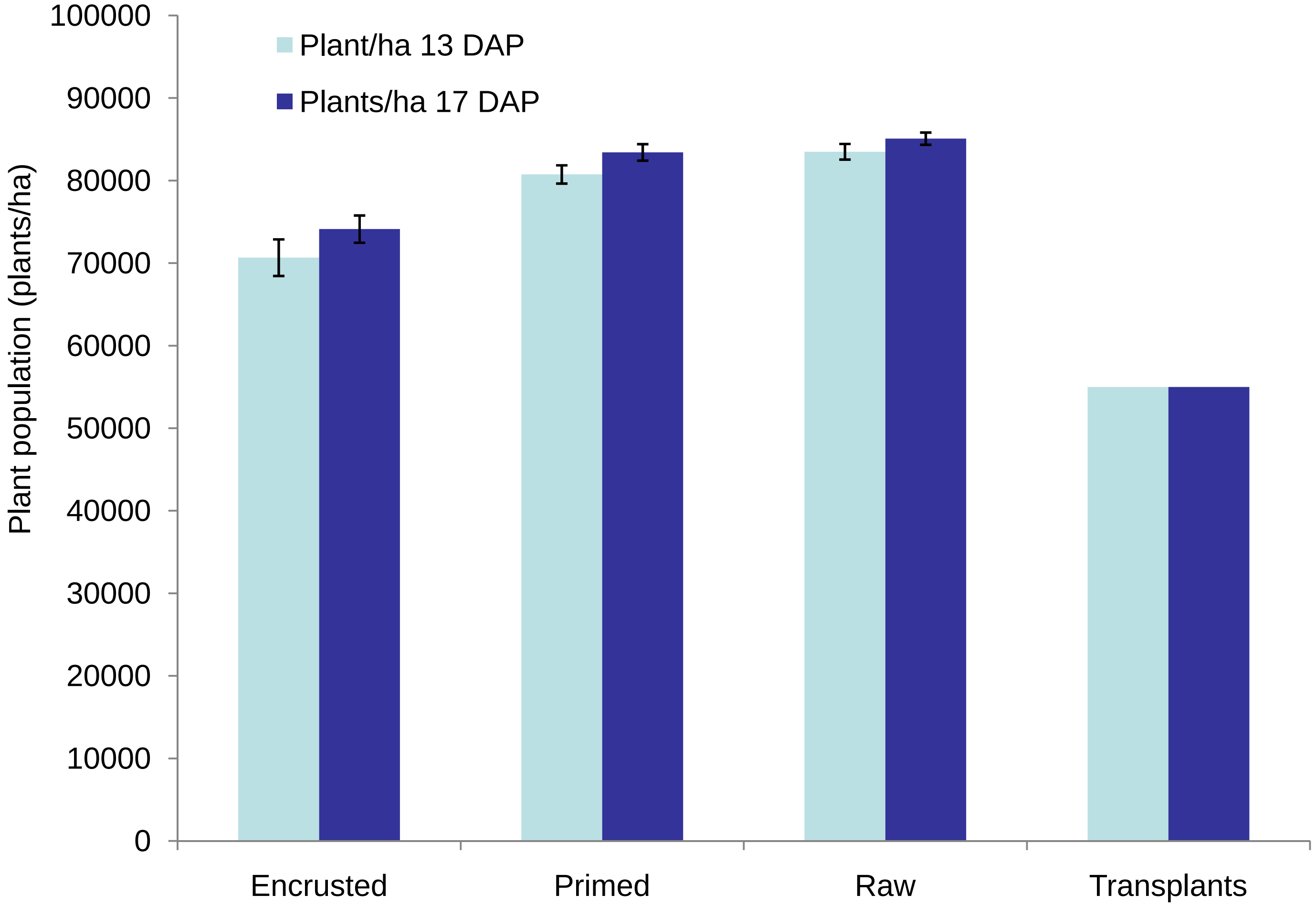
Increasing the plant density from 60,000 plants per hectare to 90,000 improved the head resistance to damage. The may be have been due to smaller heads which were produced as a result of the higher density.

Establishment Techniques

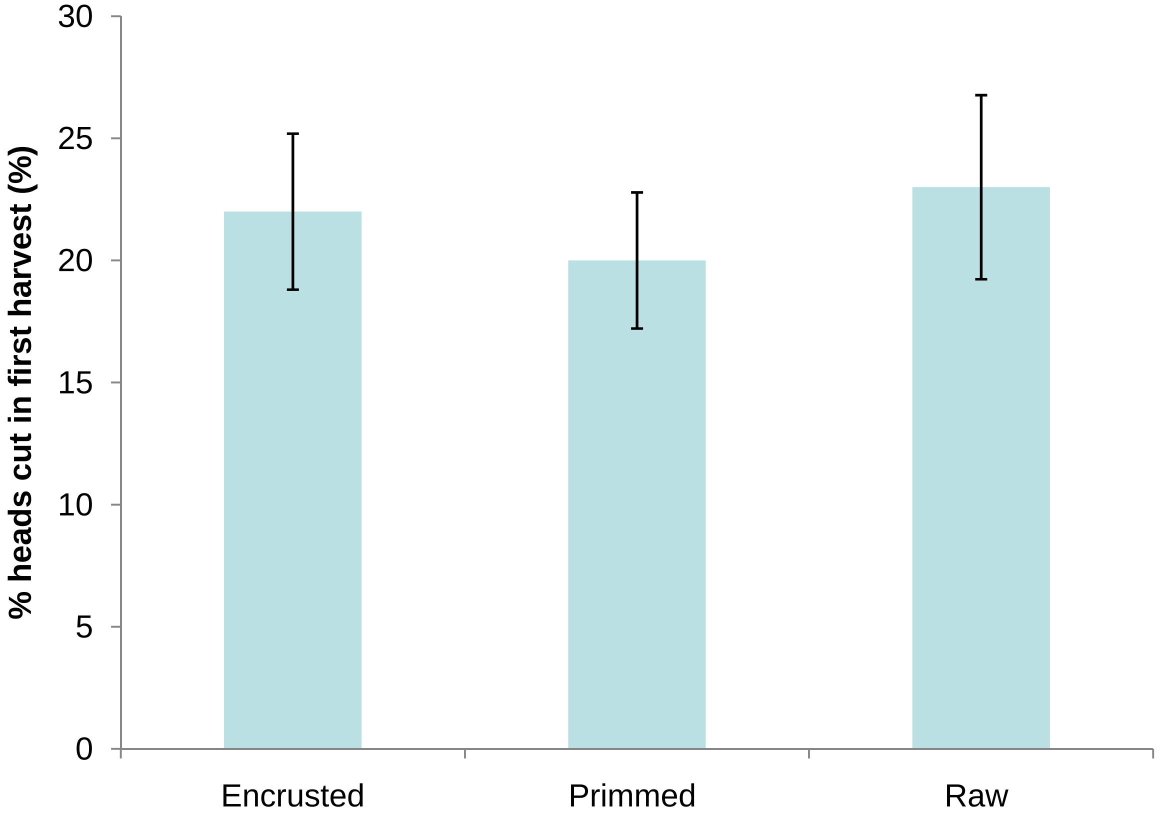


- Seed encrusting and priming
- Direct seeding v's transplants
- Age of seedlings

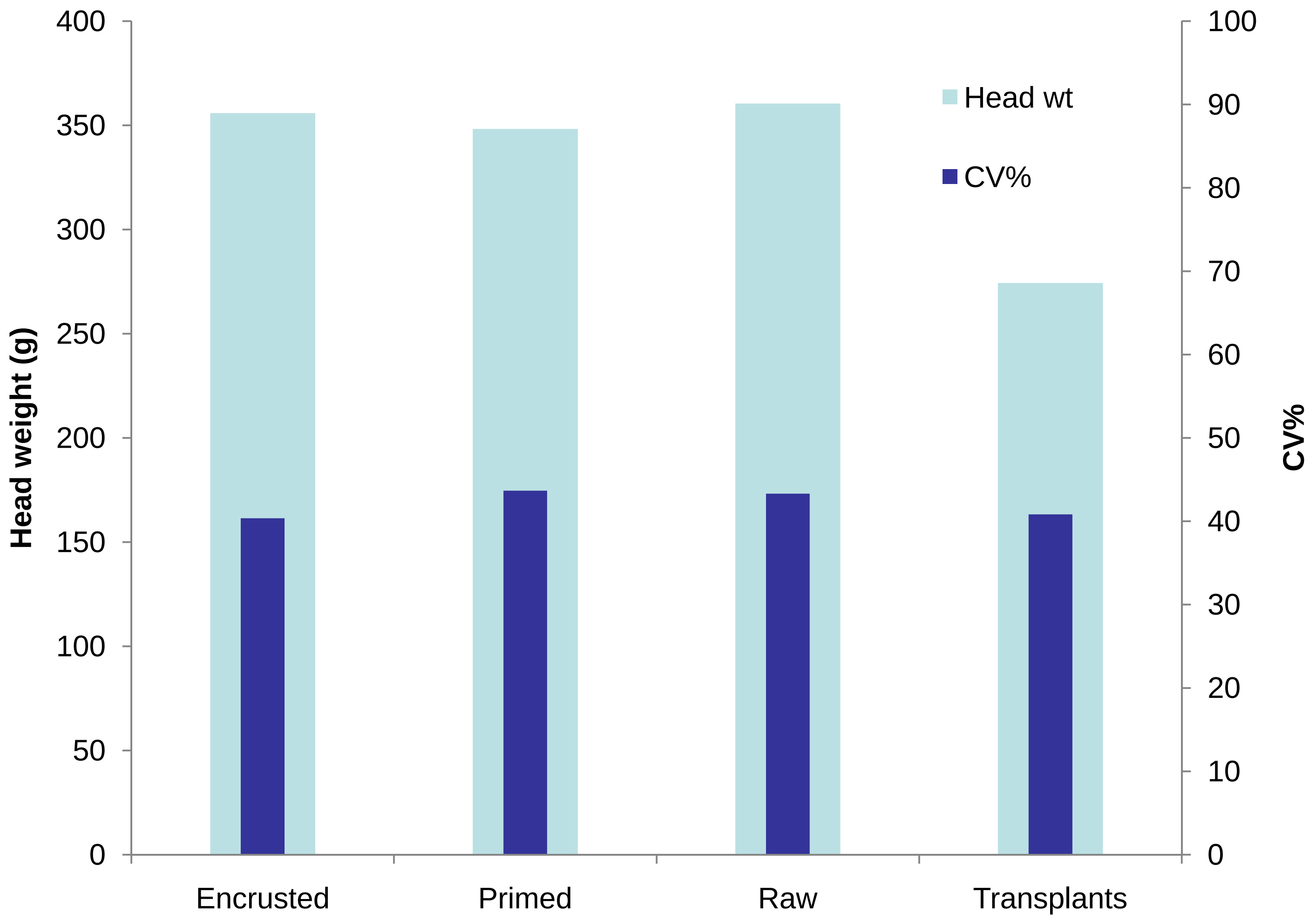
Seedling Establishment



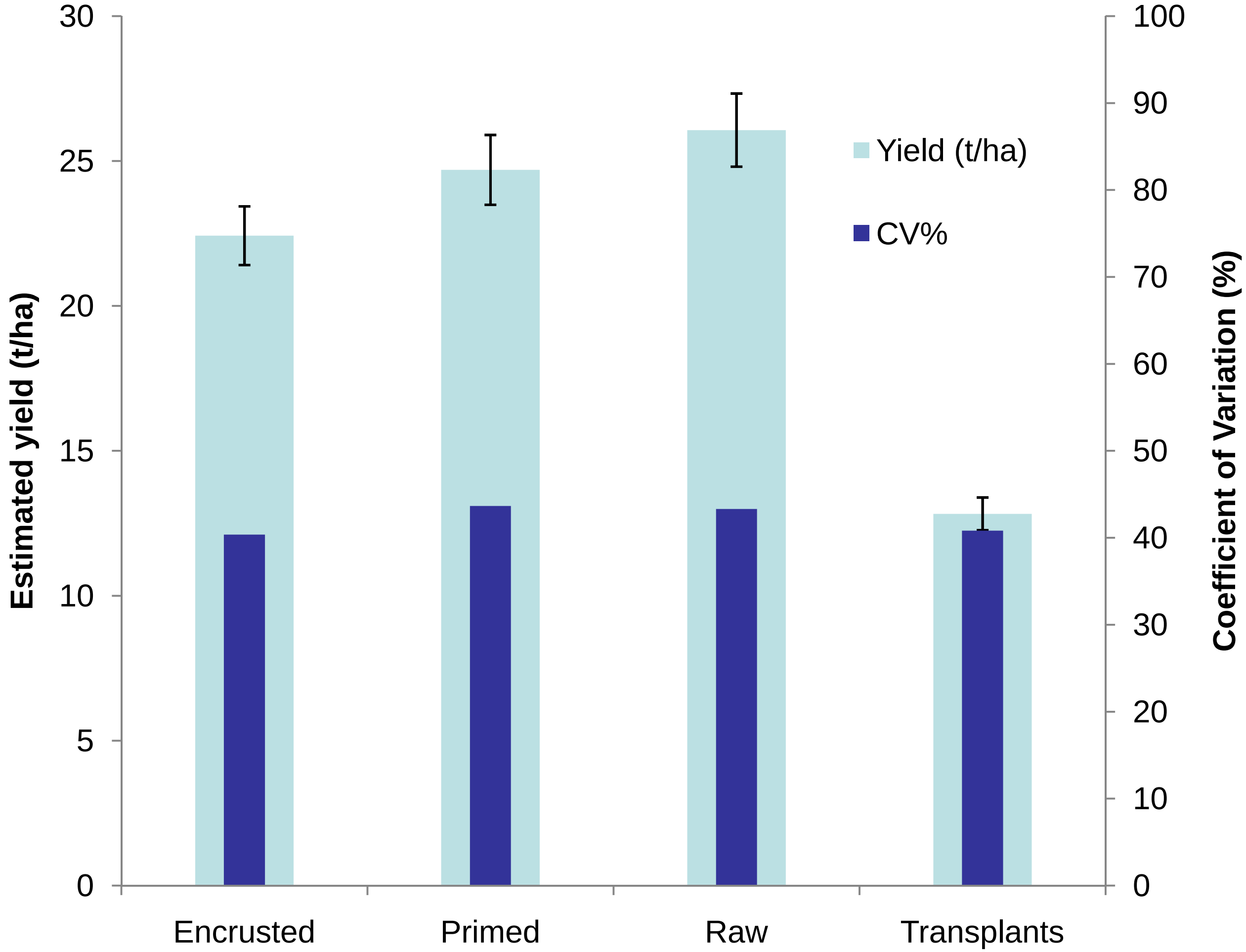
Percentage of heads cut at 1st Harvest



Head weights and variability at harvest

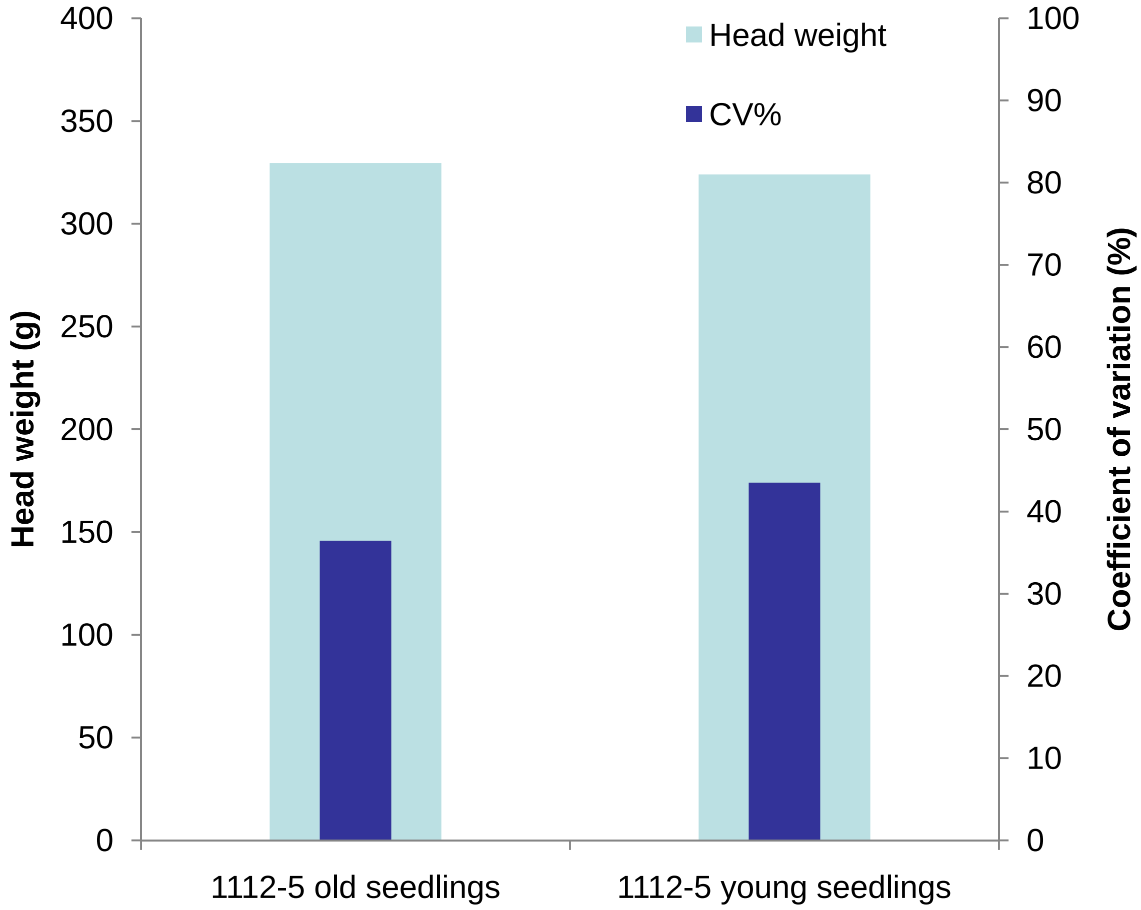


Estimated Yield



Age of Seedlings

Effect of seedling age on head weight and variability



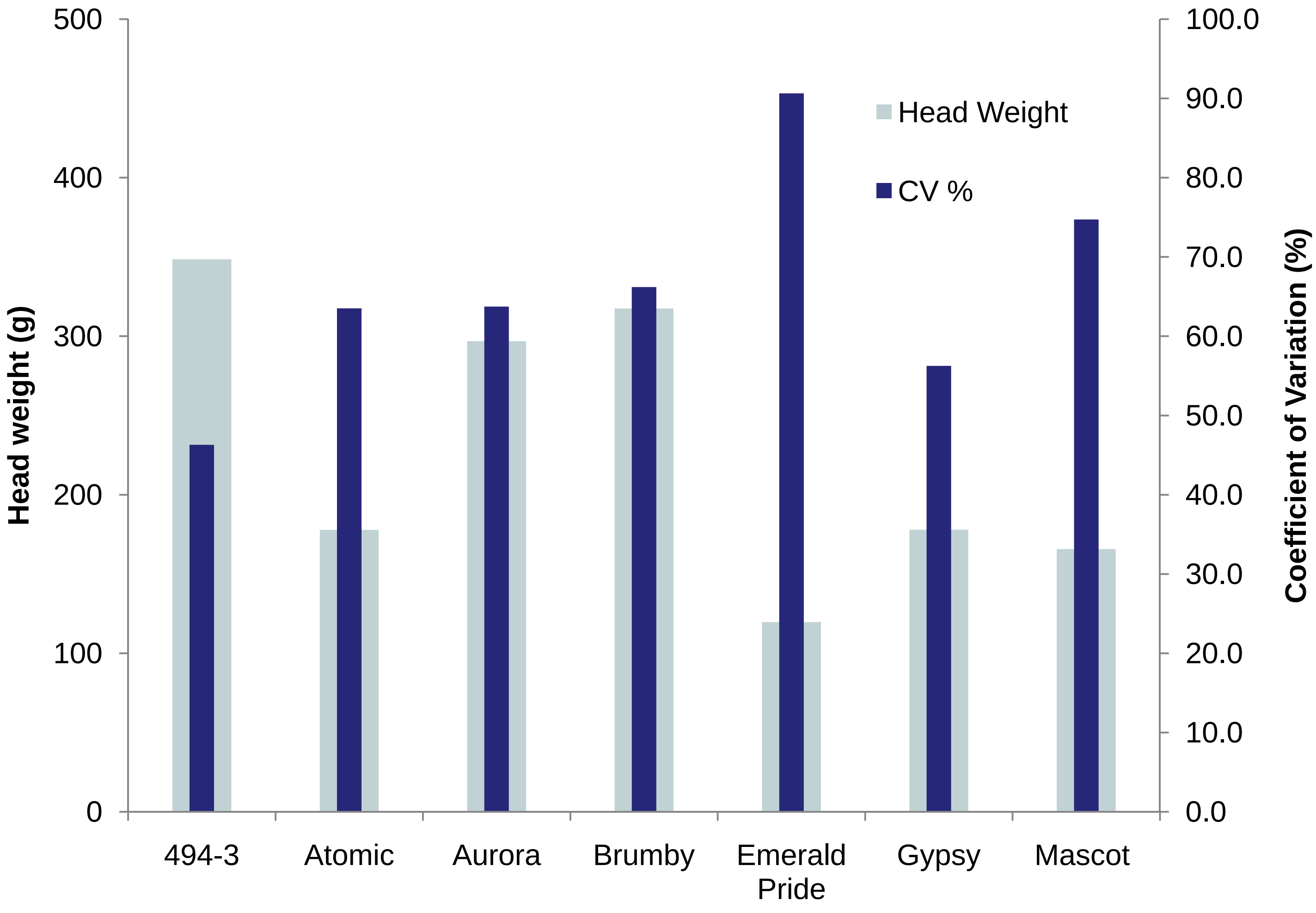
Older seedlings are not affecting yield or uniformity

Variety Assessments

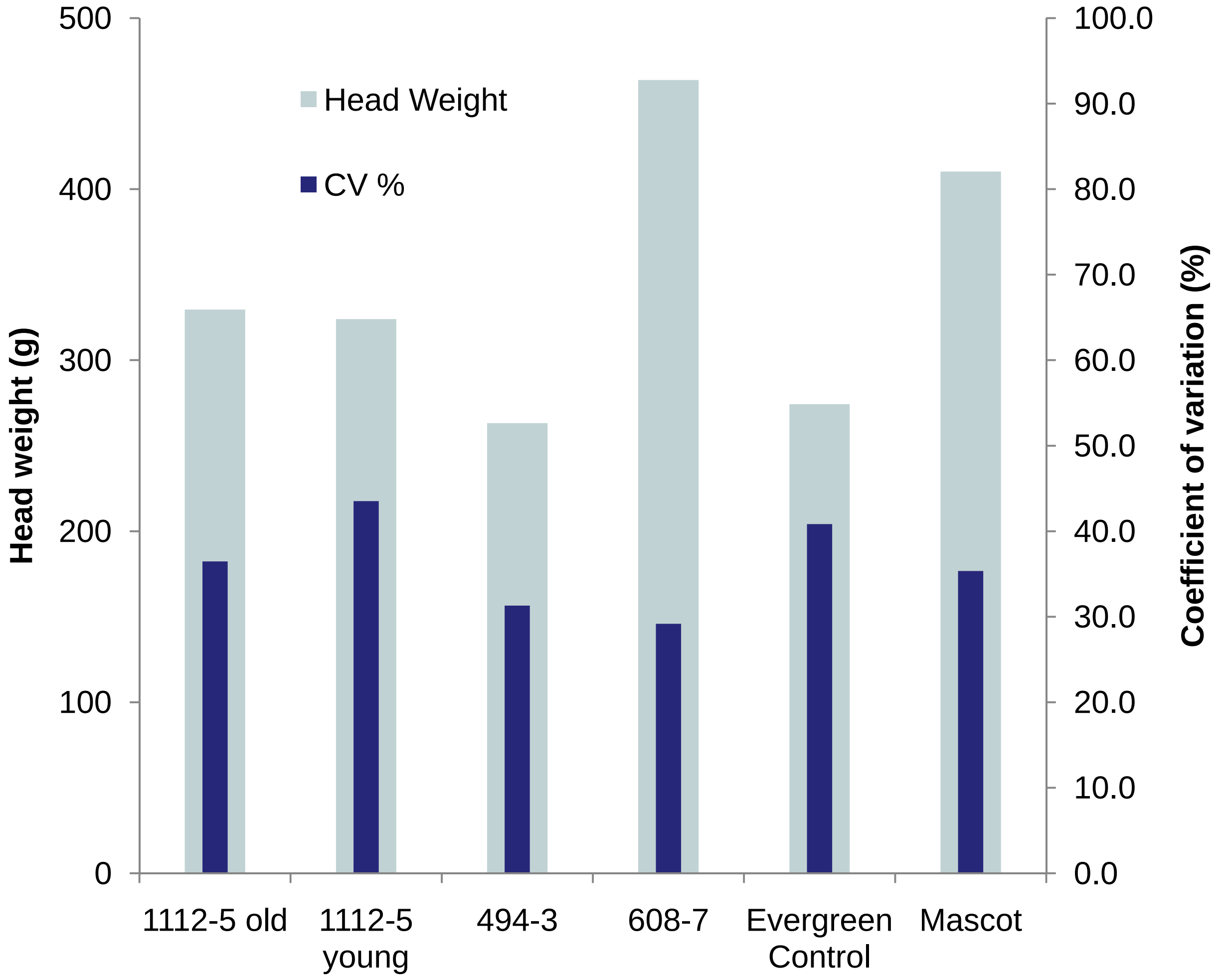
Variety	Planting 1	Planting 2	Planting 3	Planting 4
494-3	x	x		
Atomic	x			
Aurora	x			
Brumby	x			
Emerald Pride	x			
Gypsy	x			
Mascot	x	x		
1112-5		x	x	
608-7		x	x	x
Evergreen		x	x	x
568-7			x	
Bravo				x

Small Plot Variety Assessments

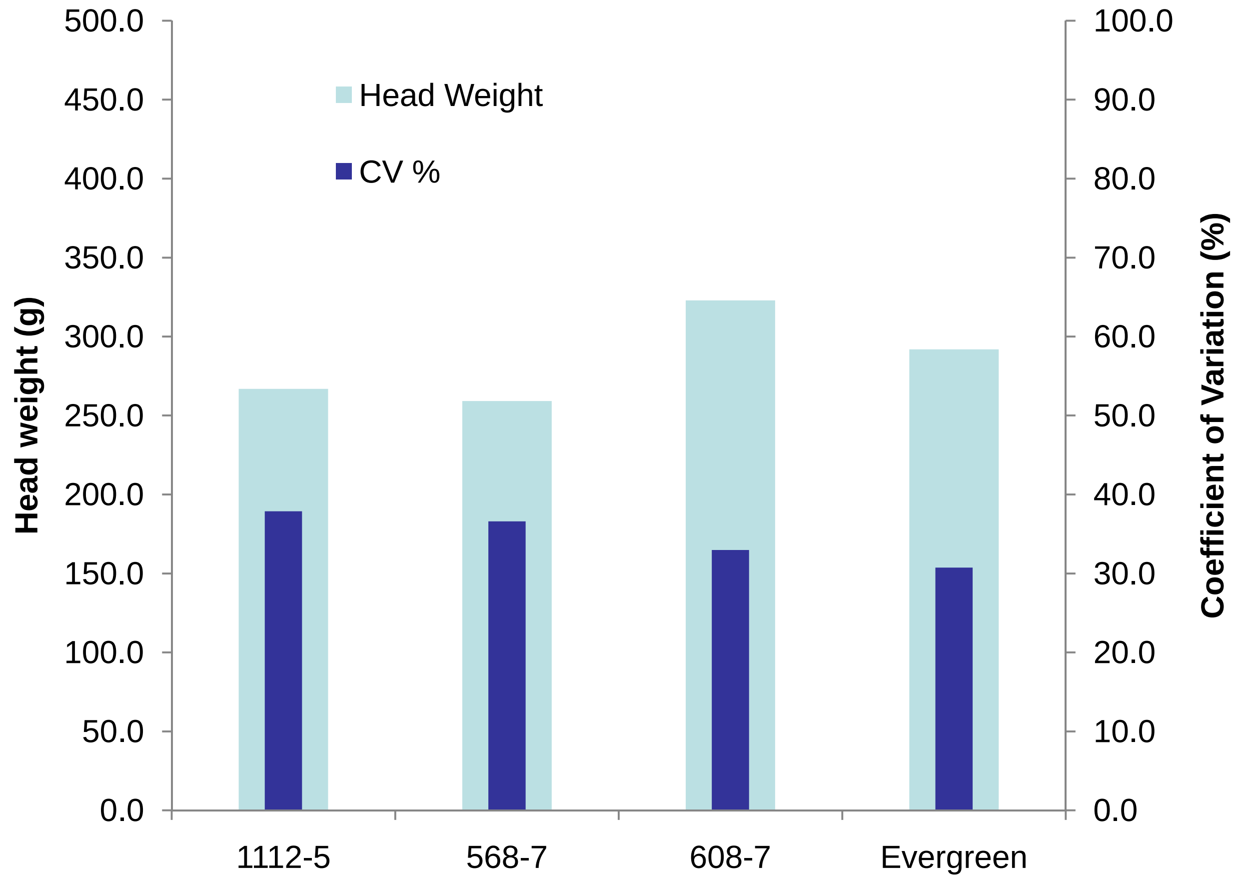
Planting 1 – Head wt and variability



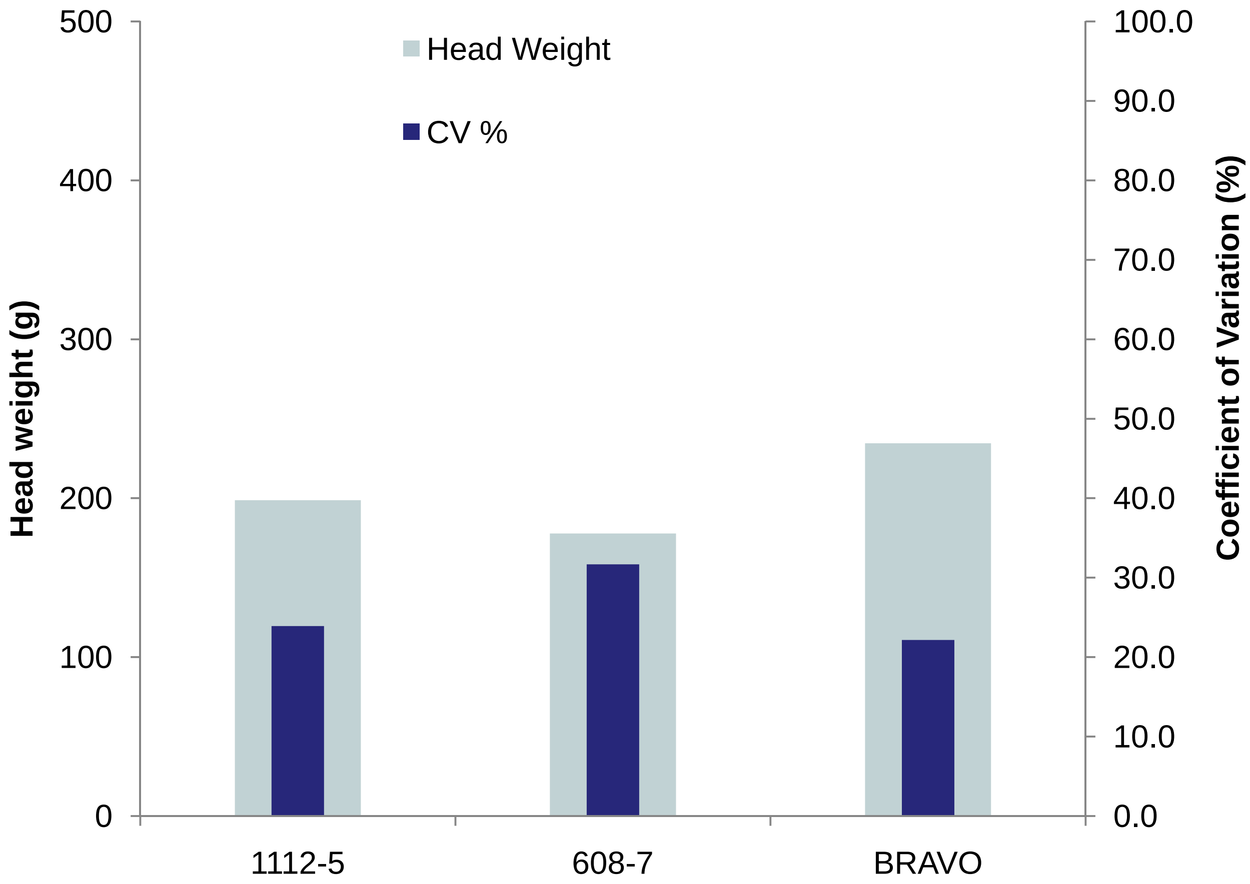
Planting 2 – Head wt and variability



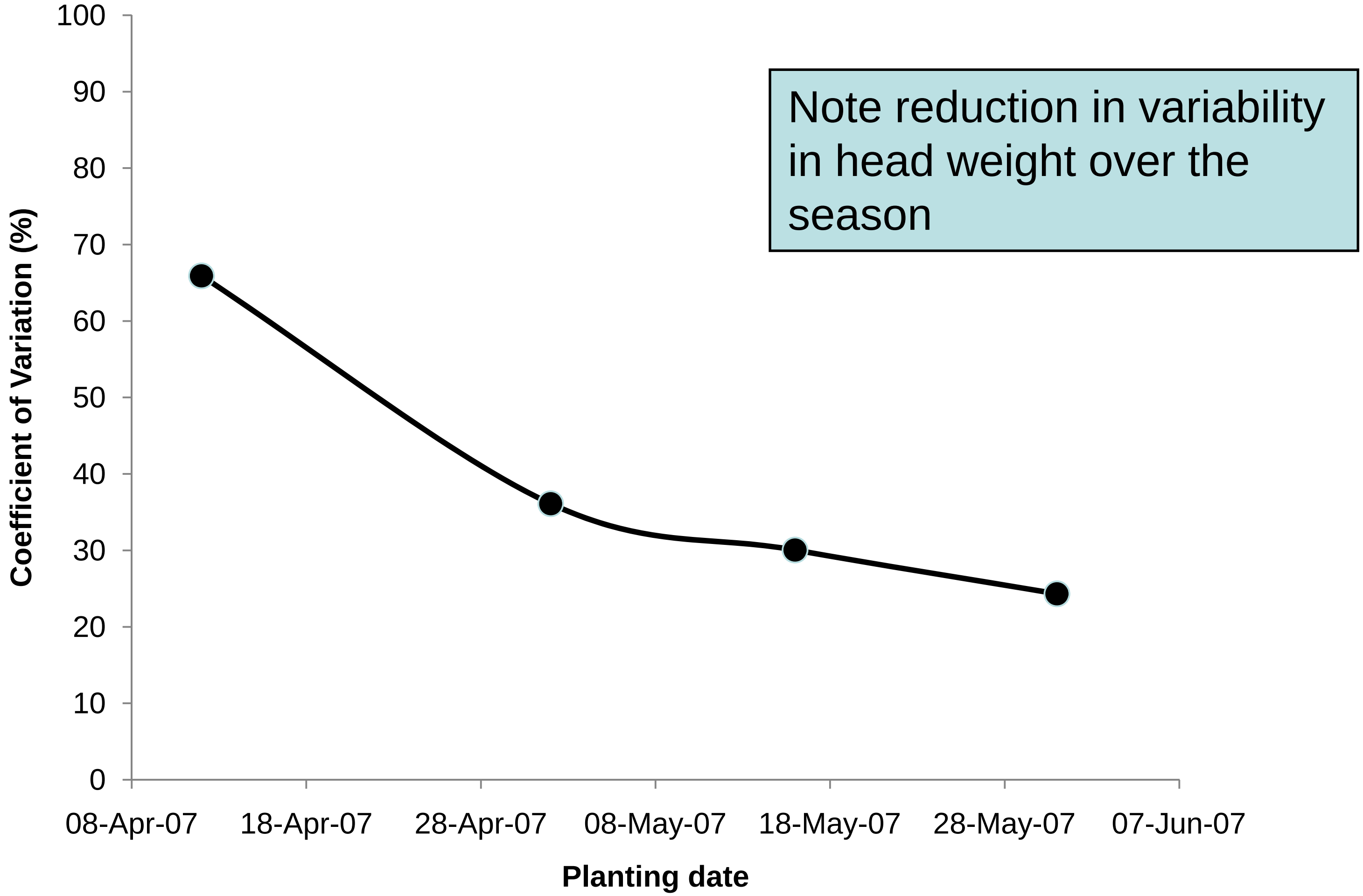
Planting 3 – Head wt and variability



Planting 4 – Head wt and variability



Trend in variability over the season



Variety Summaries

Variety	Head Weight	CV %	Head Diameter	Stem Width	Head Shape	Head Colour	Head Density	Bead Size	Bead Uniformity
494-3	348.5	46.3	132.1	31.0	3.0	4.3	2.2	2.4	2.5
Atomic	177.9	63.5	91.6	31.6	3.6	3.9	2.2	2.0	2.1
Aurora	296.9	63.7	115.0	33.2	4.1	4.2	2.3	2.3	2.2
Brumby	317.5	66.2	111.2	29.5	4.2	4.2	2.5	2.2	2.4
Emerald Pride	119.7	90.6	78.3	25.7	2.8	3.8	1.7	1.8	2.2
Gypsy	178.0	56.3	97.7	28.4	3.7	3.7	2.1	2.0	2.2
Mascot	165.7	74.7	83.9	32.3	3.6	3.9	2.3	1.9	2.3

Variety	Head Weight	CV %	Head Diameter	Stem Width	Head Shape	Head Colour	Head Density	Bead Size	Bead Uniformity
1112-5 old	329.6	36.5	121.8	32.5	4.1	4.1	2.5	1.8	2.5
1112-5 young	324.0	43.5	117.0	32.9	4.5	4.1	2.5	1.9	2.4
494-3	263.2	31.3	121.8	28.2	2.5	3.6	1.8	2.5	2.5
608-7	463.8	29.2	147.4	34.3	2.1	3.8	2.0	2.1	1.6
Evergreen Control	274.3	40.8	121.0	29.6	2.8	4.1	2.2	1.8	2.4
Mascot	410.3	35.3	140.2	35.1	2.6	4.0	2.3	1.8	2.4

Variety	Head Weight	CV %	Head Diameter	Stem Width	Head Shape	Head Colour	Head Density	Bead Size	Bead Uniformity
1112-5	266.9	37.9	132.2	28.9	3.1	3.9	2.1	2.1	2.5
568-7	259.1	36.6	127.6	29.9	3.2	3.9	2.2	2.1	2.6
608-7	322.9	33.0	133.4	35.5	2.8	3.7	2.1	2.7	2.8
Evergreen	291.9	30.7	136.1	31.6	2.6	3.8	2.1	2.2	2.5

Variety	Head Weight	CV %	Head Diameter	Stem Width	Head Shape	Head Colour	Head Density	Bead Size	Bead Uniformity
1112-5	198.7	23.9	118.1	25.0	2.8	3.8	1.8	2.3	2.5
608-7	177.8	31.7	102.1	27.3	2.8	3.9	2.0	2.3	2.7
BRAVO	234.5	22.2	119.9	29.9	2.5	3.7	1.8	2.6	2.6

494-3

Brumby

Atomic

Aurora

Emerald Pride

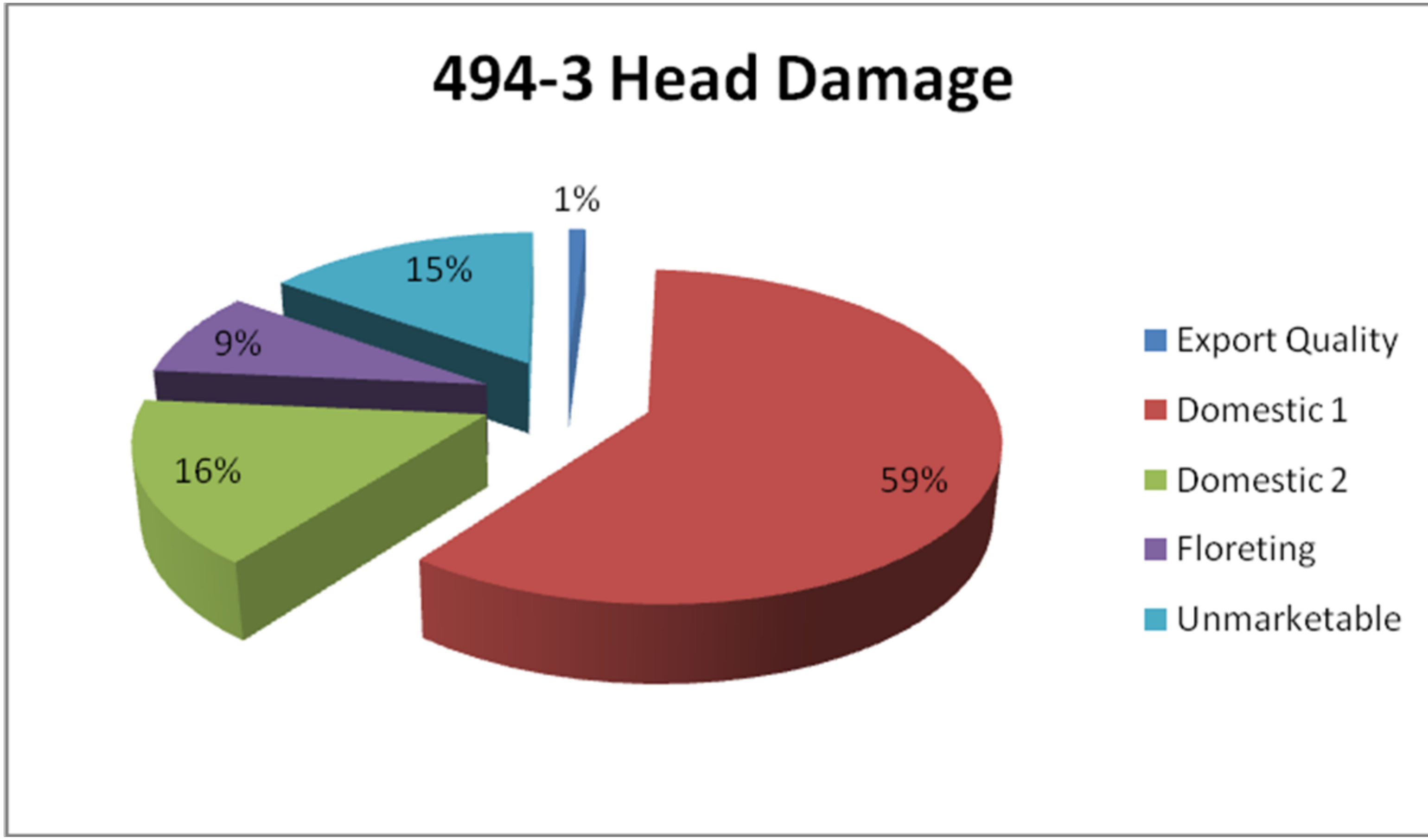
Gypsy

Mascot

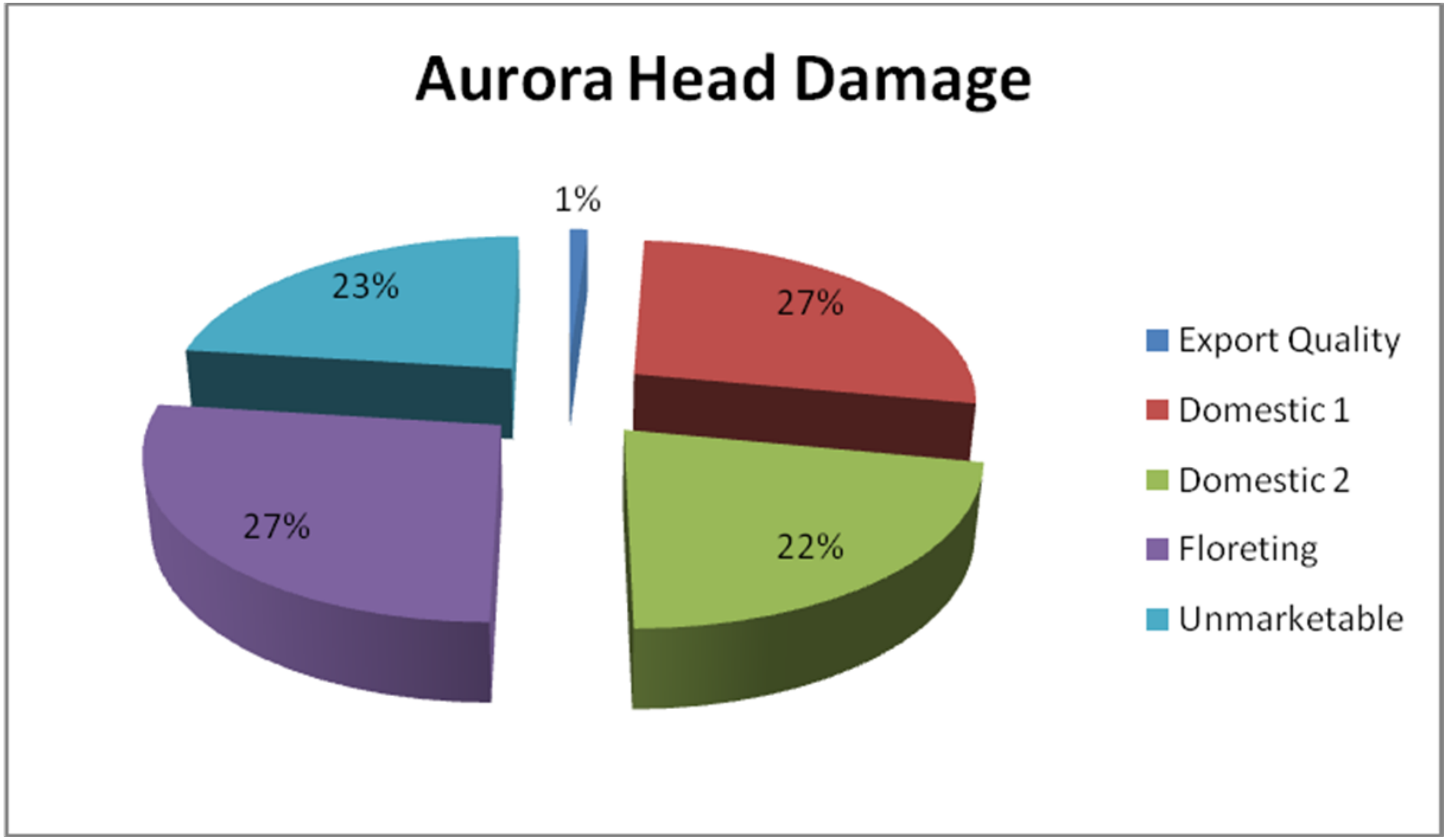
Mechanical Harvesting

Focus on assessing mechanical damage to head and stem

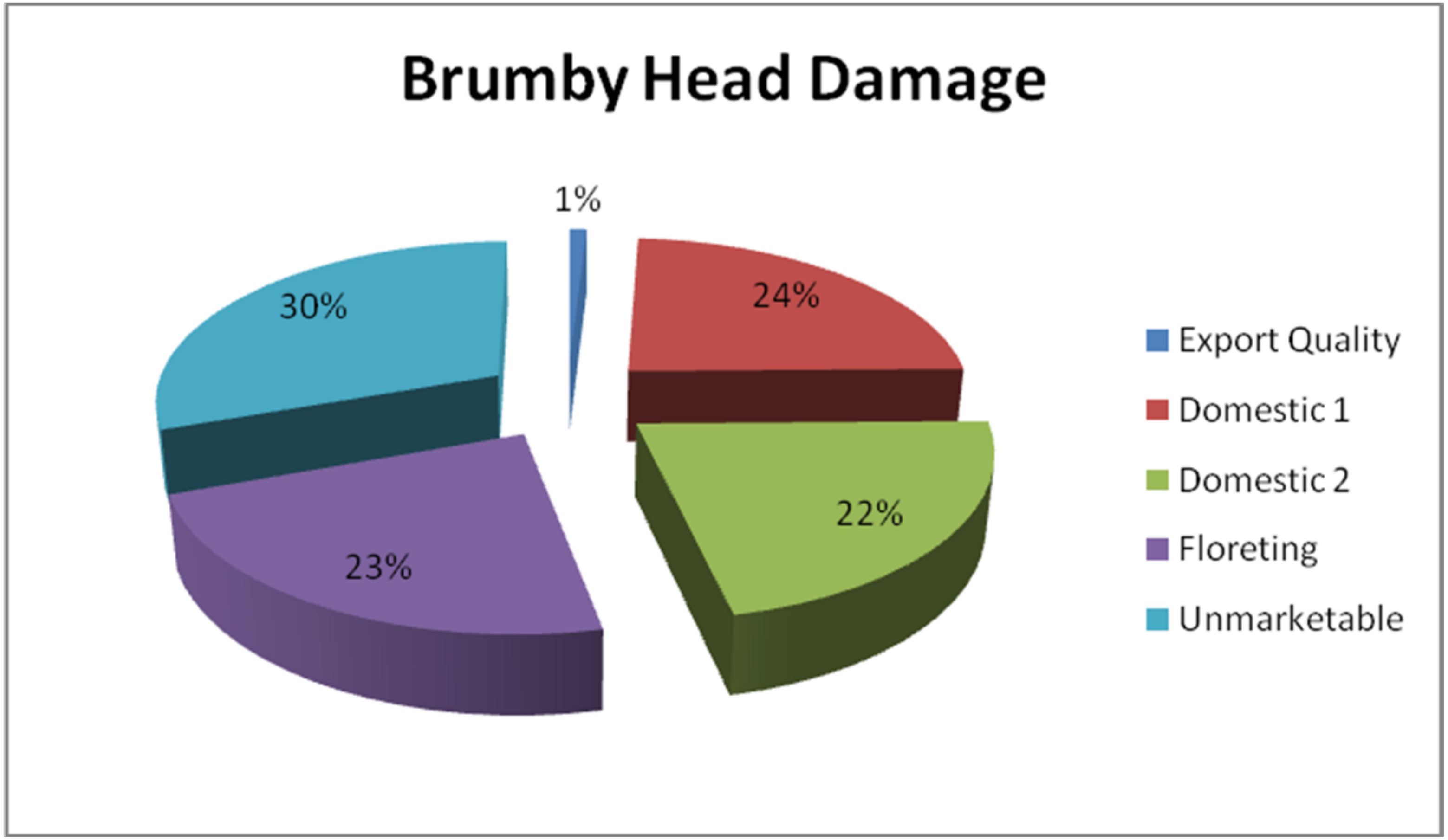
Machine Harvest Trial 1



This variety was very resistant to damage caused by mechanical harvesting. While very little product was undamaged, around 60% was still suitable for grade domestic use.

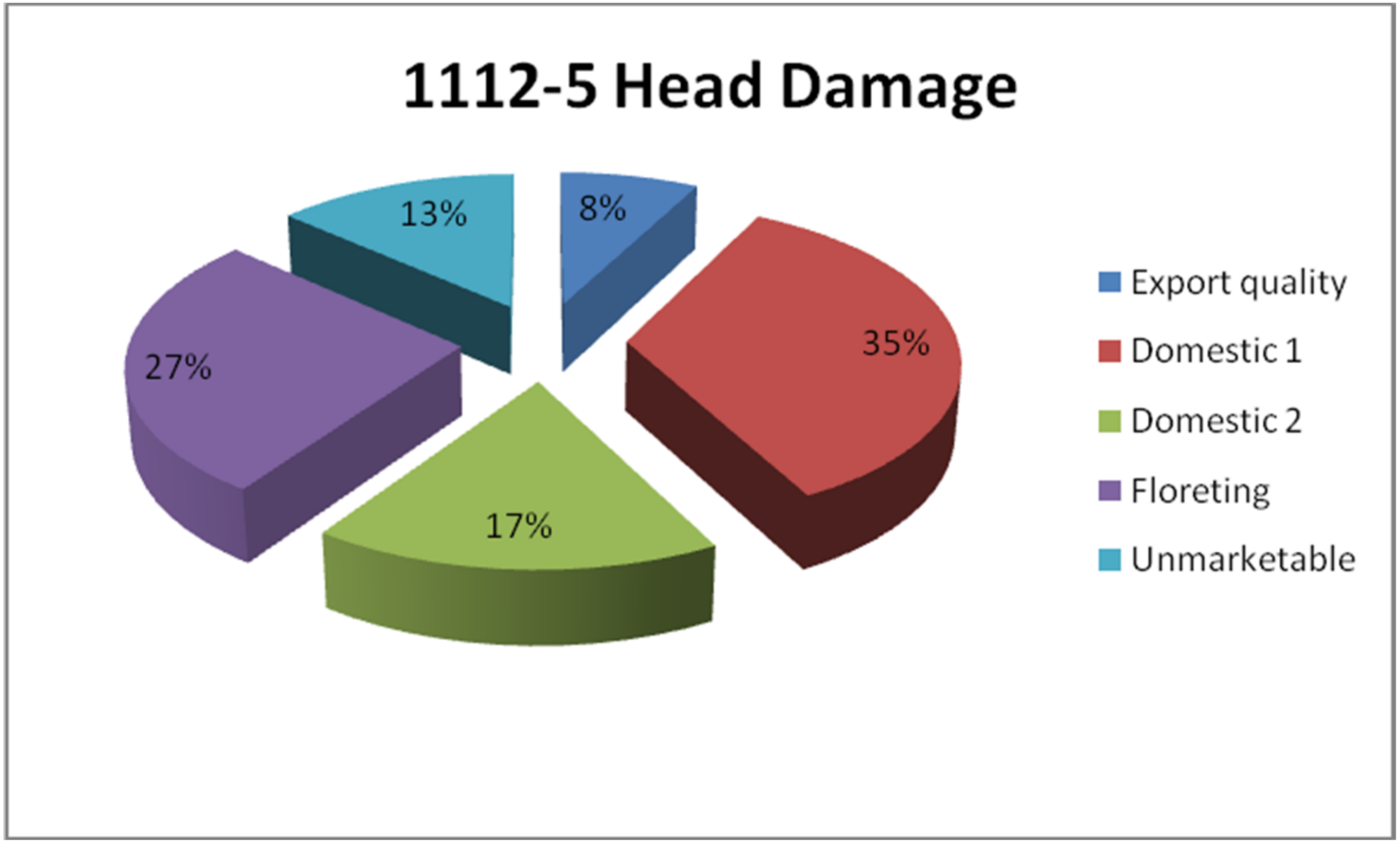


Aurora was more susceptible to damage than 494-3. Again, only 1% of heads were undamaged and 27% were suitable for domestic grade 1 product. In the case of Aurora, stem damage was more of a limitation than for 494-3

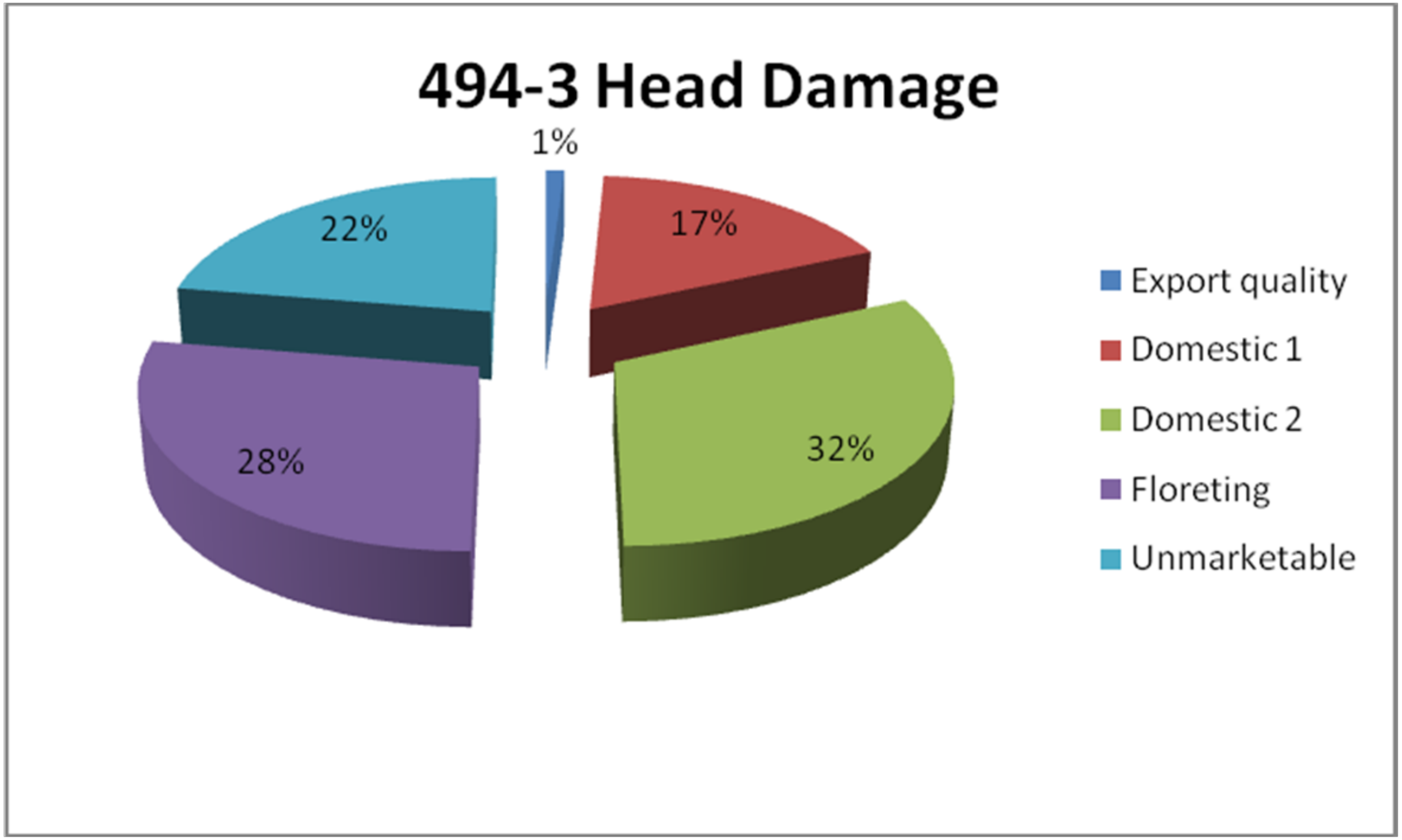


The head damage response for Brumby was similar to that for Aurora. The stems of Brumby however were more resistant to damage with 29% remaining undamaged

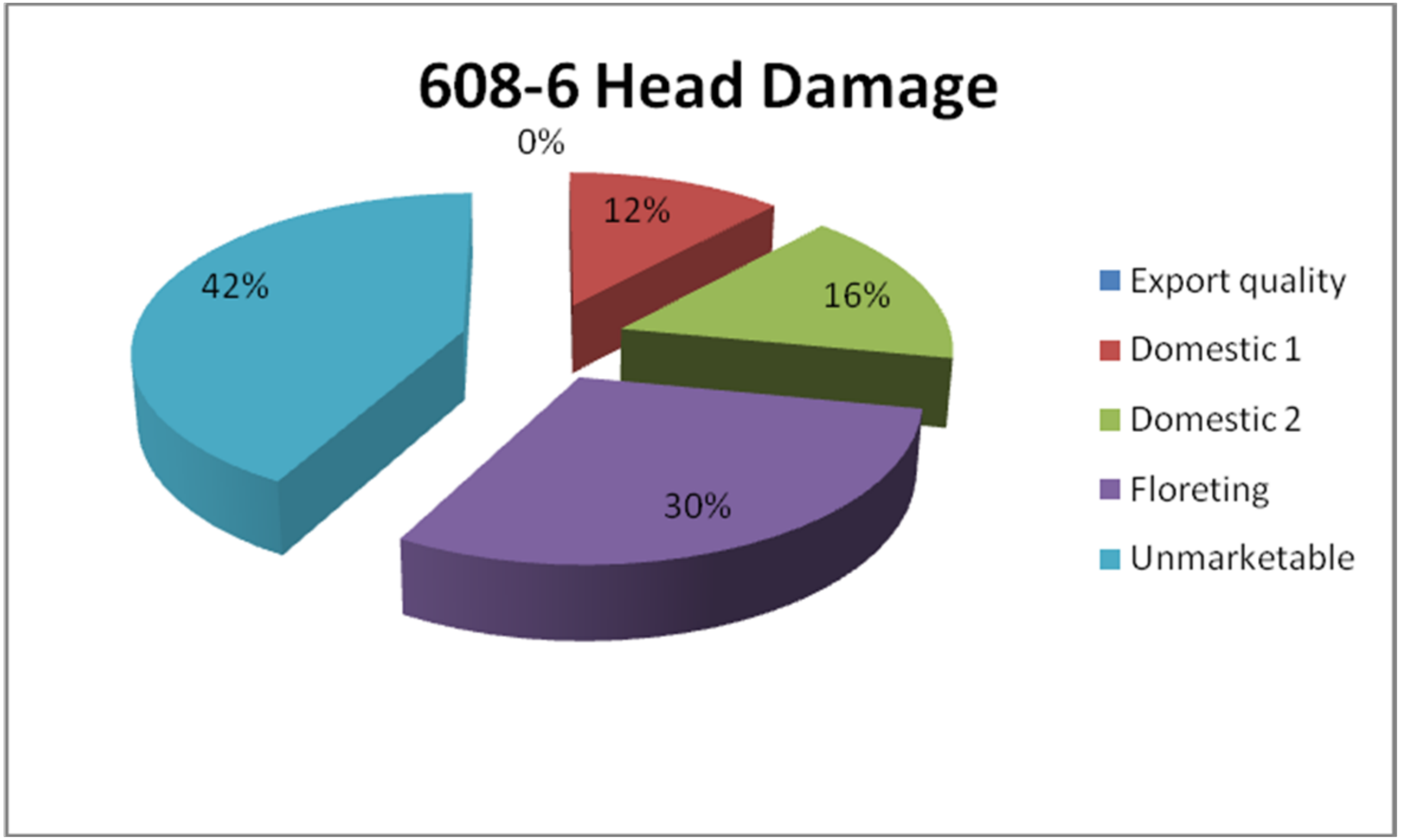
Machine Harvest Trial 2



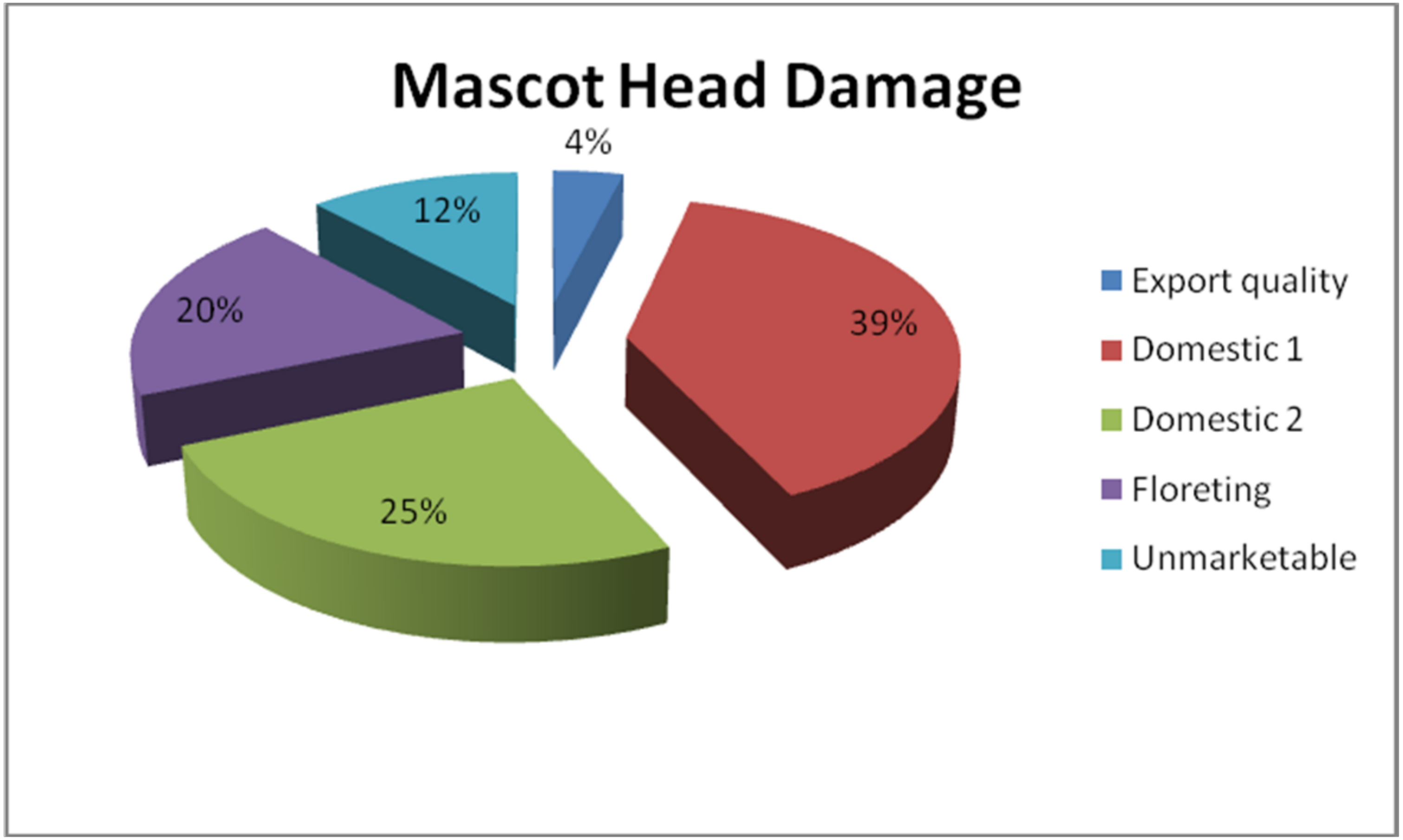
The 1112-5 head is moderately sensitive to damage from the mechanical harvester with over half heads still marketable to the fresh market. The stems however of this variety are very resistant to damage



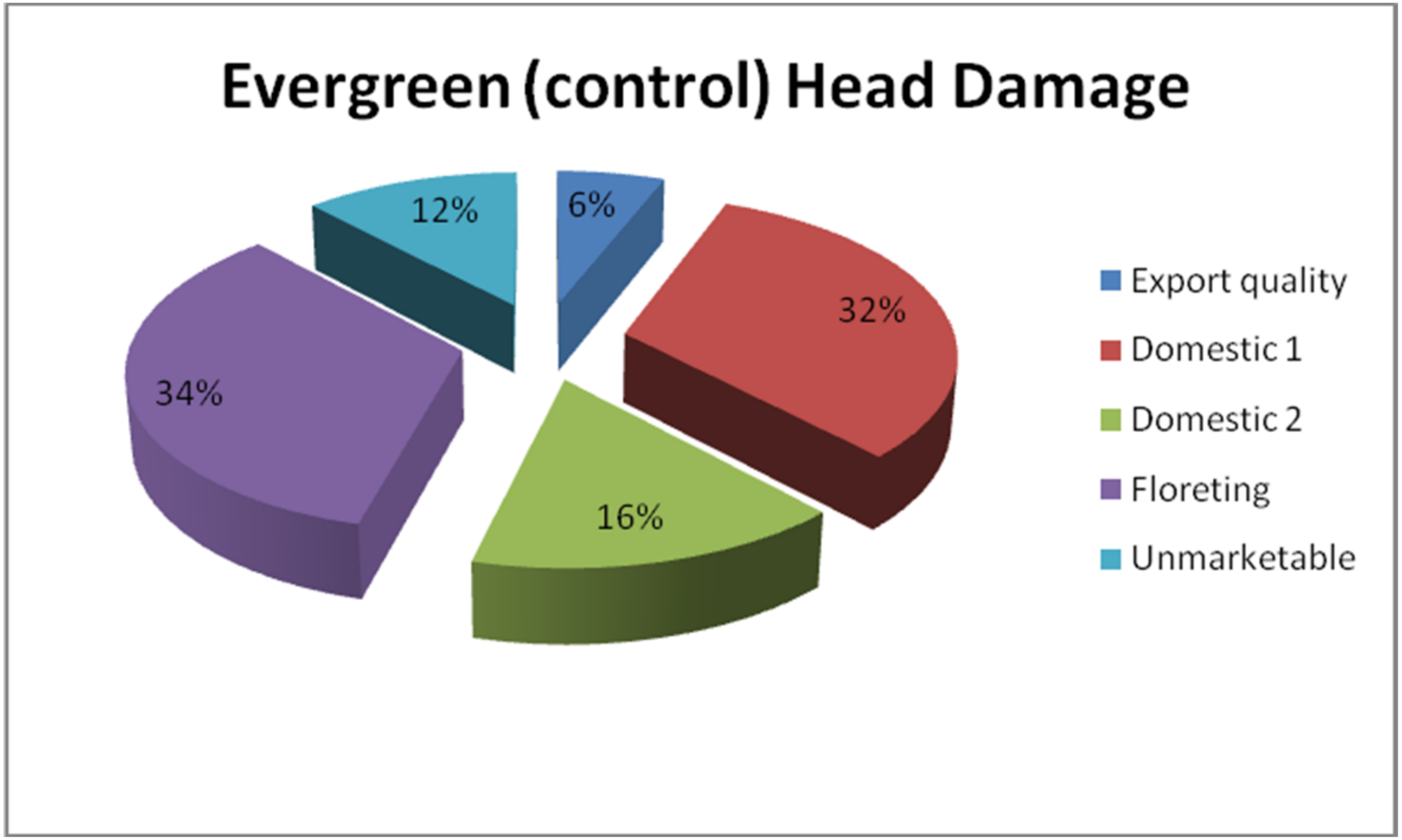
In this trial, 494-3 heads were not as resistant to damage as in the first trial. The stems however are highly resistant.



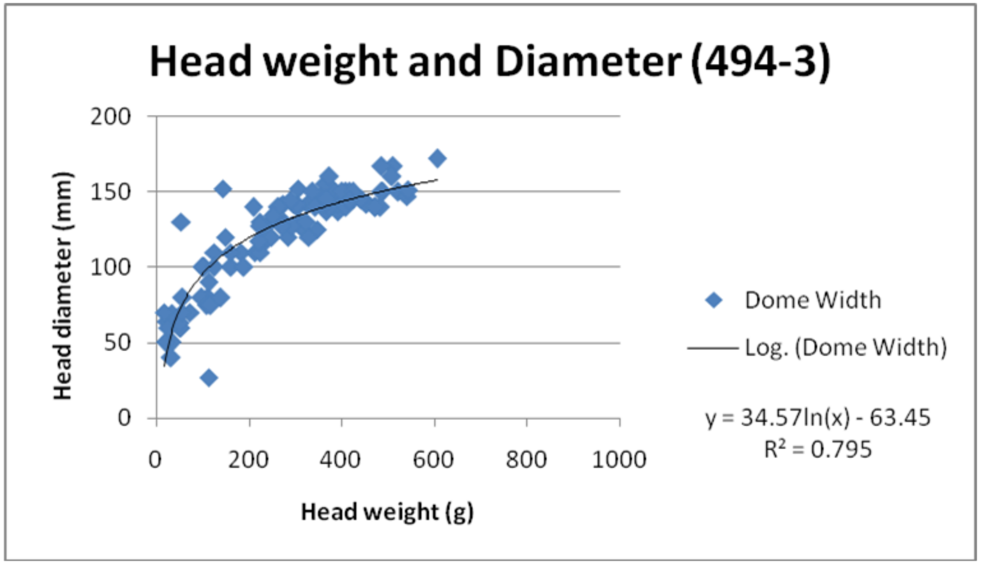
Variety 608-6 heads are highly susceptible to damage from the harvester with 72% either unmarketable or suitable for processing only.

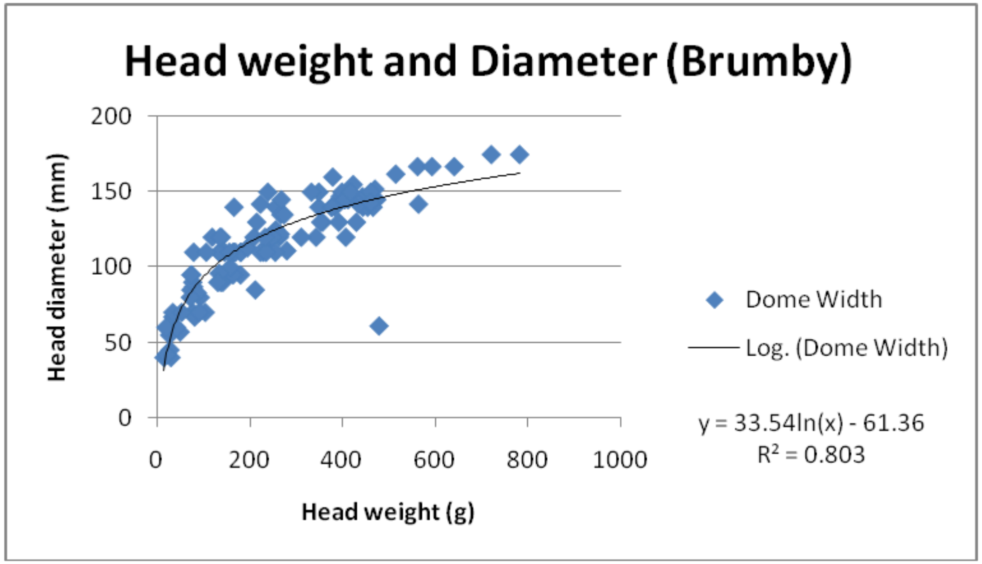


Mascot heads were moderately resistant to mechanical damage



Evergreen heads were only moderately resistant to mechanical damage, but the stems were very highly resistant. The most resistant of all the varieties tested so far.





Head wt and damage

493 had less damage than Brumby and also had a tighter grouping of head size – might affect resistance to damage.

Summary

- Row orientation has a significant effect
- Density affects head size but not uniformity. May be important in mechanical damage
- Seed encrusting not helpful, and direct seeding may be better than t/p for main crop
- Medium density minimises row effect
- Variety 494-3 best for row effect (mascot and atomic OK) also least variability overall
- Variability *declines strongly* over the season
- 494-3 showed least mechanical damage

Next Trials

- Variety assessments over 3 sites
- Some new genetics
- Irrigation (trickle and overhead sprinkler)
- Nutrient survey
- Planting depth
- Postharvest
- Discuss