Project Number:	SF 137
Project Title:	Timing of nitrogen applications to optimise growth and yield without adversely affecting fruit storability and frost sensitivity
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DISCLAIMER

The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

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GROWER SUMMARY

Headline

The rate of nitrogen applied to pot grown blueberries significantly altered growth and yield but hand no effect on fruit size or quality.

Background and expected deliverables

The blueberry crop is relatively new to the U.K. with most crops currently grown in pots. There is a need for data on the nutrition requirements of pot grown blueberries. The U.K. is unique in its reliance on pot grown systems for blueberries and so to date, research elsewhere has generally been conducted on field grown crops.

To maximise yield of blueberry bushes, optimum growth in pots is required, with larger bushes offering significantly greater yield potential. Nitrogen application is important to encourage growth but is not without potential problems. During fruiting, high nitrogen application has been shown to reduce fruit firmness in a number of crops and may reduce blueberry storage life. Commercial experience has shown that damage to branches and developing flowers caused by frosts during autumn and winter can have deleterious effects on yield, and late nitrogen applications seem likely to increase sensitivity to frost. Excessive nitrogen applications at the time of autumn flower initiation have the potential to reduce flower number. Each of these effects will have a considerable influence on yields. This project will address these issues by testing the effect of three constant levels of nitrogen during the first six months of the project. Then, over the following three seasons, the effects of increasing or decreasing nitrogen levels during three critical phases of growth: early spring growth, fruiting and autumn flower initiation will be tested.

This work could lead to a number of commercial benefits:

- Pot grown plants are more sensitive to changes in the nutrients applied through the irrigation system and so this presents growers with an opportunity to manipulate nutrient balance to improve production.

- An understanding of the role of nitrogen at specific times of the year to promote growth of blueberries would allow the targeting of nitrogen applications where they would have most benefit.

- Determining how or whether nitrogen can be applied prior to fruiting without reducing storability, will inform those aiming to extend the storage season of blueberries.

- Yield losses due to frost damage are not sustainable and so a method of reducing the risk of frost damage is needed.

Summary of the project and main conclusions

During 2012, the first year of the project, three constant concentrations of nitrogen were applied to a subset of plants of both Duke and Aurora in a randomized block design. Nitrogen was applied at 60, 120 and 180mg/L using dosatrons to achieve the desired treatments. Nitrogen level significantly affected growth of plants with higher nitrogen levels causing greater growth. Higher nitrogen levels decreased yield. Leaf, feed and compost analysis confirmed differences in applied nitrogen did influence nitrogen uptake. However, there were no significant effects on fruit size or fruit quality including fruit ^{o}brix, size and storability.

The second part of the project aims to determine the effect of raising and lowering nitrogen concentration at specific growth stages during the season – autumn flower initiation (August to October), spring growth and flowering (April to May), and fruiting (June to August). During autumn 2012, the first treatment was applied where separate plants were transferred from 120mg/L N to both 60mg/L N and 180mg/L N. Whilst the higher nitrogen concentration did cause slightly more growth, this difference was not significant.

The project continues for another three seasons and during 2013, the effect of spring and summer nitrogen treatments will be determined.

Financial benefits

The project is only in its first year and definite conclusions on the effect of treatments on yield and fruit quality can only be made following further experimental work.

Action points for growers

At this stage in the project there are no specific action points for growers as further evidence of the effects seen is needed.

SCIENCE SECTION

Introduction

The blueberry crop is relatively new to the U.K. and with most grown in pots, there is a need for data on the nutrition requirements of blueberry plants. The U.K. is unique in its reliance on pot grown systems for blueberries primarily. Growers in the U.K. favour soilless substrates because of the problems associated with soil type and pH and the problem of controlling vine weevil in the soil. The bushes are generally fed using drip irrigation with a specific blueberry feed which can be manipulated throughout the year to a much greater extent than in soil grown plantings. This gives the grower an opportunity to alter the nutrient balance depending on growth stage.

U.K. production of blueberries has expanded in recent years with the focus on early forced production of varieties such as Duke and late production with varieties such as Aurora. CA storage of blueberries has been used to extend the season further but this requires quality, firm fruit to enable storage for a sufficient duration. There are reports in a number of crops where excessive nitrogen has been shown to adversely affect fruit quality. In cranberries, the effect was to increase fruit rots from 5 to 10% (Davenport, 1996). In apples, excessive nitrogen applications can result in reductions in storage life, possibly through effects on fruit cell wall development or effects on fruit respiration rate (Fallahi *et al*., 1997). In strawberry, fruit firmness during storage was reduced by higher nitrogen applications which also reduced fruit total soluble solids concentrations (Mukkun *et al*., 2001). Nitrogen level is an important factor in determining fruit quality and storage but is also required to encourage growth and so an application strategy is therefore required which optimises growth without adversely affecting fruit storage.

Maximising the yield of blueberry requires early growth to produce larger bushes with a greater yield potential. One way of achieving this would be to apply high levels of nitrogen to the bushes throughout the year. A number of studies have identified the beneficial effect of the ammonium form of nitrogen over nitrate nitrogen. However, there are reports where a balance of these forms of nitrogen is recommended (Hanson, 2006). Townsend (1967) compared a combination of ammonium N and nitrate N with nitrogen applied only in the form of nitrate or ammonium. Where nitrate N only was used, the root development was adversely affected and growth was reduced. However, there was no significant difference between the growth of bushes given combination of ammonium N and nitrate N or the application of ammonium N alone. Similarly, Rosen *et al*. (1990) found growth was most vigorous in blueberry shoots and roots when nitrogen was applied as a combination of both nitrate and ammonium forms even though leaf nitrogen was greatest when only ammonium nitrogen was applied. Tamada (2004) found growth was increased when nitrogen was supplied in the form of NH_4SO_4 and NH_4NO_3 but where nitrogen was applied only in the nitrate form, growth was adversely affected. It seems that there is a general consensus in the literature that applying nitrogen only in the nitrate form is detrimental to growth. There are a number of reports which suggest a combination of nitrate-N and ammonium–N has either similar effects to or is better than applying nitrogen only in the ammonium form. In the project described here, a combination of potassium nitrate, monoammonium phosphate and ammonium sulphate were used to achieve a ratio of 70% ammonium N and 30% nitrate N.

So it is clear that nitrogen does increase growth in blueberries when applied either as ammonium or as a combination of ammonium and nitrate nitrogen. It is less clear though what the effect is on yield. Whilst Kozinski (2006) found excess application of nitrogen did reduce yield, as this experiment was run using soil-grown crops, it is not clear how this would apply in pot grown plants. It is also not clear whether the decrease in yield was because flower initiation was adversely affected or whether growth was excessive creating competition for assimilates. Flower initiation occurs during the autumn under conditions of shortening photoperiods (Hall and Ludwig, 1961). At this time then, a greater application of nitrogen could influence flower bud formation such that yield was then affected the following year adding a further complication to analyzing such data.

Plant dormancy is also induced during the autumn in preparation for the onset of winter and this is connected to cold hardiness. In a number of soft fruit crops, autumn nitrogen applications have been shown to reduce frost hardiness (Palonen and Buszard, 1997). In blueberry, once cropping is complete, growers tend to try and maximise growth during the autumn to improve yield in the following year. Application of nitrogen during this period could result in a lowering of cold hardiness. For this reason, nitrogen fertilization usually ceases in autumn.

In principle, therefore a higher nitrogen level would favour growth and would result in a larger bush size with a potentially higher yield. However, commercial experience of excessive growth causing detrimental effects on fruit quality, bud break and frost damage mean an optimum level is yet to be established and there are a number of feed programmes being recommended to growers. Clarification of the optimum level of nitrogen is required. If excessive nitrogen does have these negative effects, it would be useful to know whether there are particular periods during the year when nitrogen can be manipulated to increase growth without the plants suffering damage in other ways.

To maximise yield of blueberry bushes, optimum growth is required, with larger bushes having significantly greater yield potential. This requires the accurate application of nitrogen to encourage growth without inducing other associated potential problems. For example, during fruiting, high nitrogen application has been shown to reduce fruit firmness in a number of crops and may reduce blueberry shelf and storage life. Commercial experience has shown that frosts during autumn and winter can have significant effects on yield. Late nitrogen applications seem likely to increase sensitivity to frost. Excessive nitrogen applications at the time of autumn flower initiation have the potential to reduce flower number. Each of these effects could have a considerable influence on yields.

This project will address these issues firstly by testing the effect of three constant levels of nitrogen during the first six months of the project. Then, over the following three seasons, the effects of increasing or decreasing nitrogen levels during three critical phases of growth will be tested. The growth phases include early spring growth, fruiting and autumn flower initiation. Growth, yield and fruit development will be recorded in a number of ways to monitor the effect of these treatments.

The overall aim of the project will be to develop a strategy for applying nitrogen which achieves maximum growth without negative effects on fruit quality, storability, flower initiation and frost sensitivity.

Materials and methods

This project started in April 2012 to address two objectives:

1. Testing the effect of three constant nitrogen levels on growth and yield
2. Examining the effect of timing the increasing and decreasing of nitrogen feed levels during three phases of growth: early spring growth, fruiting and autumn flower initiation.

The project is being run at Brogdale Farm, Faversham, Kent. Three year old blueberry bushes of the varieties Duke and Aurora were sourced from Hall Hunter Partnership (HHP) in 25L pots on 6th March 2012. Duke was sourced from Heathlands Farm, Wokingham and Aurora was sourced from Tuesley Farm, Milford. Prior to being loaded for delivery, plants were selected for uniformity using a standard system. For Duke the plants required three to five main structural branches and for Aurora, plants with two to three main structural branches were selected.

On arrival at Brogdale, the pots of the variety Duke were placed on black Mypex floor covering in a Spanish Tunnel. The tunnel was covered from bud break until the end of cropping at which point the plastic was removed. The Aurora pots were placed outside on black Mypex floor covering in line with commercial practice.

Objective 1 - March 2012 - October 2012: The effect of constant nitrogen concentrations throughout the year

Three feed solutions were supplied to plants with 60ppm N, 120ppm N, 180ppm N from March to October 2012. 42 plants of each variety were arranged in a randomised block design with six plots per treatment and seven plants per plot. Irrigation was supplied to achieve a target of 60% soil moisture whilst maintaining EC within set limits. The nitrogen was in the form of 70% ammonium nitrogen and 30% nitrate nitrogen.

Shoot lengths of tagged and labelled shoots were recorded monthly from March to October 2012 to determine whether the nitrogen treatments stimulated different levels of growth. In addition, fruit were harvested weekly and the number and the weight of fruit were recorded for each plot. Fruit ^{o}brix was recorded from 20 fruit per plot twice during the cropping period of each variety along with shelf life.

Objective 2 - October 2012 - October 2015: The effect of nitrogen applications at three specific growth stages

A separate batch of 315 plants of each variety is being used for the nitrogen timing treatments. These were sourced from HHP in March as above and were grown on at Brogdale for four months at 120ppm N from April 2012 to August 2012. At this point, on 15th August, the first treatment applications started with the application of the autumn treatments until 15th October (Treatments 5 and 6 below). Timings are based on specific growth stages although approximate timings are shown below for reference.

The plants were arranged in a randomized block design with six plots per treatment and 7 plants per plot. Three separate lines of irrigation were installed for the three nitrogen treatments to allow the plants to be plugged into the correct nitrogen treatment at the three points during the season outlined below (Figure 1):

T1. A nitrogen level of 120mg/L is applied throughout the year but raised to 180mg/L from the end of harvest until 90% leaf fall (August – October).

T2. A nitrogen level of 120mg/L is applied throughout the year but decreased to 60mg/L from the end of harvest until 90% leaf fall (August – October).

T3. A nitrogen level of 120mg/L is applied throughout the year but raised to 180mg/L from bud break until first green fruit (February – April).

T4. A nitrogen level of 120mg/L is applied throughout the year but decreased to 60mg/L from bud break until first green fruit (February – April).

T5. A nitrogen level of 120mg/L is applied throughout the year but raised to 180mg/L from first green fruit to the end of harvest (May to July).

T6. A nitrogen level of 120mg/L is applied throughout the year but decreased to 60mg/L from first green fruit to the end of harvest (May to July).

T7. A standard nitrogen concentration of 120mg/L is applied to one batch of plants throughout the year.

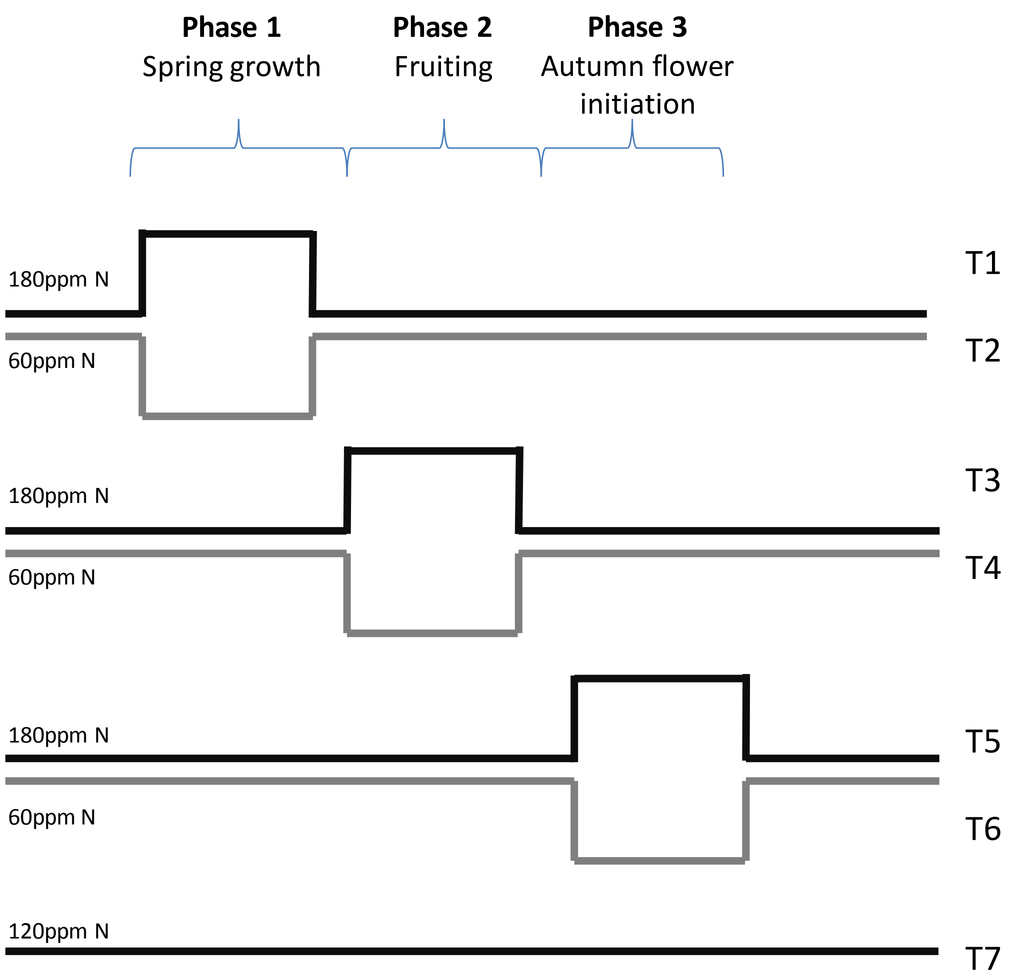

Figure 1. The treatments being applied in Objective 2 of the project

From each treatment, cropping, growth and plant nutrition will be assessed. These assessments begin in 2013 apart from the growth measurements from T5 and T6 which began in autumn 2012.

Growth Shoot growth from labelled branches will be measured at the end of each of the three nitrogen application timings at the following timings – green fruit, end cropping, 90% leaf fall.

Cropping Fruit will be harvested, counted and weighed, separated into Class I, Class II and Waste fruit to determine the effect of treatment on yield and overall fruit quality.

Storability Fruit will be placed into two cold stores – an air store at 2°C at Brogdale and assessed daily until deemed non-marketable and a CA store at Hall Hunter Partnership and assessed after 4, 6, 8 and 10 weeks. Assessments will be made as follows:

- % fruit with shrivel
- Weight loss during storage
- Fruit firmness
- Fruit collapse
- Colour
- Flavour
- Overall marketability based on commercial specifications supplied by HHP.

Flower initiation Blueberries initiate flowers from late August to November. The following spring, the percentage of floral buds will be counted and the average number of flowers per bud will be recorded.

Percentage bud break In May, the percentage of buds breaking from each treatment will be assessed.

Plant nutrition At the end of each application treatment, leaf samples will be taken and analysed for nutrient content. In addition, regular samples of irrigation input and run-off will be analysed.

Pesticide applications

For vine weevil control, three preventive applications of nematodes were made in April, August and October although no grubs were seen during the year. Calypso was applied against aphids in July.

Date	Trade name	Active ingredient	Application rate	Application regime	Approval status
27th July 2012	Calypso	Thiacloprid	250ml/ha	1 application	This product has a specific off-label approval (SOLA) for use on this crop. Outdoor – 20060335 Under protection – 20081332
1st April 2012	Nematop	*Heterorhabditis bacteriophora*	66,667 per plant	1 application	
30th August 2012	Nematop	*Heterorhabditis bacteriophora*	66,667 per plant	1 application	
31st October 2012	Nemopak S	*Steinernema feltiae*	66,667 per plant	1 application	

Statistical analysis

ANOVA has been used to determine significance of treatment effects with LSDs used to determine the significance of differences between individual treatments. The data for Duke and Aurora have been analysed separately.

Results – Objective 1

Duke - Number of fruit

The effect of nitrogen treatment on the fruit number produced per bush is shown in Figure 2. As this was the first year of cropping the fruit numbers produced per plant were generally low. However, there was a significant increase in number of fruit as the nitrogen concentration decreased with the highest number of fruit being produced by those plants in the low nitrogen treatment (P=0.022). The difference between the high and medium nitrogen treatments was not significant but the difference between these two treatments and the low nitrogen was significant at P<0.05. This difference only became apparent during the second half of the cropping period (Figure 3). As the plants all started at the same stage of growth and were supplied from the same field, the effect on fruit number must have been down to flower and fruit abortion. That the yield difference only became apparent in the second half of the cropping period suggests that it is the later flowers that are being aborted or not setting fruit.

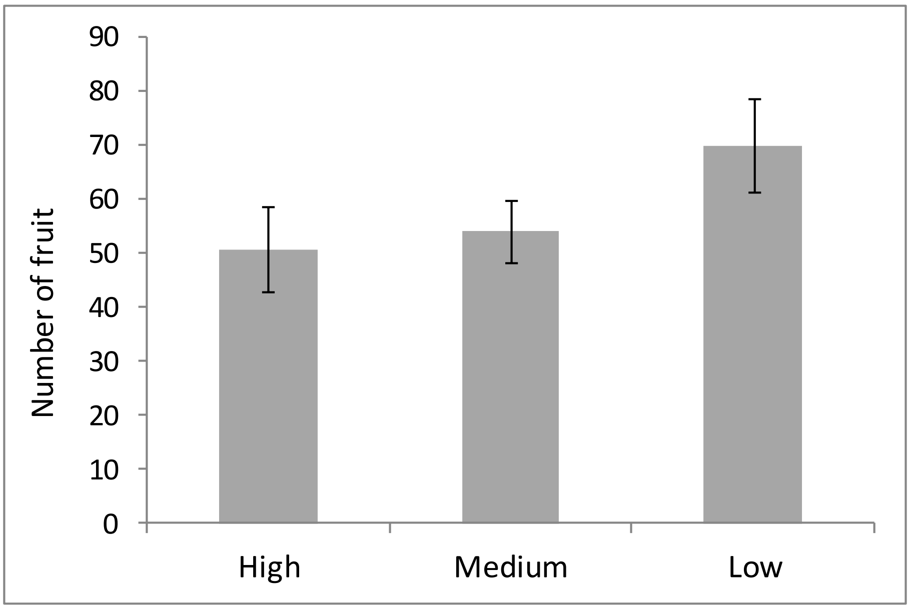

Figure 2. The effect of nitrogen treatment on the number of fruit produced by the Duke plants of the variety Duke. Standard error bars are shown.

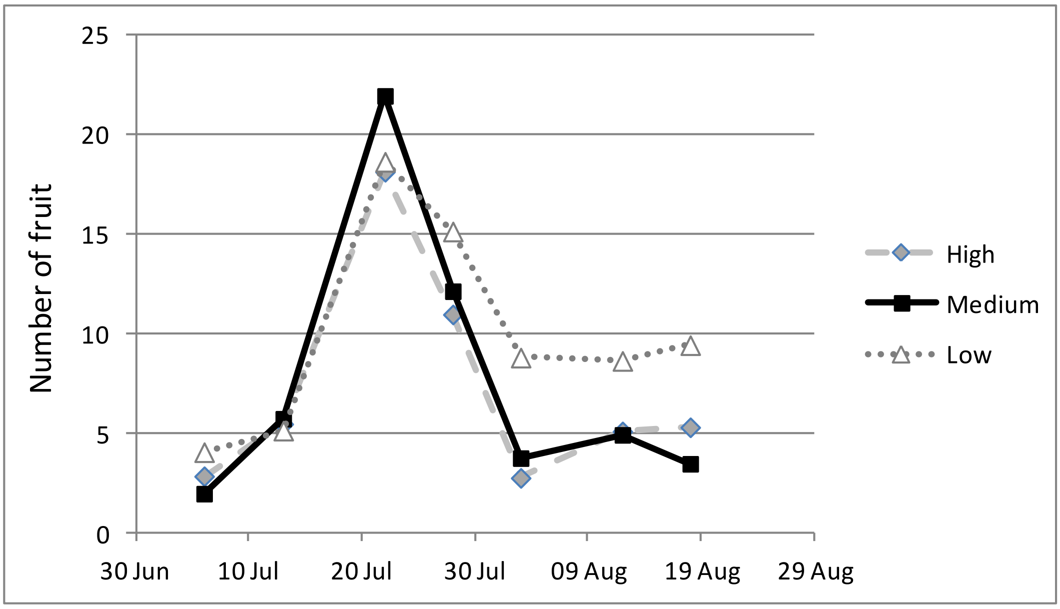

Figure 3. Cropping profile of the Duke plants in the three nitrogen treatments showing the number of fruit produced per plant at each pick over the whole cropping period.

Aurora - Number of fruit

The effect of nitrogen treatment on the fruit number produced per bush for the variety Aurora is shown in Figure 4. Whilst there was a general increase in fruit number produced per bush as nitrogen concentration increased, overall this was not significant (P=0.088). However, the individual difference between the fruit number produced by the plants in the lowest nitrogen treatment and the plants in the highest nitrogen treatment was significant. This difference equated to about 20 fruit per bush, an increase of about 60% over the plants in the high N treatment. The difference between the data for Duke and Aurora was that the Aurora plants in the low N treatment produced the greatest number of fruit over the complete cropping period rather than just in the second half of the cropping period (Figure 5). The fruit number harvested on the last pick was much greater than the penultimate pick. This was due to the fruit needing to be picked because the weather was becoming increasingly inclement as autumn temperatures lowered and rainfall increased.

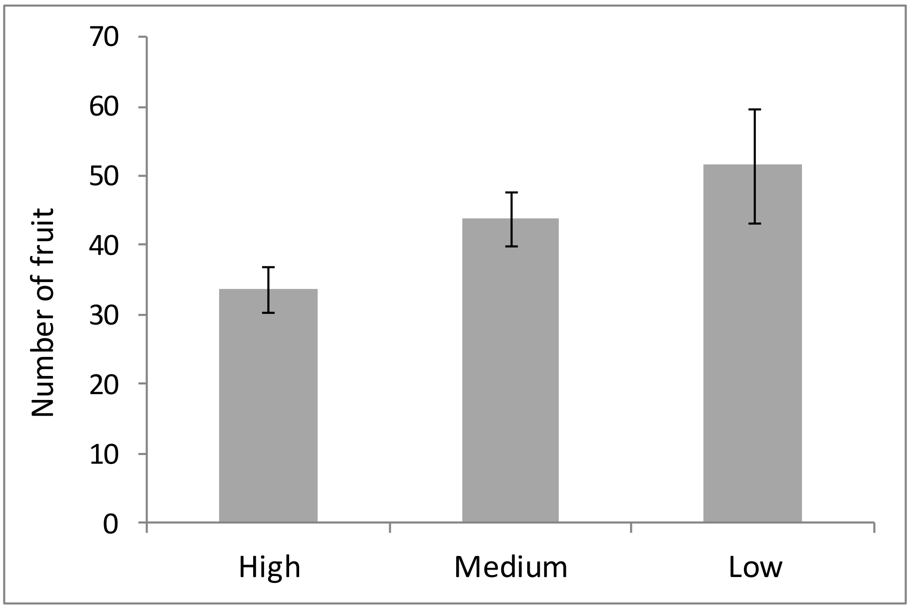

Figure 4. The effect of nitrogen treatment on the number of fruit produced by plants of the variety Aurora. Standard error bars are shown.

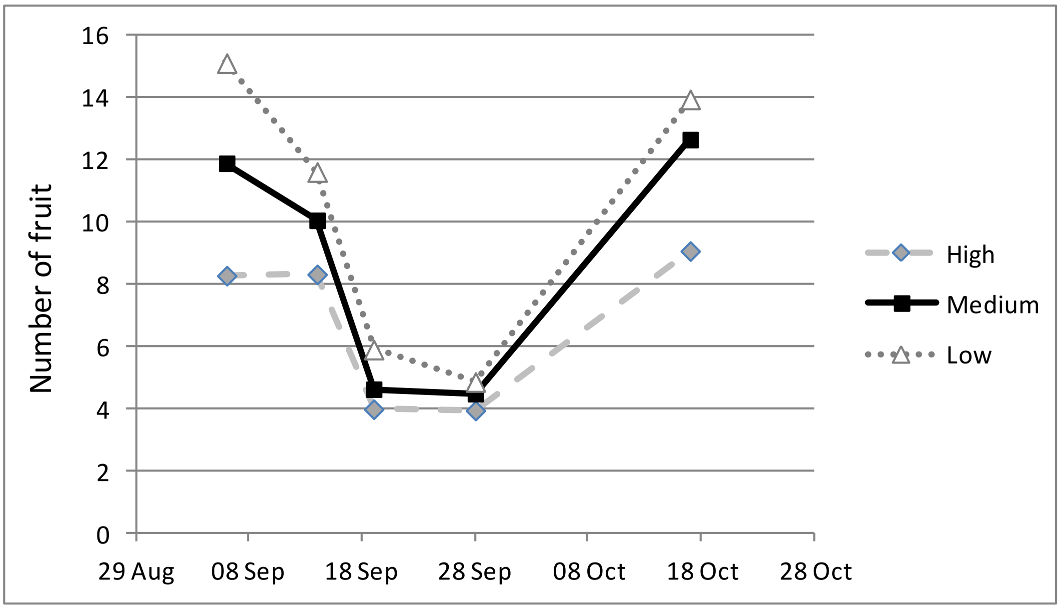

Figure 5. Cropping profile of the plants in the three nitrogen treatments showing the number of fruit produced per plant at each pick over the whole cropping period.

Duke - Yield

The effect of nitrogen treatment on yield per plant of Duke is shown below in Figures 6 and 7. There was a general increase in yield as nitrogen concentration decreased although this was not significant (P=0.23). The difference in yield between the high and low nitrogen treatments was about 20g per plant. The difference became apparent during the latter half of the cropping period following the main peak of production in July.

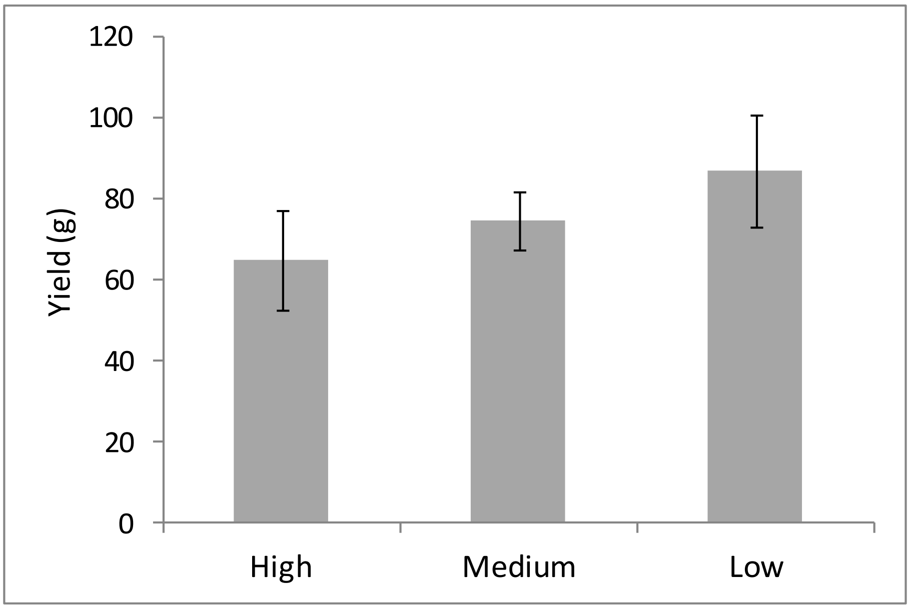

Figure 6. The effect of nitrogen treatment on the yield produced by plants of the variety Duke. Standard error bars are shown.

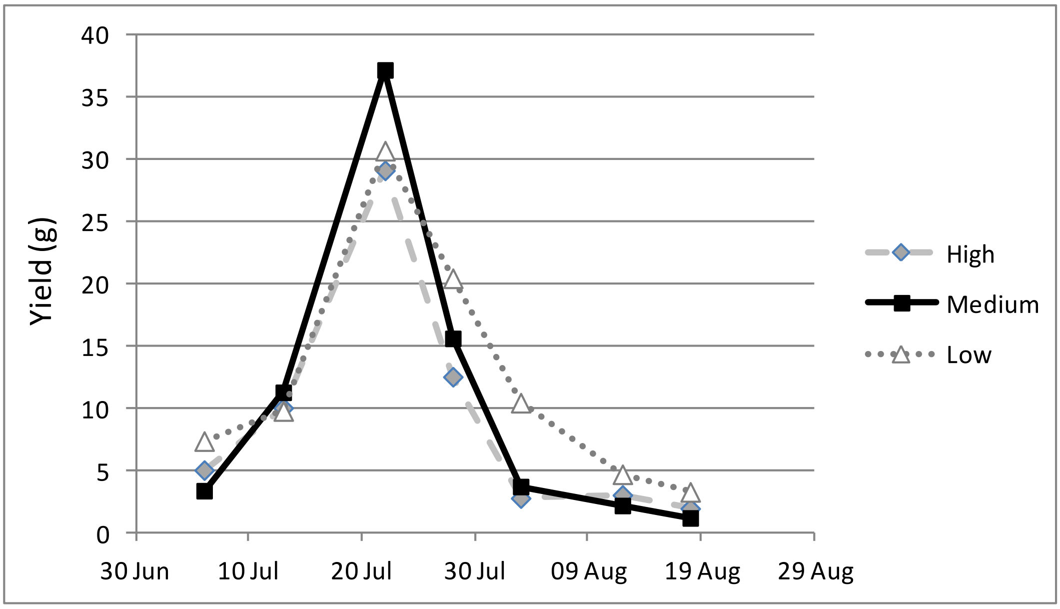

Figure 7. Cropping profile of the plants in the three nitrogen treatments showing the yield produced per plant at each pick over the whole cropping period.

Aurora - Yield

The effect of nitrogen treatment on yield per plant of Aurora is shown below in Figures 8 and 9. As for Duke, there was a general increase in yield as nitrogen concentration decreased but again the overall effect was not significant (P=0.077). However, the individual difference between the yield of plants in the low N and high N treatments was significant (P<0.05) and equated to about 25g per plant. In contrast to Duke where the difference in treatment came about during the second half of the cropping period, here the yield difference was most apparent during the first four picks.

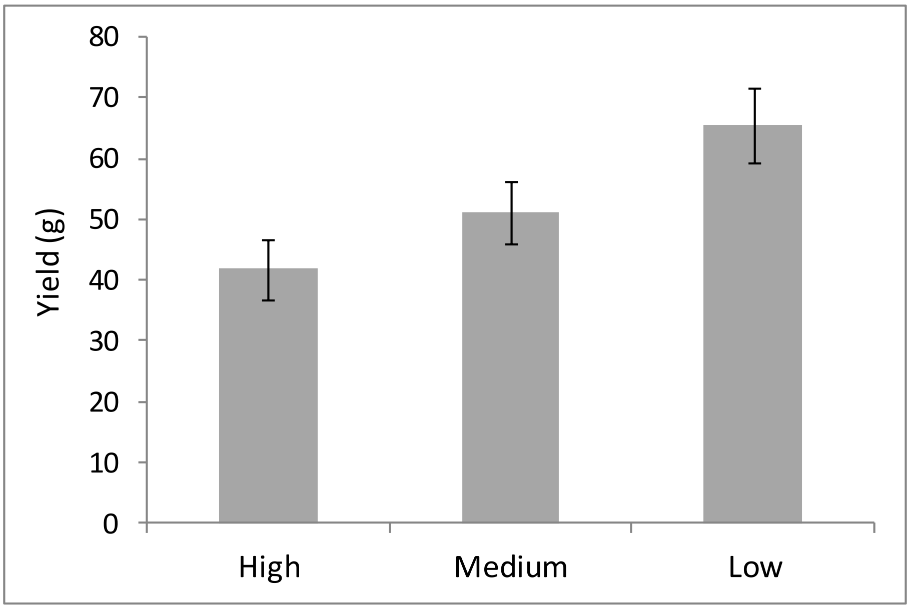

Figure 8. The effect of nitrogen treatment on the yield produced by plants of the variety Aurora. Standard error bars are shown.

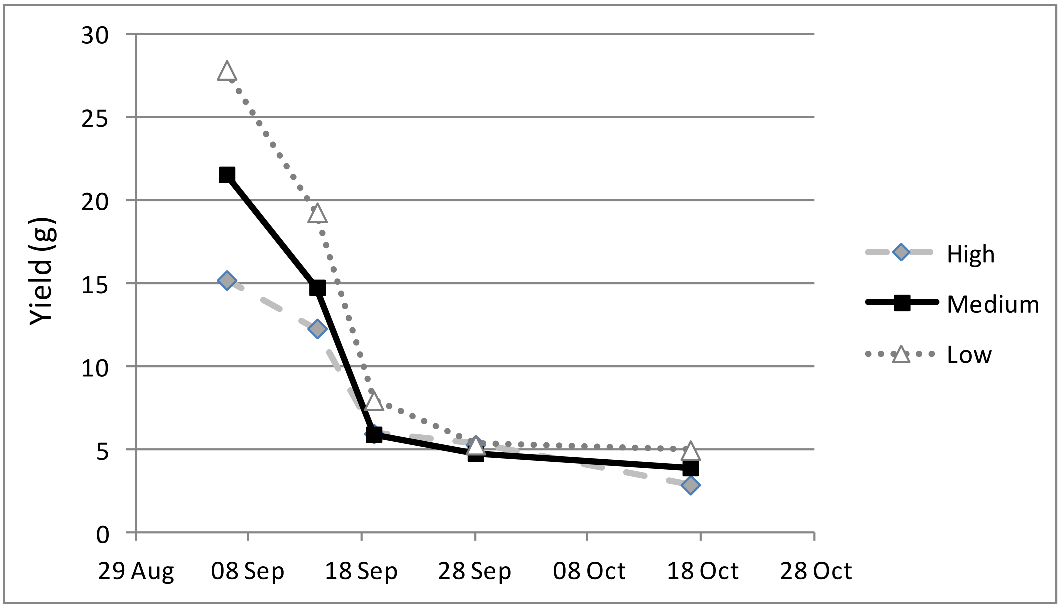

Figure 9. Cropping profile of the plants in the three nitrogen treatments showing the yield produced per plant at each pick over the whole cropping period.

Fruit size

There was no effect of treatment on fruit size for either Duke (Figures 10 and 11) or for Aurora (Figures 12 and 13). For Duke the average fruit size over the whole cropping period was between 1.2 and 1.4g and for Aurora the fruit were slightly smaller. However the fruit size declined significantly over the course of cropping falling from 2g per fruit to 0.5g for Duke and 1.8g to 0.4g for Aurora. Clearly a large part of the fruit from both varieties would have had to be graded as non-marketable based on fruit size alone but it is interesting that there was no significant effect at any point during cropping, even at the start when fruit size was at its greatest.

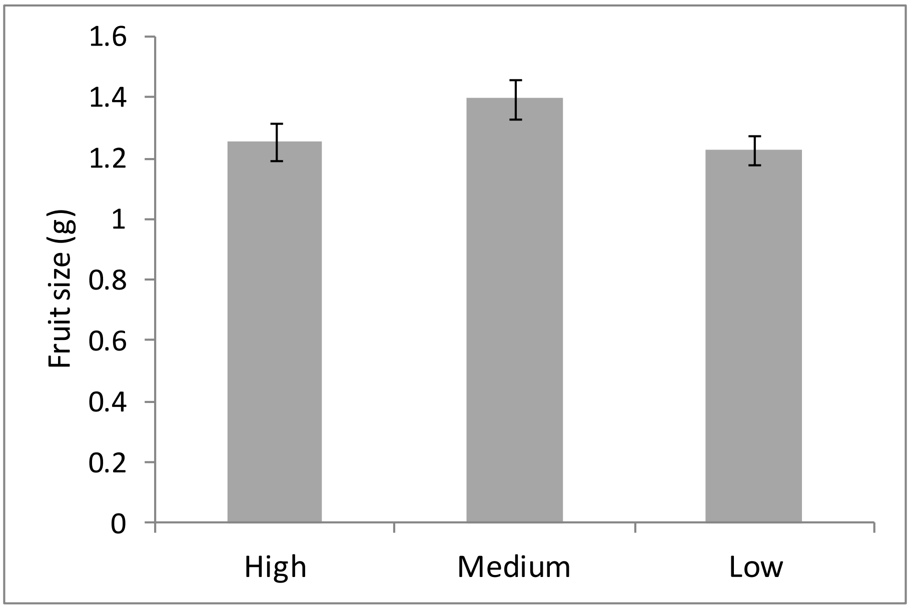

Figure 10. The effect of nitrogen treatment on the size of fruit produced by plants of the variety Duke. Standard error bars are shown.

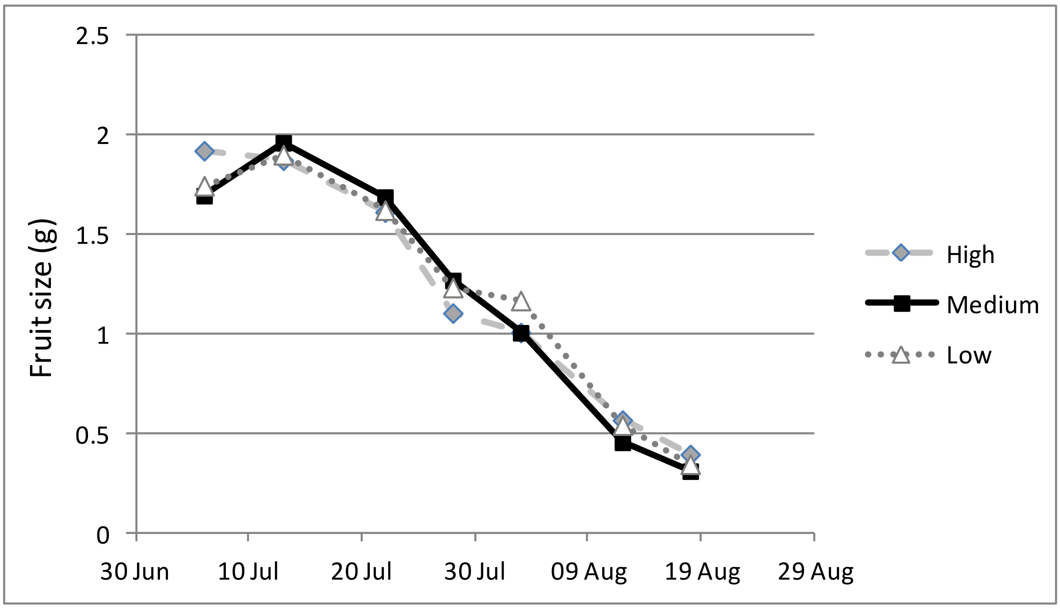

Figure 11. Fruit size of Duke over the cropping period.

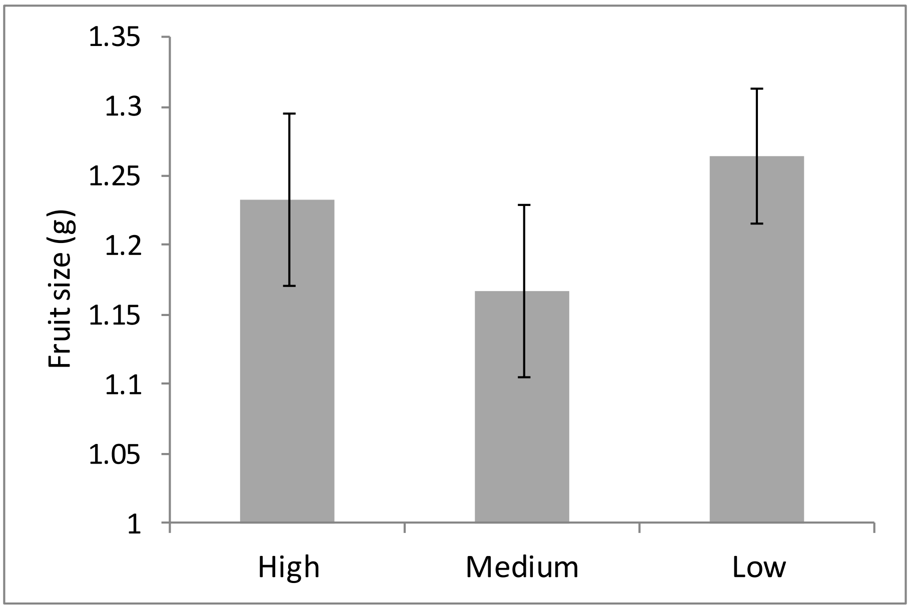

Figure 12. The effect of nitrogen treatment on the size of fruit produced by plants of the variety Aurora. Standard error bars are shown.

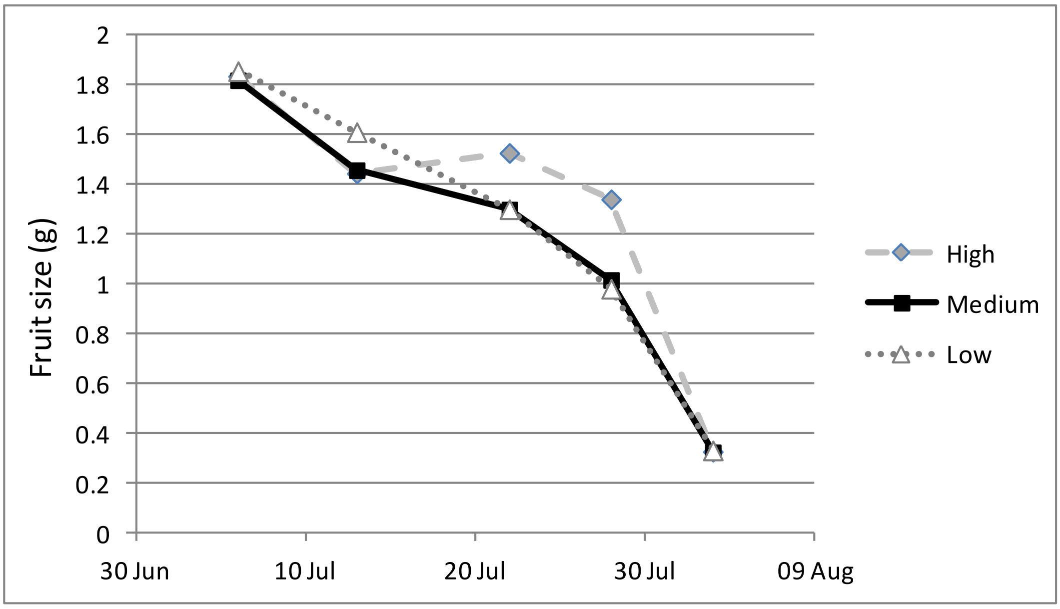

Figure 13. Fruit size of Aurora over the cropping period.

Total soluble solids

20 fruit were sampled from each plot on two dates for testing for total soluble solids for both Duke and Aurora. The average results for each variety are given in Table 1 (Duke) and Table 2 (Aurora). Whilst the effect of treatment on ^{o}brix was significant on the first sampling date for both varieties, there was no consistent effect making it difficult to draw definite conclusions.

Variety	Treatment	23rd July	28th July
Duke	High N	12.5 **a**	13.6 **a**
Duke	Med N	12.4 **a**	13.3 **a**
Duke	Low N	13.0 **b**	13.3 **a**
P-value		0.008	0.52

Table 1. The effect of treatment on fruit total soluble solids content (°brix) for Duke. Letters show significant differences between treatments and the P-value is given for each ANOVA conducted.

Variety	Treatment	6th September	14th September
Aurora	High N	11.3 **a**	11.9 **a**
Aurora	Med N	10.7 **b**	10.8 **a**
Aurora	Low N	11.0 **ab**	10.9 **a**
P-value		0.072	0.49

Table 2. The effect of treatment on fruit total soluble solids content (°brix) for Aurora. Letters show significant differences between treatments and the P-value is given for each ANOVA conducted.

Shoot Length - Duke

The shoot length was measured monthly on 9 tagged branches per pot, 216 branches per treatment, from when growth started in May to the end of the growing season in October (Figure 14). The shoots tagged were the three uppermost buds on the existing second year wood. As the buds expanded and the shoots increased in length, they were measured monthly. There was no significant effect on the growth of shoots which in all treatments increased from an average of 50mm to 350mm over the course of the measuring period.

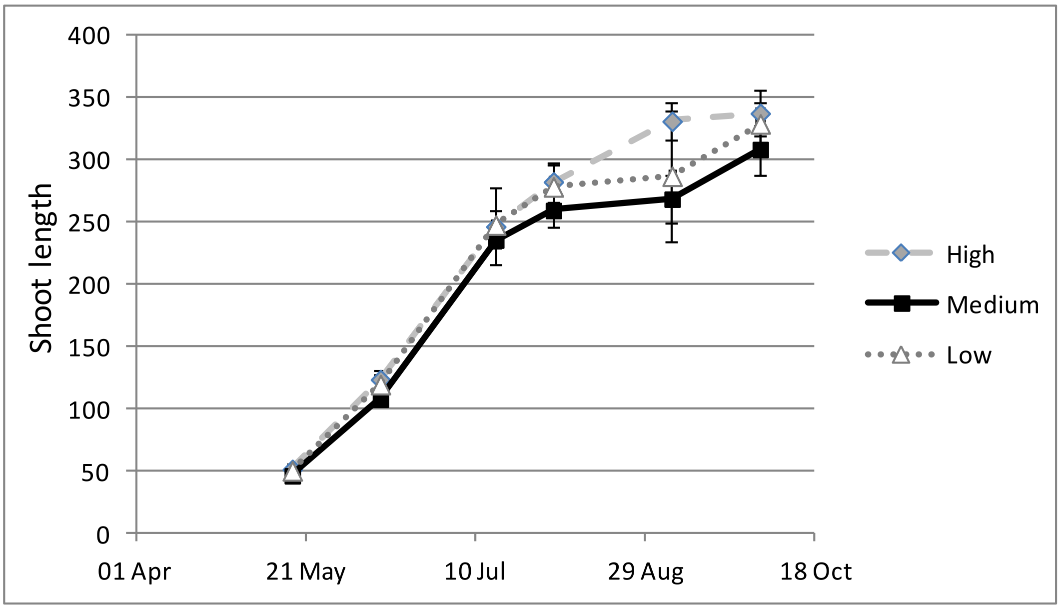

Figure 14. Growth in length of tagged and labelled shoots of Duke from when the buds started to develop to the end of the growing season in October. Standard error bars are shown for each measuring date.

Shoot Length - Aurora

Shoots of Aurora were tagged slightly later because the plants were not in a Spanish tunnel and so started growing later (Figure 15). For Aurora, the shoots that were tagged were those emerging from the base of the plant, different to the Duke because when measurements of Duke started, these shoots were not present. In this case there was a significant effect of nitrogen concentration on shoot growth. As nitrogen increased the shoot growth also increased. Clearly the different shoots responded differently to the nitrogen treatments and in future, only shoots emerging from the base of the plants will be measured. Growth of the shoots of Duke slowed in August but not in Aurora. This was due to the tunnel being removed from over the Duke plants following the end of picking, in line with commercial practice. The removal of the tunnel reduced temperatures and so as a result the growth of shoots slowed. In Aurora the plants were outside throughout the season and so the plants didn't experience any sudden change in temperature.

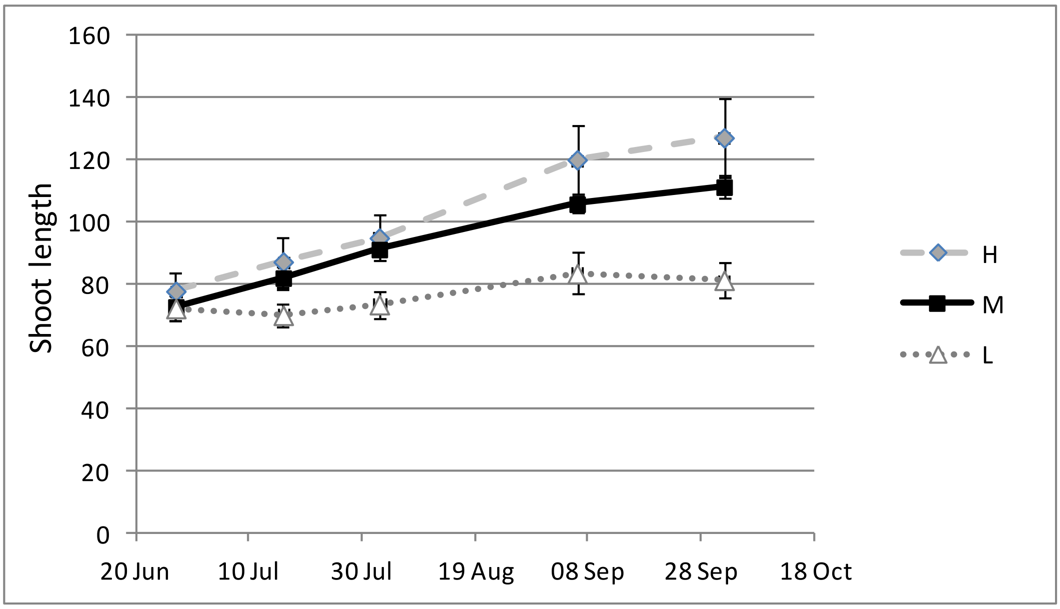

Figure 15. Growth in length of tagged and labelled shoots of Aurora from when the buds started to develop to the end of the growing season in October. Standard error bars are shown for each measuring date.

Fruit storability

The effect of nitrogen treatment on the storage life of fruit was tested on four occasions for both varieties. Fruit was harvested and then placed in an air cold store at 2^{o}C and assessed weekly for three weeks. Fruit was deemed to be either marketable or non-marketable based on the percentage of fruit showing signs of wrinkles or *Botrytis* (Figures 16 and 17). There was very little *Botrytis* in the samples. The reason fruit was generally downgraded was the presence of wrinkles and the assessments were necessarily strict to overcome potential issues with partiality of assessments. For Duke, there was around 40% of fruit which was considered non-marketable two weeks after the first pick. This percentage generally increased until after the last pick when there was around 80% non-marketable fruit. The effect of nitrogen treatment was not significant although in each assessment, it was the low nitrogen treatment which caused the highest percentage of non-marketable fruit.

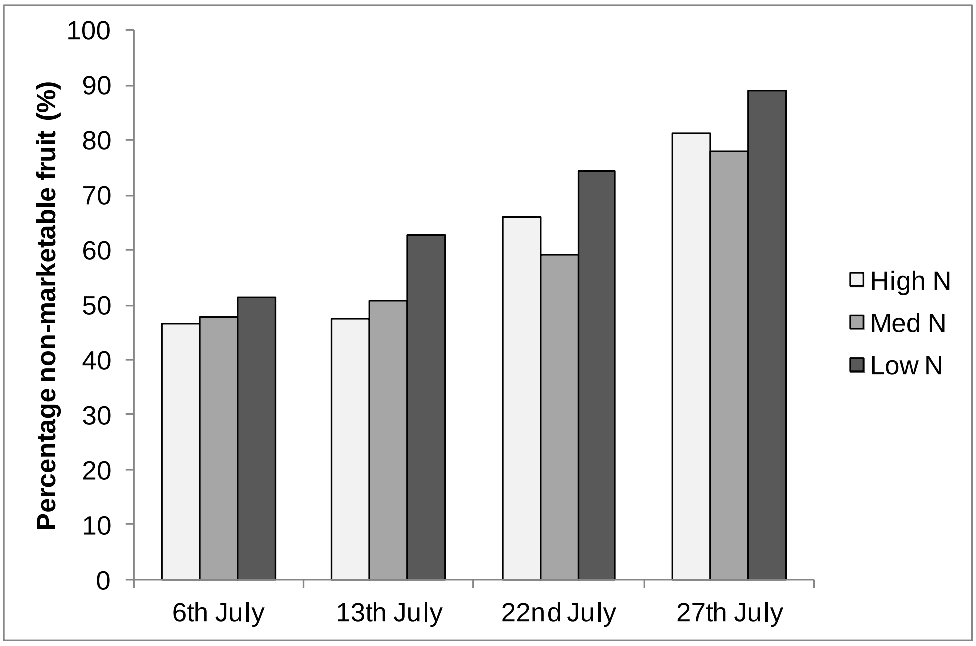

Figure 16. The percentage non-marketable fruit for Duke following two weeks of air storage at 2^{o}C for fruit harvested on the dates shown (P=0.28).

For Aurora, the percentage non-marketable fruit varied between pick dates and on assessments carried out. On three out of the four harvest dates there was most non-marketable fruit in the low nitrogen treatment. However, once again the effect of nitrogen treatment was not significant. As part of Objective 2 in 2013, further tests will be conducted both in air and in CA storage.

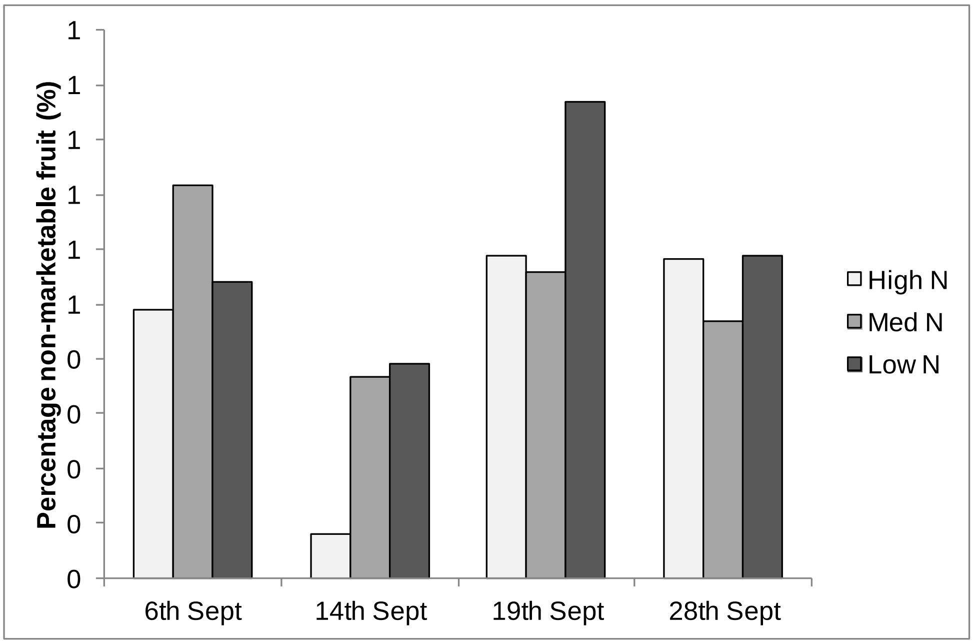

Figure 17. The percentage non-marketable fruit for Aurora following two weeks of air storage at 2^{o}C for fruit harvested on the dates shown (P=0.39).

Feed analysis

The input feed was analysed monthly from May to September to monitor the level of nitrogen being applied in the three treatments (Figure 18 - Duke and Figure 20 - Aurora). The runoff collected on the same day was also analysed to give the total nitrogen output from each treatment (Figure 19 - Duke and Figure 21 - Aurora). There were clear differences between the treatments in the concentration of nitrogen being applied. The aim was to achieve 60mg/L in the low N treatment, 120mg/L in the medium N treatment and 180mg/L in the high N treatment. It needs to be noted that whilst these were not met, there was a consistent and considerable difference in the nitrogen applied between the three treatments. The variation is essentially caused by using dosatrons to apply feed which can result in differences from day to day. The output (runoff) analysis followed a very similar pattern whereby the low N treatment had essentially used almost all nitrogen in the feed, with medium N and high N following the expected pattern. That there were clear differences between the treatments in both input N and output N is important as this is the reason for the effects on growth and yield seen and described above.

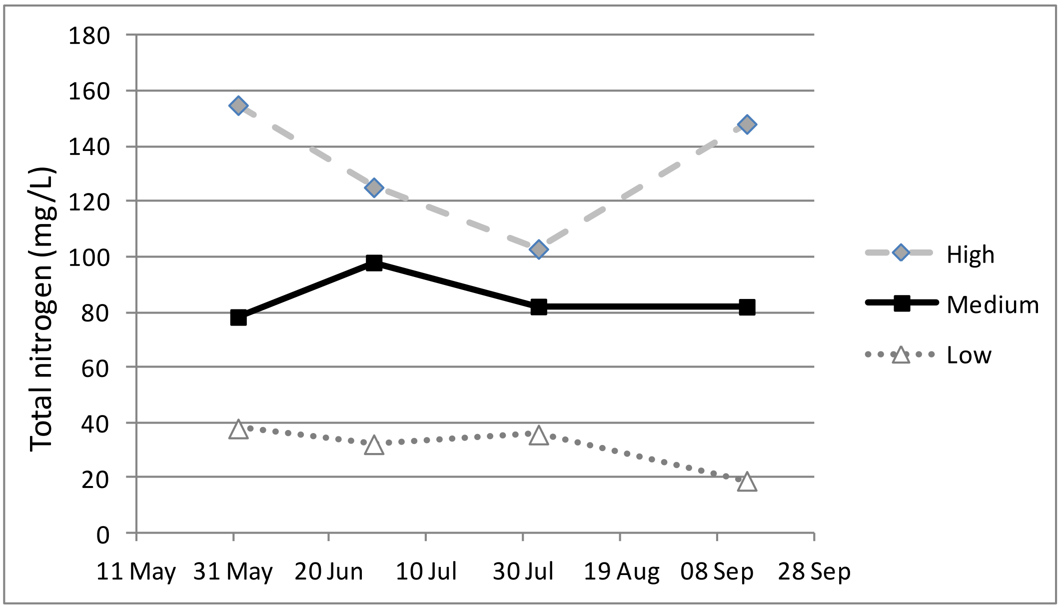

Figure 18. The concentration of nitrogen being applied in the three nitrogen treatments from analyses conducted on four dates from May to September. Data for Duke.

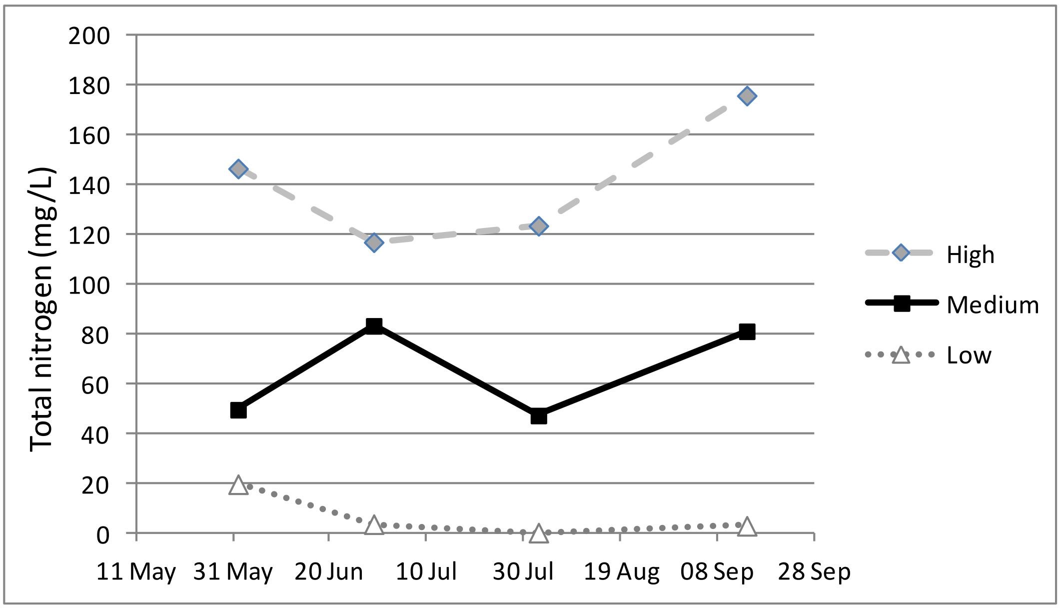

Figure 19. The concentration of nitrogen in the runoff of the three nitrogen treatments from analyses conducted on four dates from May to September. Data for Duke.

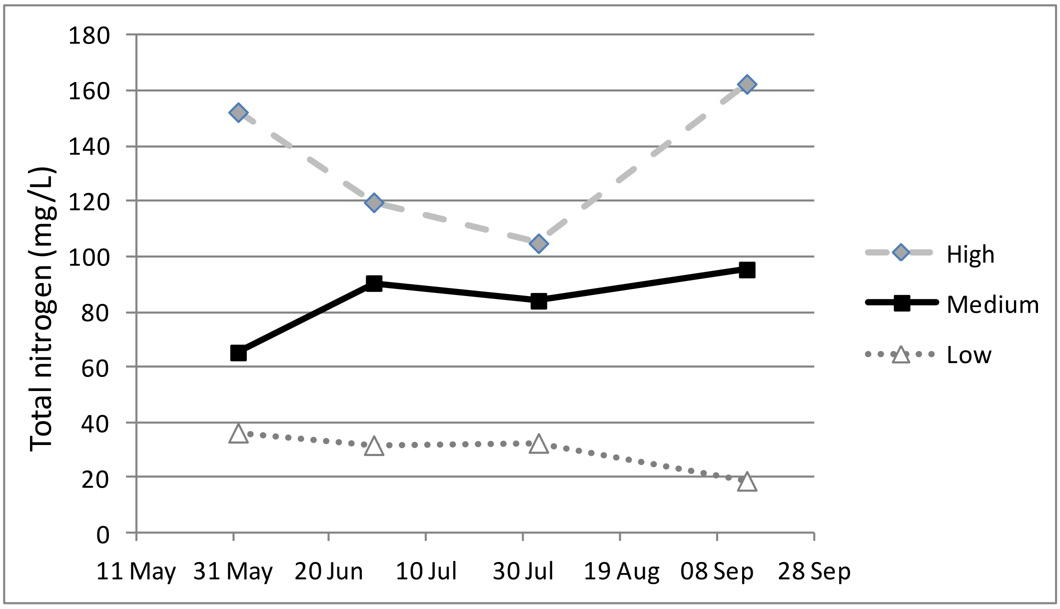

Figure 20. The concentration of nitrogen being applied in the three nitrogen treatments from analyses conducted on four dates from May to September. Data for Aurora.

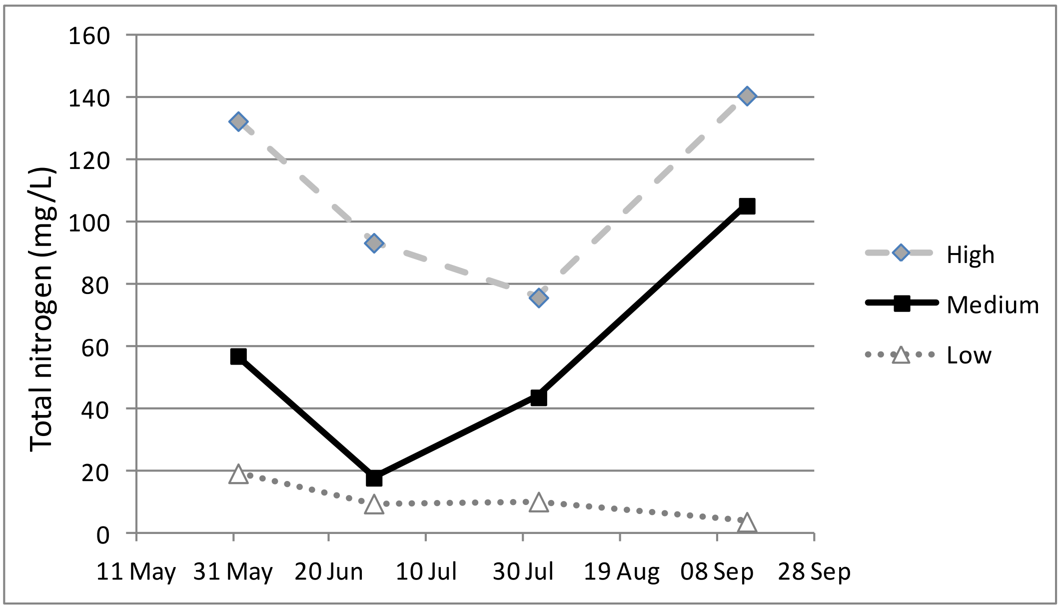

Figure 21. The concentration of nitrogen in the runoff from analyses conducted on four dates from May to September. Data for Aurora.

Compost analysis

Compost samples were taken on 7th June from each variety and each treatment. To avoid taking too much compost from each pot, only one sample per treatment was analysed and the results are given in Tables 3 (Duke) and 4 (Aurora). The total nitrogen content of the compost was affected by the nitrogen input concentration as would be expected. High levels of nitrogen were present in compost from the high N treatment and much lower levels in the low N treatment. Interesting though was the fact that the percentage of the nitrogen present in the ammonium form was also greatest in the high N treatment in both varieties. The ammonium N percentage in the input feed was 60%. In the High N treatment, the compost contained a similar proportion of nitrogen in the ammonium form. Because the amount of N supplied in the medium and low nitrogen treatments may have been less than was required, relatively more ammonium nitrogen was taken up by the plants

Variety	Treatment	pH	Total N	No3	NH4	% Ammonium nitrogen
Duke	High N	5.0	24.58	8.88	15.70	64%
Duke	Med N	5.1	13.22	10.90	2.32	22%
Duke	Low N	5.1	2.97	2.03	0.94	32%

Table 3. The effect of nitrogen regime on compost pH and nitrogen compost analysis for Duke from samples taken on 7th June.

Variety	Treatment	pH	Total N	No3	NH4	% Ammonium nitrogen
Aurora	High N	4.6	50.6	16.47	34.17	67%
Aurora	Med N	4.8	13.9	10.41	3.51	26%
Aurora	Low N	4.8	2.1	1.54	0.54	26%

Table 4. The effect of nitrogen regime on compost pH and nitrogen compost analysis for Aurora from samples taken on 7th June.

Nitrogen leaf analysis

Samples of 42 leaves per plot were taken from each treatment for both Duke and Aurora on two occasions (28th June and 15th August). The treatment averages are shown in Table 5 (Duke) and Table 6 (Aurora). For Duke there was a significant difference in leaf nitrogen for the sample taken on 28th June where leaf nitrogen increased from 2.54% in the low nitrogen treatment to 2.75% in the high nitrogen treatment. For samples taken on 15th August, there was no significant effect of treatment on leaf nitrogen although the leaf nitrogen did increase from 1.85% to 2.03% from Low N to High N.

Variety	Treatment	28TH June	15TH August
Duke	High N	2.75 **b**	2.03 **a**
Duke	Med N	2.66 **ab**	1.88 **a**
Duke	Low N	2.54 **a**	1.85 **a**
P-Value		0.024	0.132

Table 5. The effect of nitrogen regime on nitrogen leaf analysis (% dry weight) for Duke from samples taken on 28th June and 15th August. Letters show whether individual treatment results are significantly different based on multiple range tests and the P-value from each ANOVA is also given.

For Aurora there was a significant difference in leaf nitrogen for sample taken on both 28th June and 15th August. Leaf nitrogen was significantly greater in the high N treatment than the low N treatment in samples taken on both dates.

Variety	Treatment	28TH June	15TH August
Aurora	High N	2.82 **b**	1.94 **a**
Aurora	Med N	2.50 **a**	1.85 **b**
Aurora	Low N	2.47 **a**	1.69 **c**
P-Value		0.019	0.004

Table 6. The effect of nitrogen regime on nitrogen leaf analysis (% dry weight) for Aurora from samples taken on 28th June and 15th August. Letters show whether individual treatment results are significantly different based on multiple range tests and the P-value from each ANOVA is also given.

Results – Objective 2

Autumn nitrogen treatments

In the second part of the experiment, high and low nitrogen treatments were applied to plants from 15th August. The plants had received the medium N treatment up until this point.

The high and low nitrogen treatments were applied from 15th August to 15th October. The aim was to test the impact of changing N levels at this time of year on the growth during the period of the applications and also on cropping etc in the following year. Following the high and low treatments, feeding finished on 15th October. For both Duke and Aurora, the shoot lengths in the autumn-high N treatment did increase slightly more than the autumn-low N treatment (Figures 22 and 23). However, for both varieties these differences were small and not significant. The effect on leaf number was greater for both varieties (Figures 24 and 25) suggesting effects on internode length which will need confirmation in future years of the project (Figures 24 and 25).

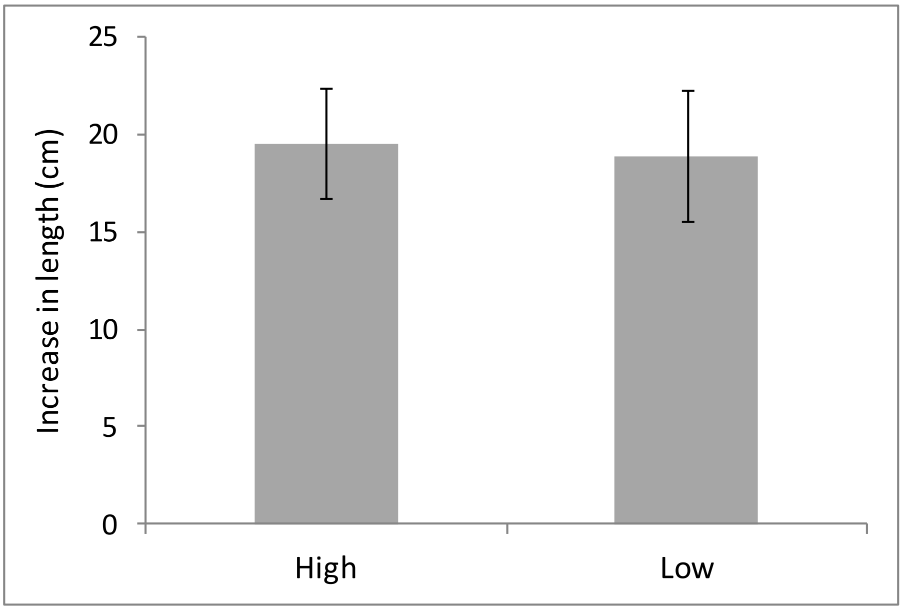

Figure 22. Increase in shoot length for plants of the variety Duke treated with high and low N during the period from 15th August to 15th October. Standard error bars are shown.

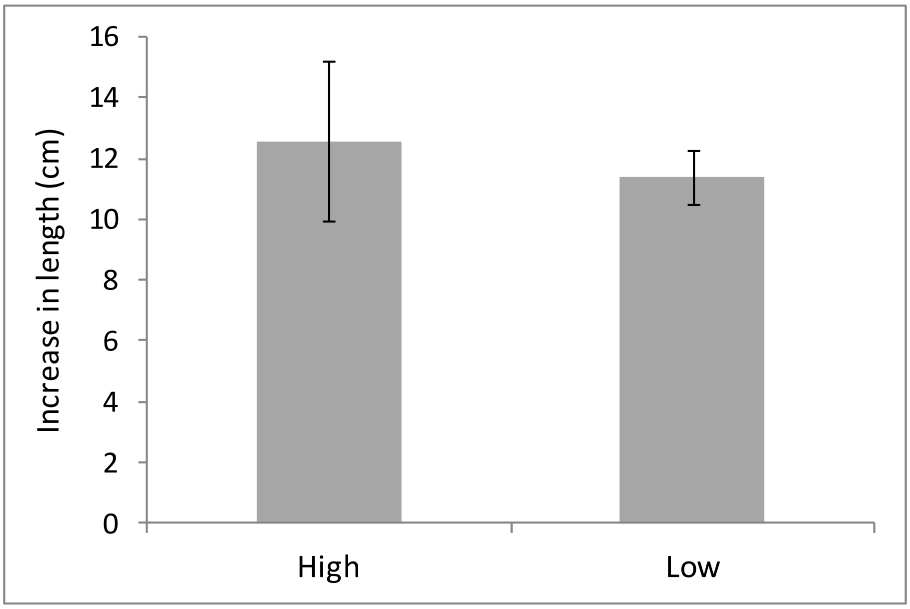

Figure 23. Increase in shoot length for plants of the variety Aurora treated with high and low N during the period from 15th August to 15th October. Standard error bars are shown.

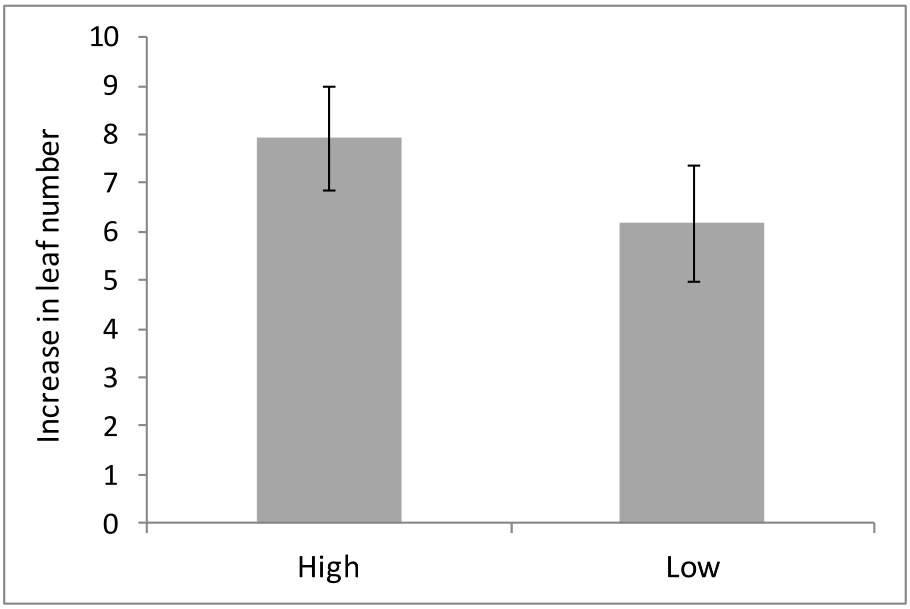

Figure 24. Increase in leaf number for plants of the variety Duke treated with high and low N during the period from 15th August to 15th October. Standard error bars are shown.

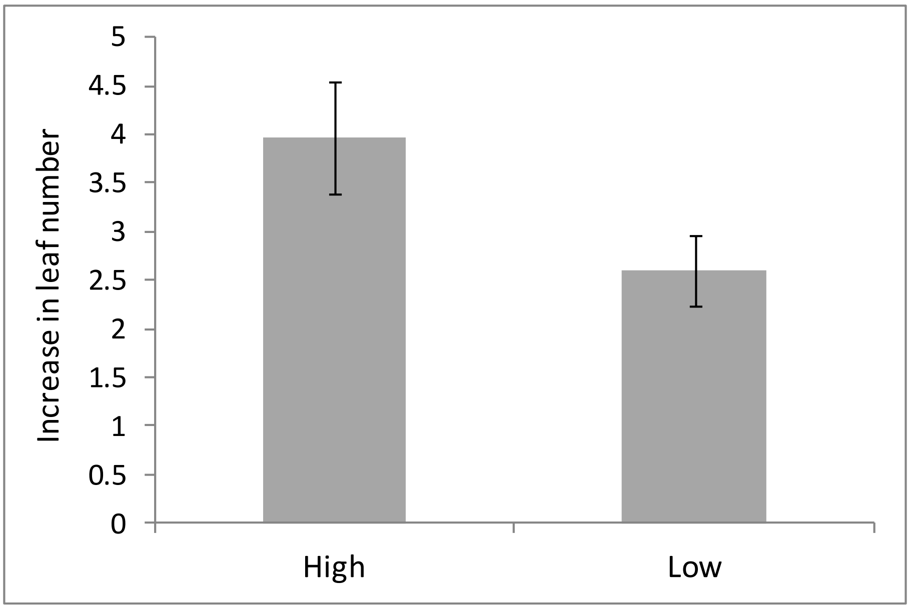

Figure 25. Increase in leaf number for plants of the variety Aurora treated with high and low N during the period from 15th August to 15th October. Standard error bars are shown.

Discussion

There was a significant effect on nitrogen usage by the plants. There were consistent differences in leaf nitrogen for both varieties. Lower nitrogen levels in the feed solution resulted in lower nitrogen levels in leaf analyses. This was also the case with the compost analysis. This means firstly that the nitrogen treatments are creating different nitrogen uptake regimes which then affected growth of the plants. That the concentration of nitrogen in the low N treatment in both the compost and the runoff was so low suggests that the input level was at the low end of what the plants require. Conversely the fact that there was nitrogen in the runoff and compost analyses of the high nitrogen treatment suggests that the high N treatment provided more nitrogen than the plants required. It will be important to monitor this as the plants grow during the project to determine whether the plants' nitrogen requirement does increase.

There were significant effects on growth and on cropping in both varieties. For Aurora growth was significantly affected by nitrogen whereas there was no significant effect on the growth of Duke shoots. This was likely to be due to the different types of shoots being measured. In future seasons the new shoots produced by the roots need to be measured as it seems to be these that are most affected by the nitrogen treatments.

That there was an effect of nitrogen treatment on yield in both varieties is clear. In both Aurora and Duke the yield increased as nitrogen application concentration decreased. The effects in both varieties were due to differences in fruit number rather than fruit size. This must mean that the nitrogen treatments caused different levels of flower and fruit abortion, with the higher nitrogen treatments increasing flower abortion. In a number of crops there is an inverse relationship between growth and yield whereby increased growth adversely affects fruiting and yield. Managing this growth and yield balance is important as the amount of growth in 2012 is likely to have an impact on yield in 2013, simply because where growth has been increased, the bushes will be larger and therefore have a greater yield potential.

The lack of effect of nitrogen treatments on fruit quality is interesting and perhaps goes against current thinking whereby the shelf life of fruit would be expected to decrease with greater nitrogen applications. Fruit quality was tested by measuring fruit size, total soluble solids content (^{o}brix) and by measuring the shelf life in a cold store. In each case there was no effect of nitrogen on fruit quality perhaps with the exception of shelf life whereby the percentage of non-marketable fruit was generally greater in the low nitrogen treatment although this effect was not significant. As the bushes develop and yields increase more fruit can be harvested at each pick allowing a more detailed examination than was possible here.

In objective 2, to determine the effect of timed nitrogen applications, the first treatment was applied where nitrogen was increased and decreased during the autumn to a separate batch of plants. The amount of autumn growth during this period was only slightly affected by the nitrogen treatment. Shoots only grew by a small amount during this period with Duke producing an extra 1.7 leaves per shoot and Aurora an extra 1.4 leaves per shoot. This suggests that the growth of the shoots had started slowing before this period and it will be interesting to determine the effects of nitrogen during the summer in 2013. It seems likely that there will be a greater effect at this time of year. Effects of the autumn treatment on frost damage and flower initiation will become clear next year.

Conclusions

The three different levels of nitrogen concentration resulted in significant differences in nitrogen usage by the bushes. This was reflected in the leaf, compost and runoff analyses results. This then affected growth and yield of the bushes although fruit quality was not affected. In future years, the effect of timed nitrogen applications will be determined.

Knowledge Transfer

Dan Chiuan will be presenting some initial results of the project at the FAST Annual Growers Conference 2013.

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