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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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

- Increasing nitrogen application in the blueberry cultivar Aurora may inhibit flower initiation for next season's crop.

Background and expected deliverables

To maximise the yield of blueberry bushes, optimum bush growth is required, with larger bushes having significantly greater potential yields. Although nitrogen application is important for encouraging growth it is not without potential problems. During fruiting, high nitrogen application has been shown to reduce fruit firmness and may also reduce 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. Late nitrogen applications are believed to increase sensitivity to frost and therefore increase the risk of frost damage. Excessive nitrogen applications at the time of autumn flower initiation also have the potential to reduce flower number. Each of these effects will have a considerable influence on yields.

Research into the nutritional requirements of blueberries around the world has focussed on soil grown crops. However the majority of UK produced blueberries are currently grown in soil-less substrates in pot grown systems and less is known about the optimum nitrogen requirements of these. It is hoped that this project will benefit UK blueberry growers in the following ways:

- Improve our understanding of how to manipulate nutrient balance in pot grown blueberries.
- Provide growers with a better understanding of the optimum time to apply nitrogen in pot grown blueberries.
- Increase our understanding of the effect that nitrogen applications made immediately before harvest have on storage potential of blueberries.
- Improve our knowledge of manipulating nitrogen application to reduce the risk of frost damage occurring.

This project will investigate the application of nitrogen to pot grown blueberries at different times of the season to ascertain the optimum application timing to maximise yields whilst reducing the risk of frost or cold injury to bushes and flowers.

The two main objectives of the work are:

Objective 1: Test the effect of three constant nitrogen levels on growth and yield (March 2012 - October 2012)

Objective 2: Examine the effect of increasing and decreasing nitrogen feed levels during three key phases of growth: early spring growth, fruiting and autumn flower initiation (October 2012 - October 2015)

Summary of the project and main conclusions

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 6 March 2012. The variety Duke was sourced from Heathlands Farm, Wokingham and the Aurora was sourced from Tuesley Farm, Milford. The 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 or three main structural branches were selected.

On arrival at Brogdale, the pots of the variety Duke were placed on a 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 cladding was removed. The Aurora pots were placed outside on a black Mypex floor covering in line with commercial practice.

Objective 1: Test the effect of three constant nitrogen levels on growth and yield (March 2012 - October 2012)

Three feed solutions were supplied to plants with 60ppm N, 120ppm N or 180ppm N from March to October 2012. Ninety plants of each variety were arranged in a randomised block design with six plots per treatment. Irrigation was supplied to achieve a target of 60% substrate moisture content whilst maintaining EC within set limits. The nitrogen applied 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 brix° was recorded from 20 fruit per plot twice during the cropping period of each variety along with shelf life.

Objective 2: Examine the effect of increasing and decreasing nitrogen feed levels during three key phases of growth: early spring growth, fruiting and autumn flower initiation (October 2012 - October 2015)

A separate batch of 252 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 15 August, the first treatment applications started with the application of the autumn treatments until 15 October 2012 (autumn high and autumn low 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 seven plants per plot. Three separate lines of irrigation for the three nitrogen treatments allowed the plants to be plugged into the correct nitrogen treatment at the three points during the season outlined below (all dates vary according to the season).

'Autumn High'. A nitrogen level of 180mg/L was applied from the end of harvest until 90% leaf fall (15 August to 15 October 2012) and then 120mg/L was applied from bud break until the end of harvest (17 April to 12 September 2013).

'Autumn Low'. A nitrogen level of 60mg/L was applied from the end of harvest until 90% leaf fall (15 August to 15 October 2012) and then 120mg/L was applied from bud break until the end of harvest (17 April to 12 September 2013).

'Spring High'. A nitrogen level of 120mg/L was applied from 15 August to 15 October 2012. 180mg/L was then applied from bud break until first green fruit (17 April to 1 July 2013) and then decreased again to 120 mg/L until 12 September 2013.

'Spring Low'. A nitrogen level of 120mg/L was applied from 15 August to 15 October 2012. 60mg/L was then applied from bud break until first green fruit (17 April to 1 July 2013) and then increased again to 120mg/L until 12 September 2013.

'Summer High'. A nitrogen level of 120mg/L was applied from 15 August to 15 October 2012 and from bud break until first green fruit (17 April to 1 July 2013). This was then increased to 180mg/L from first green fruit until the end of harvest (1 July to 12 September 2013).

'Summer Low'. A nitrogen level of 120mg/L was applied from 15 August to 15 October 2012 and from bud break until first green fruit (17 April to 1 July 2013). This was then reduced to 60mg/L from first green fruit to the end of harvest (1 July to 12 September 2013).

'Medium'. A standard nitrogen concentration of 120mg/L was applied from 15 August to 15 October 2012 and then from bud break until end of harvest (17 April to 12 September 2013).

'Low'. A nitrogen concentration of 60mg/L was applied from 15 August to 15 October 2012 and then from bud break until end of harvest (17 April to 12 September 2013).

'High'. A nitrogen concentration of 180mg/L was applied from 15 August to 15 October 2012 and then from bud break until end of harvest (17 April to 12 September 2013).

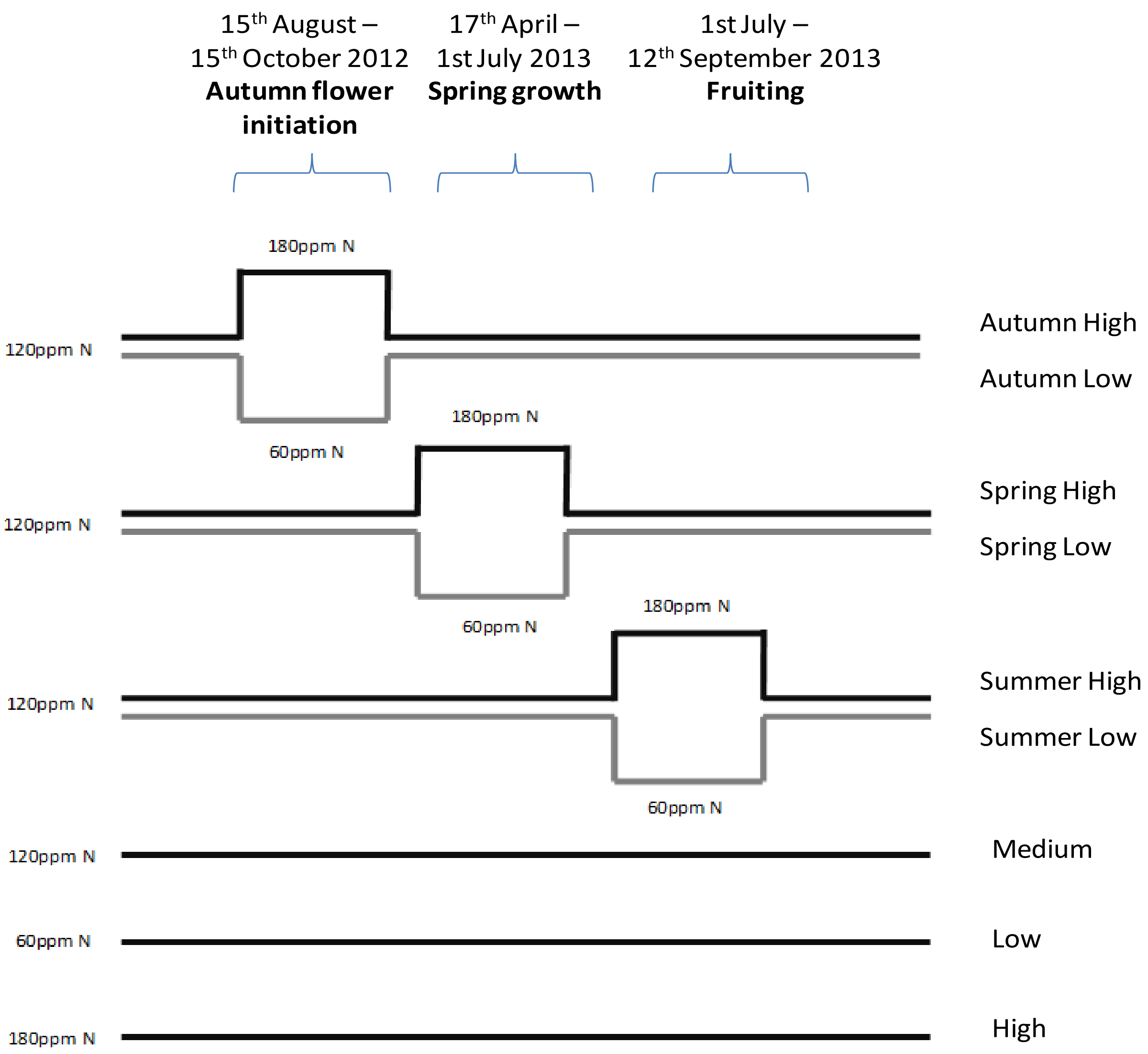

Figure 1 The treatments which were applied in Objective 2 of the project

From each treatment the growth, cropping and plant nutrition were assessed. These assessments began in 2013 apart from the growth measurements from the autumn high and autumn low treatments, which began in autumn 2012.

The assessments which were made included:

Growth	Shoot growth measured from labelled branches at the end of each of the three nitrogen application timings at the following timings – green fruit, end of cropping and 90% leaf fall.
Cropping	Fruit was 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	Both the Aurora and the Duke were placed into an air store at 2°C at Brogdale and assessed fortnightly until deemed non-marketable. The Duke was also placed into a CA store at Hall Hunter Partnership on 1 August and assessed after four and eight weeks. Assessments made fortnightly were as follows: • Percentage fruit with shrivel; • Weight loss during storage; • Fruit collapse; • Flavour; • Overall marketability based on commercial specifications supplied by HHP
Flower initiation	The percentage of floral buds was calculated and the average number of flowers per bud was recorded.
Percentage bud break	The percentage of buds which broke from each treatment was assessed.
Plant nutrition	Leaf samples were taken and analysed for nutrient content on 11 July and 4 September. In addition, irrigation input and runoff was analysed on 16 July.

Combined results for Objectives 1 and 2

Nitrogen usage by the plants varied according to treatment. There were differences observed in the total nitrogen in the inputs, runoff and also in the leaf analysis. There was a reduction in nitrogen in the leaf analysis taken in July for those treatments supplied with a low feed during the spring (low and spring low) and similarly, lower nitrogen was observed in the low and summer low samples in the September analysis. These levels of nitrogen are considered to be low when compared to industry leaf analysis ranges. Whether these levels are appropriate for all varieties of pot-grown blueberries in the UK remains to be seen.

There was a significant effect of treatment upon floral bud initiation in the Aurora whereby the low nitrogen treatment produced more floral buds. This suggests that increasing nitrogen concentration can inhibit floral bud production. Supplying low nitrogen levels during the autumn, when flower initiation occurs, resulted in some of the largest yields for both varieties, however these results were not significant. It is not clear as to whether these increases in yield were solely due to fruit size or fruit number.

Fruit quality was affected by nitrogen treatment, with significant differences seen in both Brix° and fruit size, dependent on nitrogen treatment. Although significant differences could be seen, the only consistent effect of treatment upon fruit diameter was that of the autumn low treatment, which was larger than most other treatments for both varieties. Although there were no significant differences seen in the percentage of non-marketable fruit following storage, there were differences in the cause of these losses. There were treatment differences in the losses from dehydration, collapse and *Botrytis*; the low nitrogen treatment particularly appeared to be more susceptible to fruit collapse and less prone to *Botrytis* than the other treatments.

Consistent with the results observed last year, the growth of Aurora shoots varied with nitrogen treatment, the low having significantly less growth than the other treatments. Although not significant, the Duke shoot growth also followed the same pattern. The low treatment showed reduced growth particularly during the summer and very little growth of any treatment occurred throughout the autumn. The high and medium nitrogen treatments produced similar amounts of vegetative growth, which may suggest that the medium treatment provides sufficient nitrogen for vegetative growth.

The effect of repeating the increasing and decreasing of nitrogen levels at different growth stages will be investigated over the next two seasons, and any cumulative effects of this may become apparent. Any differences in frost damage, if any occurs, will also be assessed during spring 2014 and 2015.

Main conclusions

Floral bud production in the Aurora was affected by nitrogen treatment. Although there was no effect of treatment on marketable yield, there was an effect on the fruit quality of both varieties. Consistent with the findings from the previous season, lower nitrogen levels resulted in significantly decreased growth in the Aurora. The project will continue for another two seasons and it is likely that any cumulative effects of repeating nitrogen applications at these growth phases will become apparent.

Financial benefits

The project is still in its early stages 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

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

The UK is largely reliant on pot-grown systems for blueberries, primarily because of problems associated with soil type and pH. 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 a greater opportunity to alter the nutrient balance depending on growth stage.

Production of blueberries in the UK 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. Controlled atmosphere (CA) storage of blueberries has been used to extend the season further but this requires good quality, firm fruit to enable storage for sufficient duration. There are reports in a number of crops that where excessive nitrogen has been applied, fruit quality has been adversely affected. In cranberries, the effect was increased fruit rots from 5 to 10% (Davenport, 1996). In apples, excessive nitrogen applications can result in a reduction in storage life, possibly through effects on fruit cell wall development and/or effects on fruit respiration rate (Fallahi *et al*., 1997). In strawberries, fruit firmness during storage was reduced as a result of higher nitrogen applications which also reduced fruit total soluble solids concentrations (Mukkun *et al*., 2001). Whilst being an important factor determining fruit quality, nitrogen is also required to encourage growth and so an application strategy is therefore required which optimises growth without adversely affecting fruit storage and shelf life.

To maximise blueberry yields requires early cane growth to produce larger bushes which would have the potential for greater yields and could be achieved by applying high levels of nitrogen to the bushes throughout the year. A number of studies have identified the beneficial effect of applying 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 canes with the combination of ammonium N and nitrate N compared with 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 that using only the ammonium form of nitrogen, in the form of ammonium sulphate and ammonium nitrate, resulted in increased growth over using only ammonium nitrate. 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 however what the effect is on yield. Whilst Kozinski (2006) found excess application of nitrogen did reduce yield in soil-grown crops, it is not clear whether the decrease in yield was because flower initiation was adversely affected or whether growth was excessive, therefore creating competition for assimilates. Flower initiation occurs during the autumn under conditions of shortening photoperiods (Hall and Ludwig, 1961). At this time, a greater application of nitrogen could influence flower bud formation such that yield would then be 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). For this reason, nitrogen fertilization is usually minimised after harvest.

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

The effects of increasing or decreasing nitrogen levels during three critical phases of growth (early spring growth, fruiting and autumn flower initiation) are being tested. Throughout the duration of the project, the growth, yield and fruit development are being recorded in a number of ways to monitor the effect of these treatments.

Materials and methods

The project began in April 2012 and aims to address two objectives:

1. Testing the effect of three constant nitrogen levels on growth and yield **March 2012-October 2012;**
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 **October 2012- October 2015.**

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 6 March 2012. The variety Duke was sourced from Heathlands Farm, Wokingham and the 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 or 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 or 180ppm N from March to October 2012. Ninety plants of each variety were arranged in a randomised block design with six plots per treatment. 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 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 252 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 15 August, the first treatment applications started with the application of the autumn treatments until 15 October 2012 (autumn high and autumn low 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 seven plants per plot. Three separate lines of irrigation for the three nitrogen treatments allowed the plants to be plugged into the correct nitrogen treatment at the three points during the season outlined below (all dates vary according to the season).

'Autumn High'. A nitrogen level of 180mg/L was applied from the end of harvest until 90% leaf fall (15 August to 15 October 2012) and then 120mg/L was applied from bud break until the end of harvest (17 April to 12 September 2013).

'Autumn Low'. A nitrogen level of 60mg/L was applied from the end of harvest until 90% leaf fall (15 August to 15 October 2012) and then 120mg/L was applied from bud break until the end of harvest (17 April to 12 September 2013).

'Spring High'. A nitrogen level of 120mg/L was applied from 15 August to 15 October 2012. 180mg/L was then applied from bud break until first green fruit (17 April to 1 July 2013) and then decreased again to 120 mg/L until 12 September 2013.

'Spring Low'. A nitrogen level of 120mg/L was applied from 15 August to 15 October 2012. 60mg/L was then applied from bud break until first green fruit (17 April to 1 July 2013) and then increased again to 120mg/L until 12 September 2013.

'Summer High'. A nitrogen level of 120mg/L was applied from 15 August to 15 October 2012 and from bud break until first green fruit (17 April to 1 July 2013). This was then increased to 180mg/L from first green fruit until the end of harvest (1 July to 12 September 2013).

'Summer Low'. A nitrogen level of 120mg/L was applied from 15 August to 15 October 2012 and from bud break until first green fruit (17 April to 1 July 2013). This was then reduced to 60mg/L from first green fruit to the end of harvest (1 July to 12 September 2013).

'Medium'. A standard nitrogen concentration of 120mg/L was applied from 15 August to 15 October 2012 and then from bud break until end of harvest (17 April to 12 September 2013).

'Low'. A nitrogen concentration of 60mg/L was applied from 15 August to 15 October 2012 and then from bud break until end of harvest (17 April to 12 September 2013).

'High'. A nitrogen concentration of 180mg/L was applied from 15 August to 15 October 2012 and then from bud break until end of harvest (17 April to 12 September 2013).

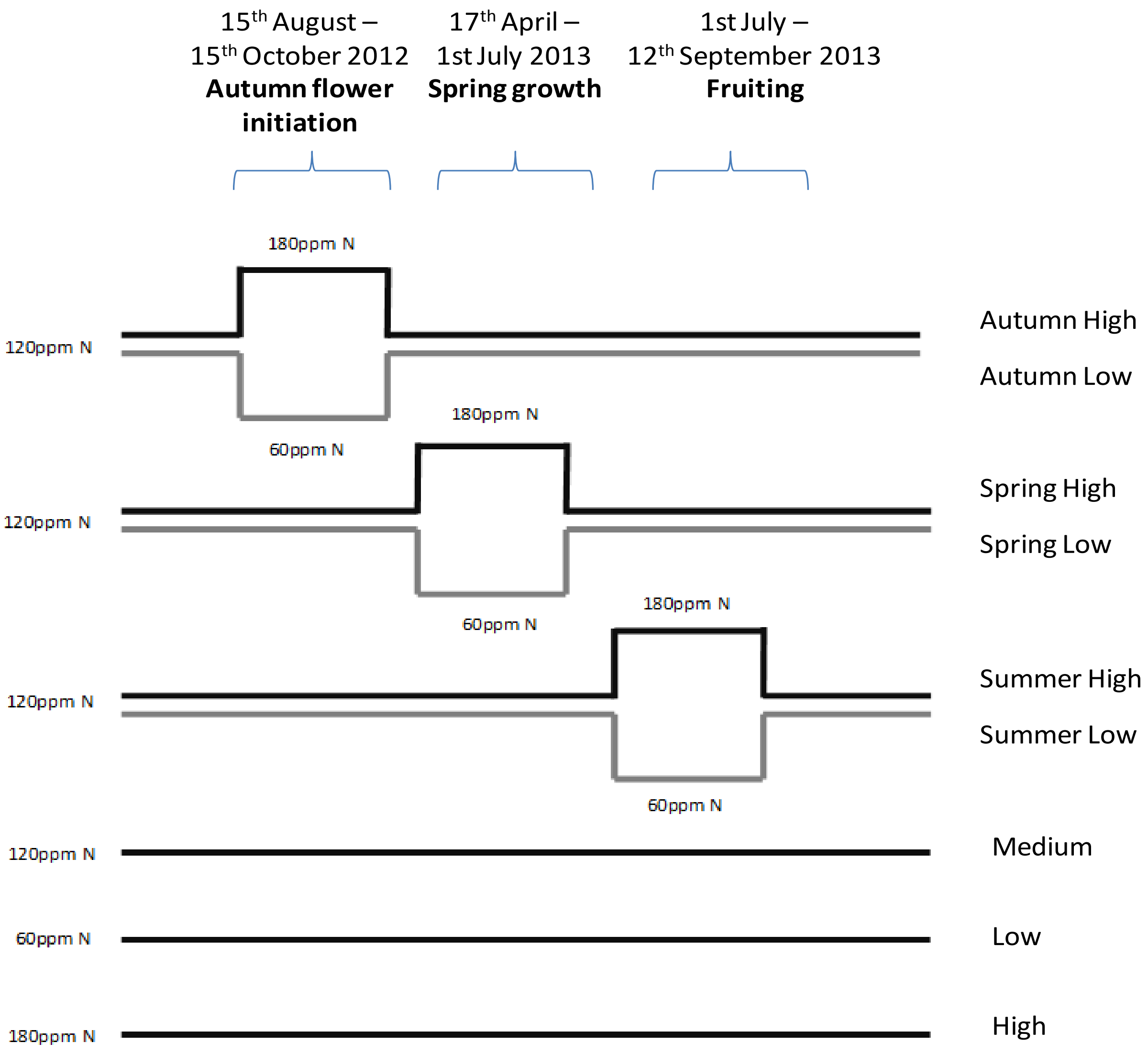

Figure 1. The treatments which were applied in Objective 2 of the project.

From each treatment the growth, cropping and plant nutrition were assessed. These assessments began in 2013 apart from the growth measurements from the autumn high and autumn low treatments, which began in autumn 2012.

The assessments which were made included:

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

Cropping Fruit was 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 Both the Aurora and the Duke were placed into an air store at 2^{o}C at Brogdale and assessed fortnightly until deemed non-marketable. The Duke was also placed into a CA store at Hall Hunter Partnership on 1 August and assessed after four and eight weeks. Assessments made fortnightly were as follows:

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

Flower initiation The percentage of floral buds was calculated and the average number of flowers per bud was recorded.

Percentage bud break The percentage of buds which broke from each treatment was assessed.

Plant nutrition Leaf samples were taken and analysed for nutrient content on 11 July and 4 September. In addition, irrigation input and runoff was analysed on 16 July.

Pesticide applications and biological control

One application of Steward was made for the treatment of light brown apple moth larvae (details can be seen in Table 1 below). Four preventative applications of nematodes for vine weevil were also made in March, August, October and November.

Date	Trade name	Active ingredient	Application rate	Application regime	Approval status
31 August 2013	Steward	Indoxacarb	170g/Ha	1 app.	This product has an extension of authorisation for minor use (EAMU) for use on this crop (0988/2013).
15 March 2013	Nemasys L	*Steinernema kraussei*	146,198 per plant	1 app.	
22 August 2013	Nematop	*Heterorhabditis bacteriophora*	133,334 per plant	1 app.	
24 October 2013	Nematop	*Heterorhabditis bacteriophora*	133,334 per plant	1 app.	
20 November 2013	Nemasys L	*Steinernema kraussei*	146,198 per plant	1 app.	

Table 1. Pesticide applications and biological control

Statistical analysis

Analysis of Variance (ANOVA) has been used to determine the significance of treatment effects with Least Significant Differences (LSDs) used to determine the significance of difference between individual treatments. The data for Duke and Aurora have been analysed separately.

Results – combined for Objectives 1 and 2

Flower initiation and bud break

Frost damage

The 2012 autumn and early winter in Kent was mild and allowed the bushes to develop winter hardiness. The lowest temperature at Brogdale was - 6.5^{o}c, recorded mid-December.

The buds, when fully dormant, can survive temperatures of - 40°c (Gough, 1994) and so the plants suffered very little frost damage.

Percentage bud break

Buds along the length of new shoots on both varieties were counted and categorised as either open (buds which had broken) or closed (those which remained dormant). The percentage of bud break along new shoots was then calculated.

Aurora

The bushes which had been supplied with continuous low nitrogen had the greatest proportion of open buds whilst the medium treatment had the least, but with very little difference between treatments (see Figure 2). There was however a significant difference in the total number of buds per shoot (P= 0.05), with the low nitrogen treatment having also a greater total bud number (see Table 2).

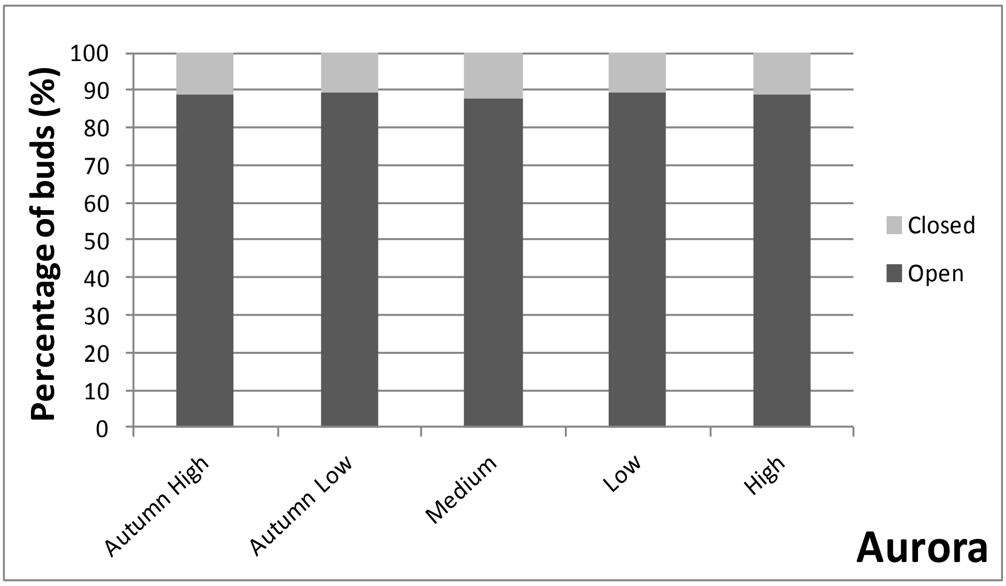

Figure 2. The effect of nitrogen treatment on the percentage of bud break for Aurora.

Treatment	Total bud number per new shoot
Autumn High	30.0 ***(a)***
Autumn Low	30.0 ***(a)***
Medium	29.4 ***(a)***
Low	33.8 ***(b)***
High	29.3 ***(a)***

Table 2. The effect of nitrogen treatment on the bud number per shoot for Aurora. The letters show significant differences between treatments (P= 0.05).

Duke

Similar to the Aurora, the medium treatment had the lowest proportion of bud break, with just 63% compared to the autumn low with 72%. The autumn high and autumn low treatments had the greatest values for bud break (see Figure 3). The autumn low treatment also had the largest bud number compared to the other treatments (see Table 3). However, no statistically significant differences were found.

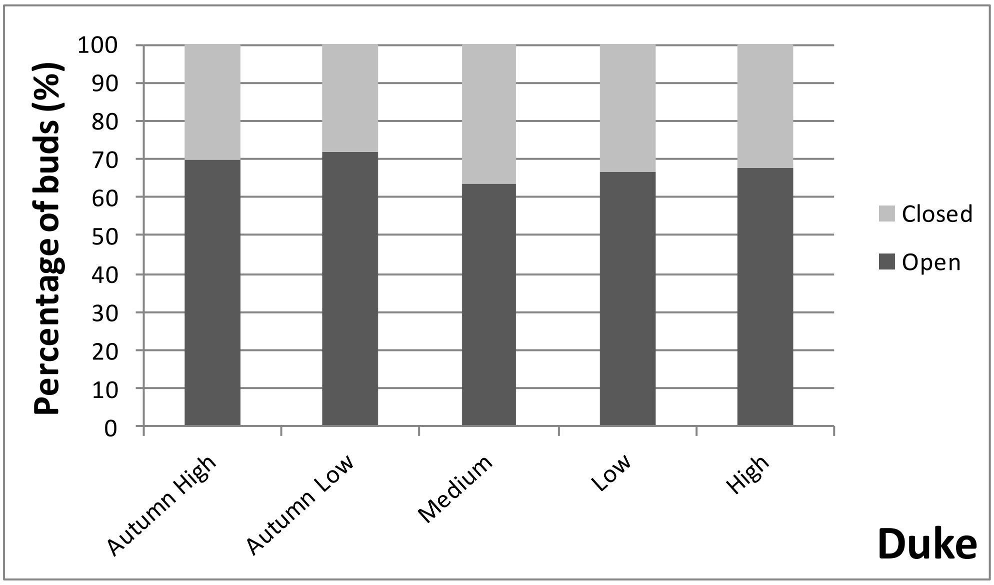

Figure 3. The effect of nitrogen treatment on the percentage of bud break for Duke.

Treatment	Total bud number per new shoot
Autumn High	28.6
Autumn Low	30.3
Medium	27.6
Low	28.6
High	27.4

Table 3. The effect of nitrogen treatment on the bud number per shoot for Duke.

Floral bud production

The numbers of floral buds were counted on three shoots per bush and the average calculated.

Aurora

There was a statistically significant effect of nitrogen treatment upon the percentage of floral buds (P= 0.002), with the low treatment having significantly more floral buds than all other treatments with the exception of autumn low (see Figure 4).

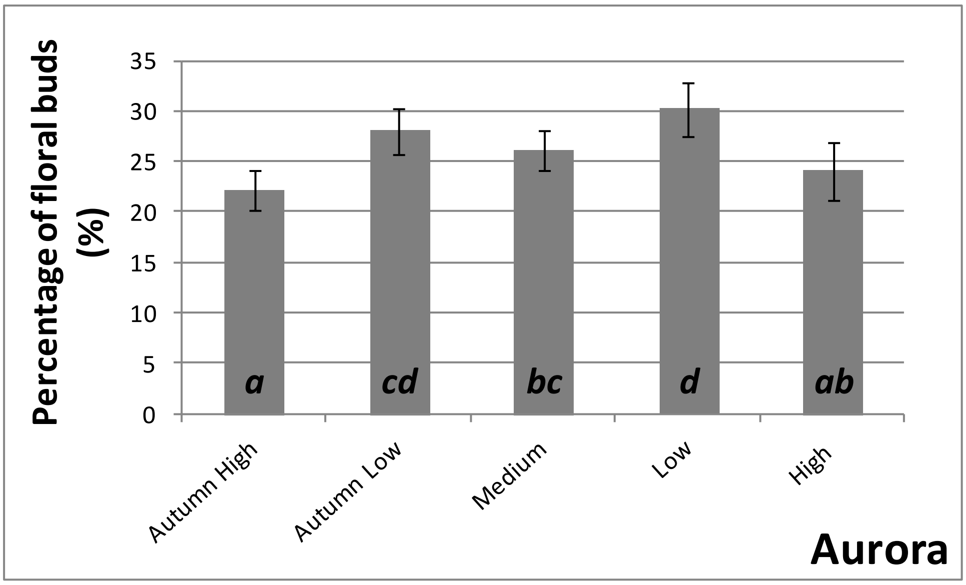

Figure 4. The effect of nitrogen treatment on the percentage of floral buds for Aurora. The letters show significant differences between treatments (P=0.002). Standard error bars are shown.

Duke

The treatment differences in the Duke followed a similar pattern to that of the Aurora however the differences were not large enough to be classed as significant (see Figure 5).

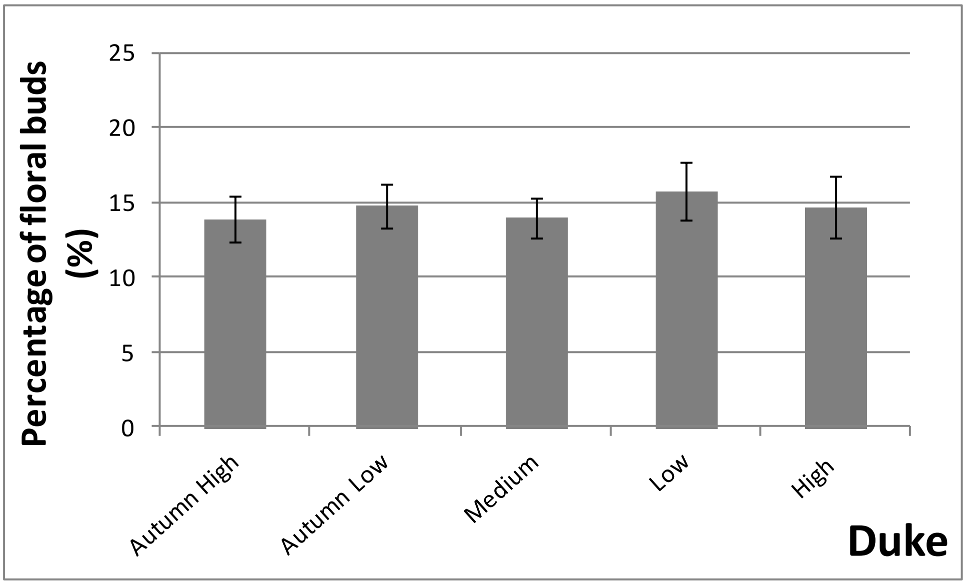

Figure 5. The effect of nitrogen treatment on the percentage of floral buds for Duke. Standard error bars are shown.

Flower number

Aurora

Although there was some variation in the average number of flowers counted per bud, there were no significant differences between treatments (see Figure 6).

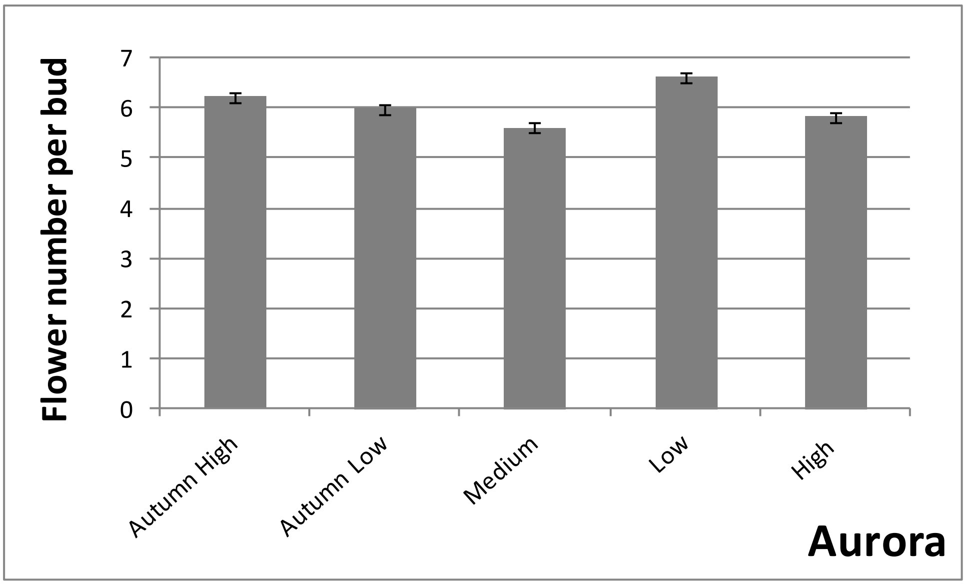

Figure 6. The effect of nitrogen treatment on the flower number per bud for Aurora. Standard error bars are shown.

Duke

There were 6 flowers on average produced per bud with very little difference between treatments (see Figure 7).

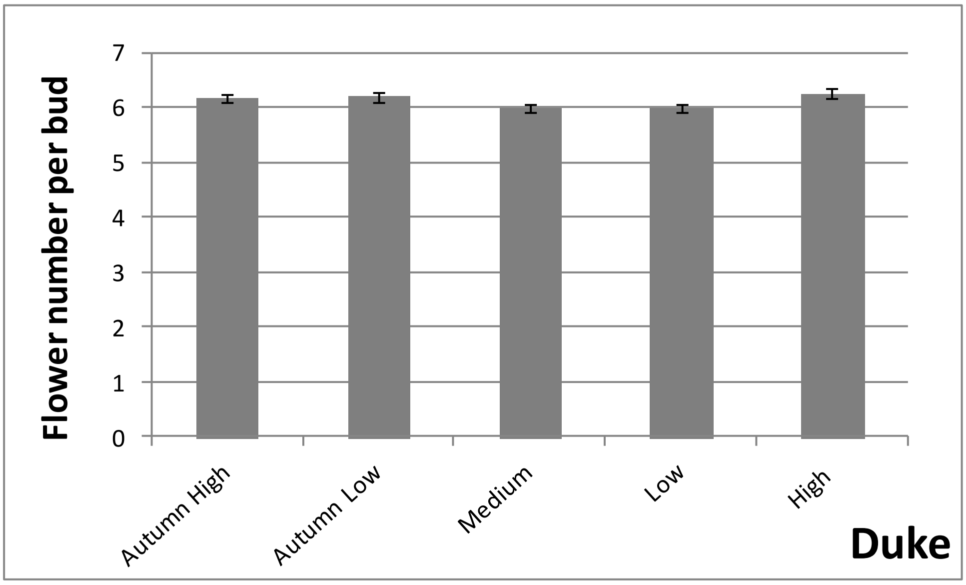

Figure 7. The effect of nitrogen treatment on the flower number per bud for Duke. Standard error bars are shown.

Cropping

Fruit Number

Aurora

The low and medium nitrogen treatments had the greatest fruit number harvested per bush and summer low had the least (see Figure 8). The spring and autumn low treatments however harvested more fruit than the corresponding high treatments (spring high and autumn high). The spring low treatment had a different cropping profile compared to the other treatments, with a similar harvest at each pick throughout the season (see Figure 9B), however there were no significant differences between treatments.

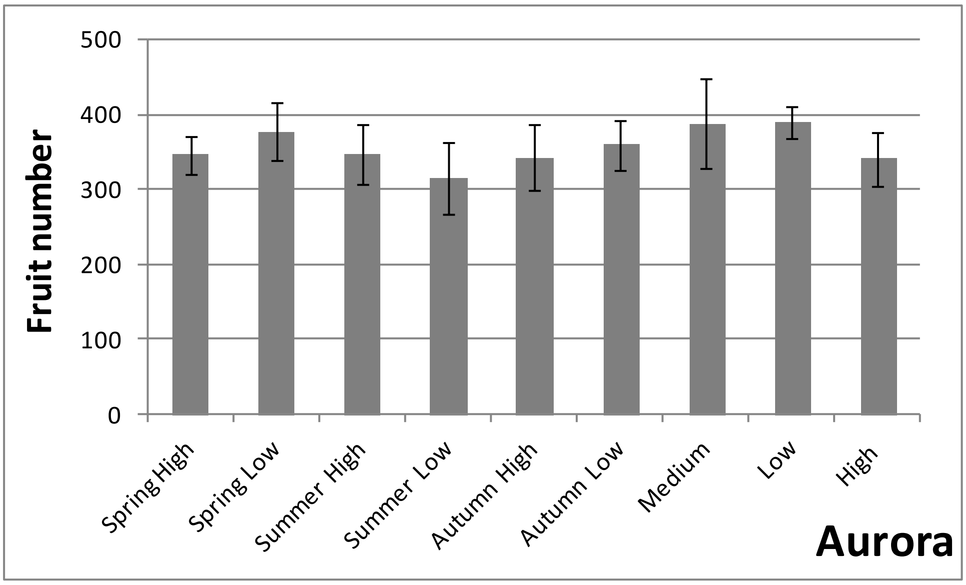

Figure 8. The effect of nitrogen treatment on the fruit number harvested from an Aurora bush. Standard error bars are shown.

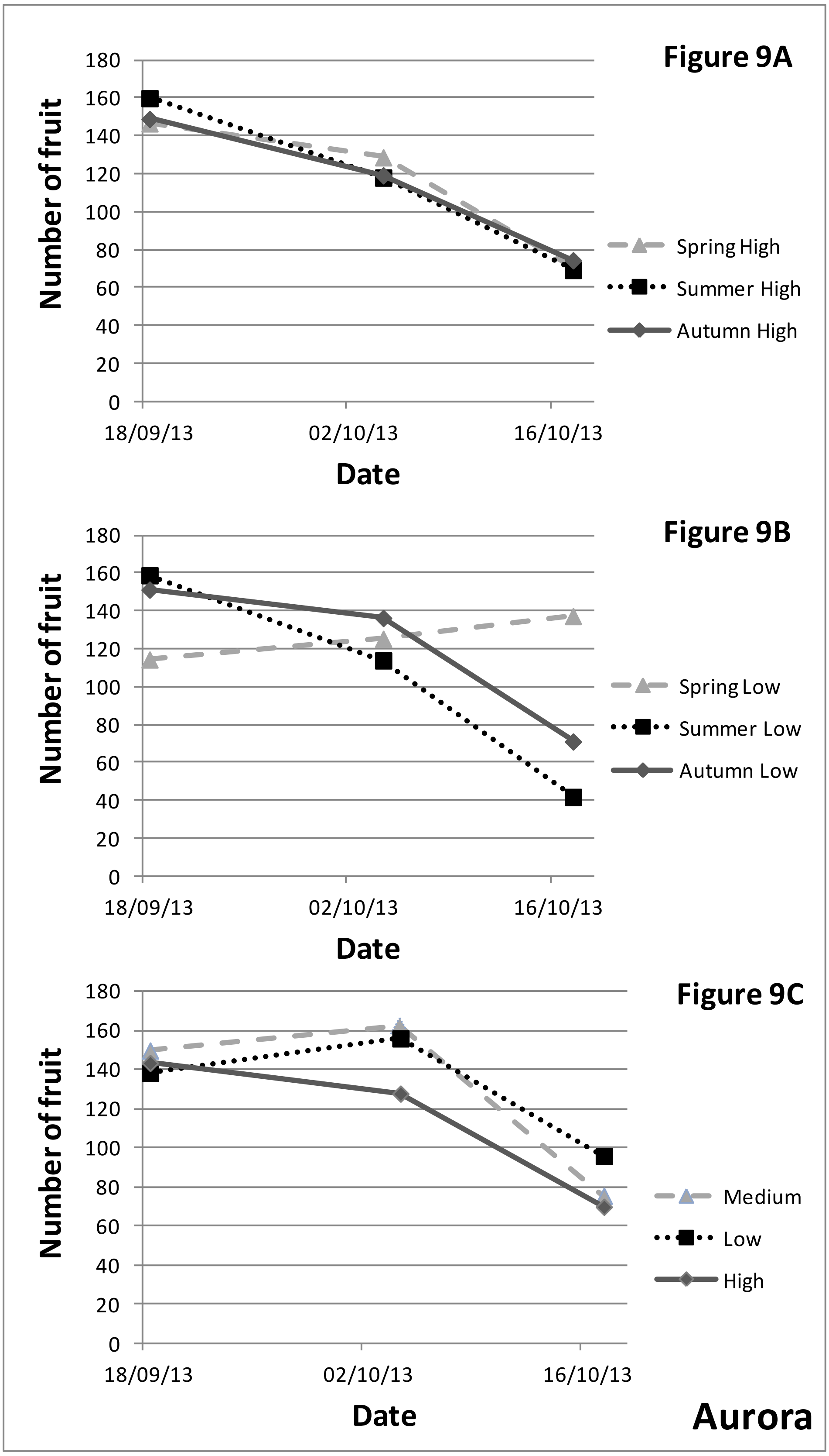

Figure 9. The effect of nitrogen treatment on the cropping profile for Aurora.

Duke

In contrast to the Aurora, the high and spring high treatments had larger numbers of fruit harvested compared to most of the other treatments (see Figure 10). In addition, the spring low and autumn low treatments also had larger fruit numbers in comparison to the other treatments as a result of a greater fourth pick (See Figure 11B). The autumn high however harvested less in comparison to the other treatments.

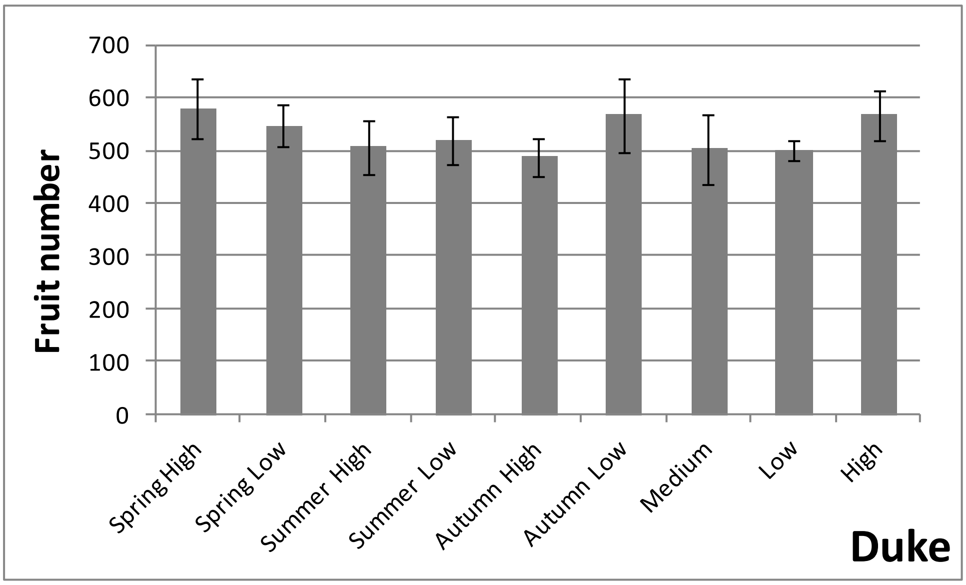

Figure 10. The effect of nitrogen treatment on the fruit number harvested from a Duke bush. Standard error bars are shown.

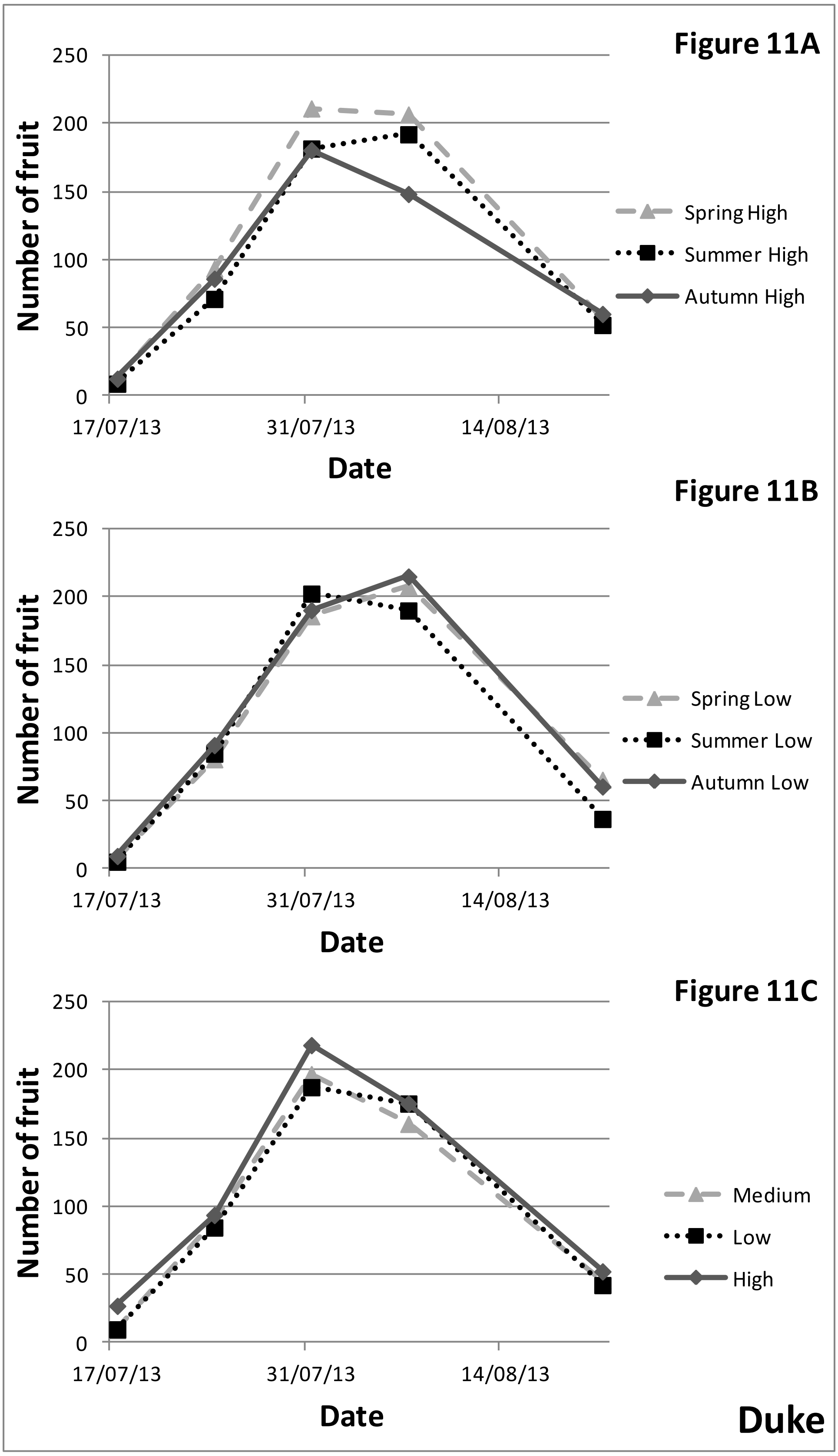

Figure 11. The effect of nitrogen treatment on the cropping profile for Duke.

Yield

Aurora

The larger total yield (kg) obtained by the medium treatment can be attributed to a larger second pick than the other treatments (see Figure 12 and 13C). The high nitrogen treatments (spring, summer, autumn and high) obtained comparable yields and this can be seen by the similar cropping profile they shared (Figure 13A). The spring low and summer low had the smallest yield throughout the growing season. There was no significant difference in total yield harvested between treatments, however there was a difference in the Class 2 yields (P=0.003) with the lowest Class 2 yield harvested from the spring high and high treatments and the highest in the low and spring low (see Table 4).

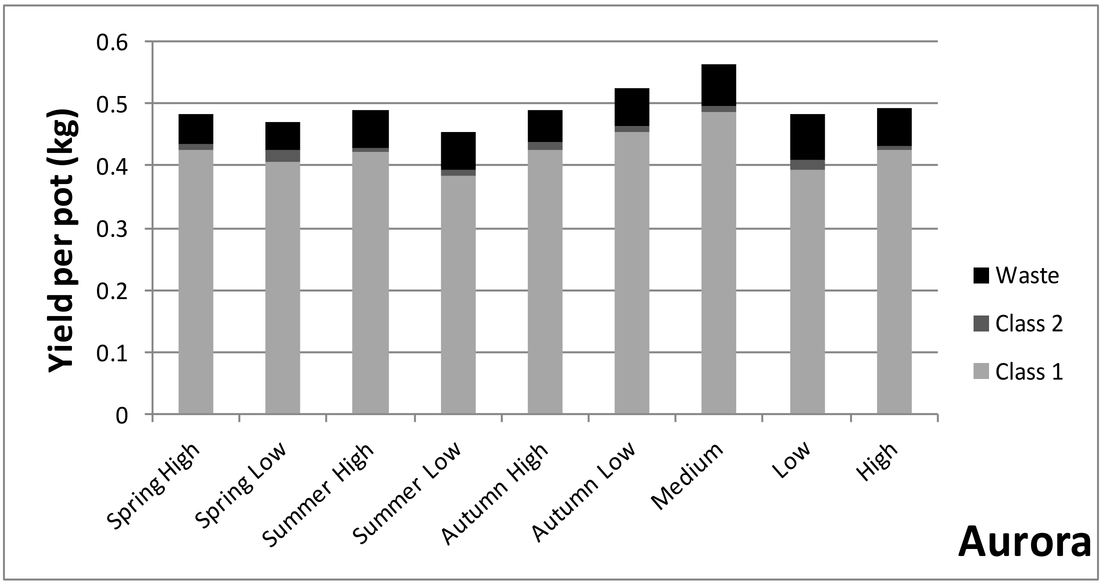

Figure 12. The effect of nitrogen treatment on the average yield per bush (kg) for Aurora.

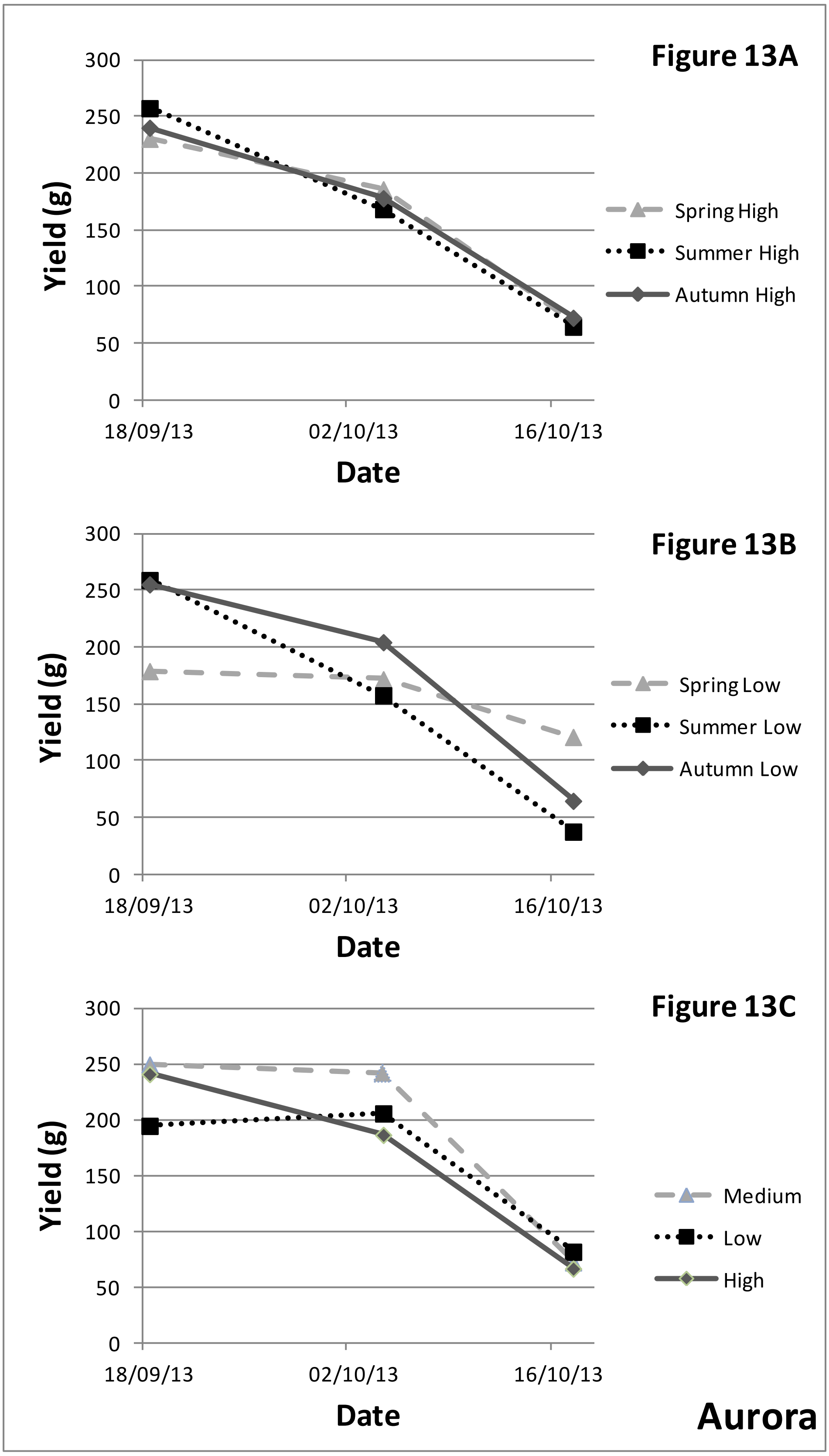

Figure 13. The effect of nitrogen treatment on the yield profile per bush for Aurora.

Treatment	Average Class 2 yield per bush (g)
Spring High	8.0 ***(a)***
Spring Low	20.9 ***(c)***
Summer High	9.1 ***(ab)***
Summer Low	9.0 ***(ab)***
Autumn High	10.0 ***(ab)***
Autumn Low	10.0 ***(ab)***
Medium	9.0 ***(ab)***
Low	15.2 ***(bc)***
High	8.2 ***(a)***

Table 4. The effect of nitrogen treatment on the Class 2 yield (g) per bush for Aurora. The letters show significant differences between treatments (P= 0.0033).

Duke

The largest yield harvested was from the spring low treatment, which averaged 0.96kg per bush compared to the lowest yield of 0.71kg from the high treatment (see Figure 14). The lower yields obtained by the high treatment resulted from a reduction in the yield harvested from the third and fourth pick in the cropping profile (see Figure 15C). The low nitrogen treatments had larger yields than those of the corresponding high nitrogen treatments. There was a significant difference of treatment upon the Class 2 yield (P=0.0029), whereby the low treatment had the least and high had the most.

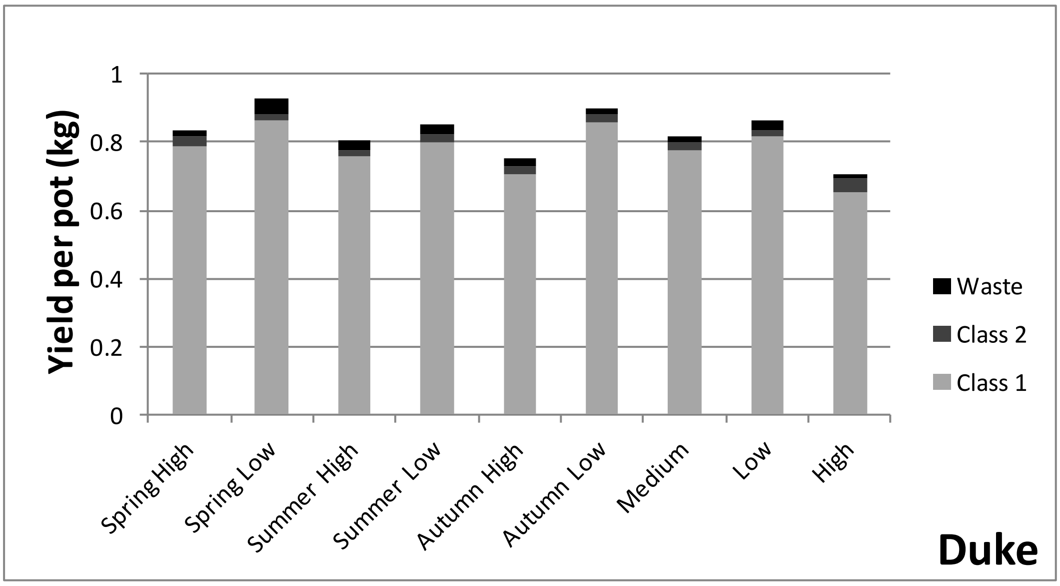

Figure 14. The effect of nitrogen treatment on the average yield per bush (kg) for Duke.

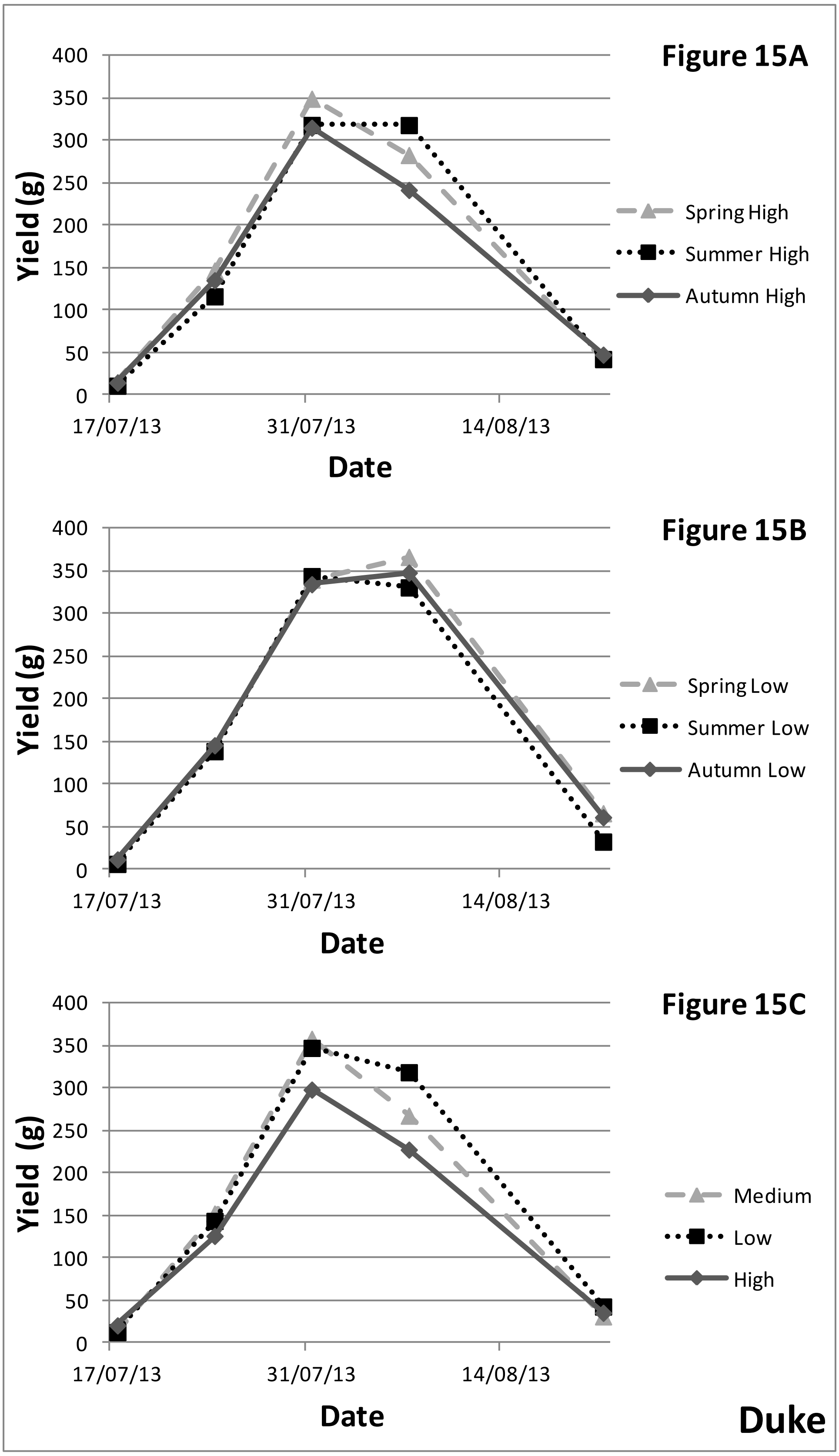

Figure 15. The effect of nitrogen treatment on the yield profile per bush for Duke.

Treatment	Average Class 2 yield per bush (g)
Spring High	29.5 ***(b)***
Spring Low	17.5 ***(ab)***
Summer High	21.5 ***(ab)***
Summer Low	23.2 ***(ab)***
Autumn High	25.2 ***(ab)***
Autumn Low	21.5 ***(ab)***
Medium	23.7 ***(ab)***
Low	14.4 ***(a)***
High	43.9 ***(c)***

Table 5. The effect of nitrogen treatment on the Class 2 yield (g) per bush for Duke. The letters show significant differences between treatments (P= 0.0033).

Fruit size

Aurora

The fruit size (g) across the season varied from 1.2 to 1.5g per treatment with the smallest fruit harvested from the low and spring low treatments, which were significantly smaller than those of the remaining treatments. The largest berries were harvested from the summer low, autumn low and high treatments.

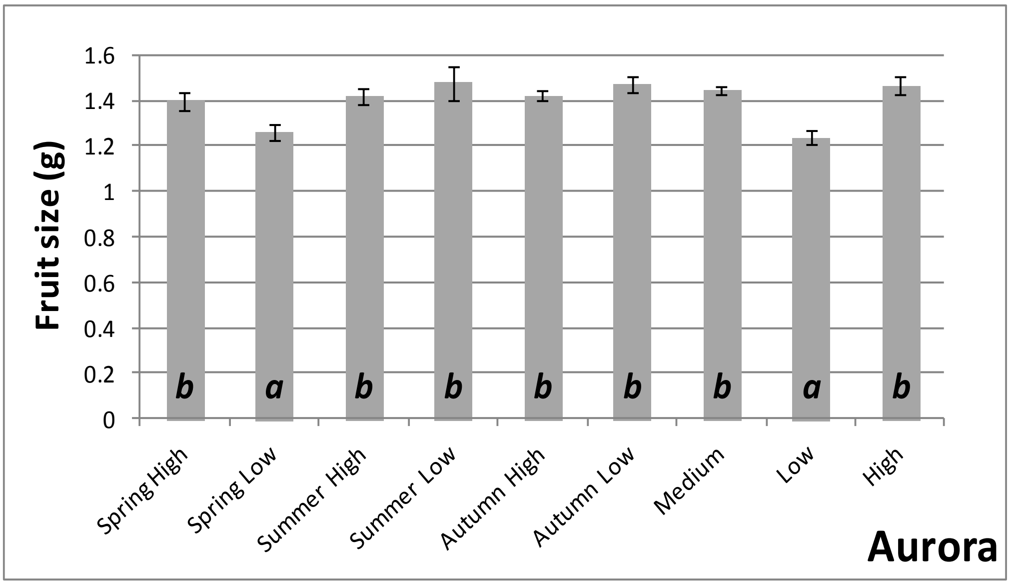

Figure 16. The effect of nitrogen treatment on the average fruit size for Aurora. Standard error bars are shown and the letters show significant differences between treatments.

Duke

The fruit size from the high nitrogen treatment was significantly smaller than those of the remaining treatments. The largest fruit harvested were from the low, spring low and summer low treatments.

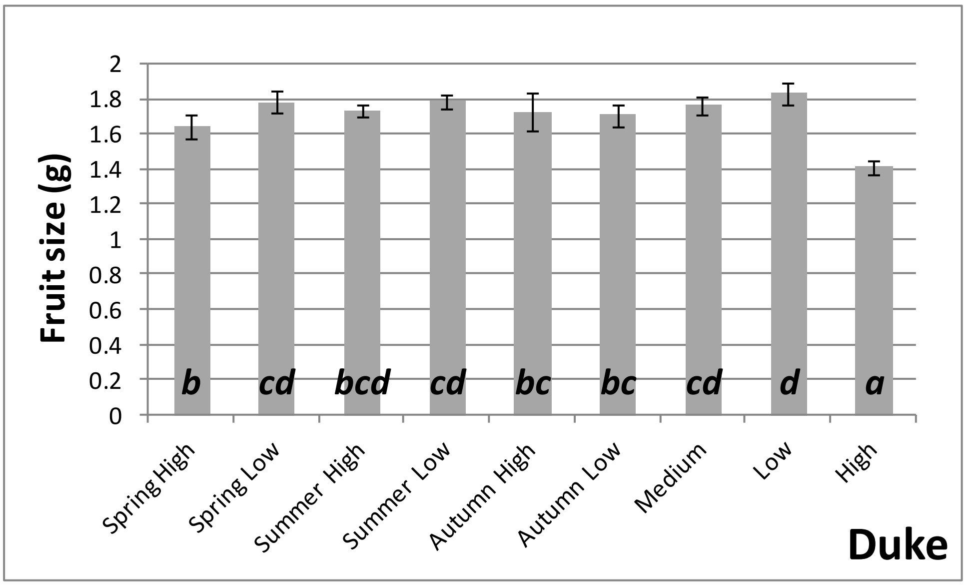

Figure 17. The effect of nitrogen treatment on the average fruit size for Duke. Standard error bars are shown and the letters show significant differences between treatments.

Fruit diameter

Aurora

There was a significant effect of nitrogen treatment on the berry size of the treatments, with the autumn low and spring high treatments producing the largest fruit (see Figure 18).

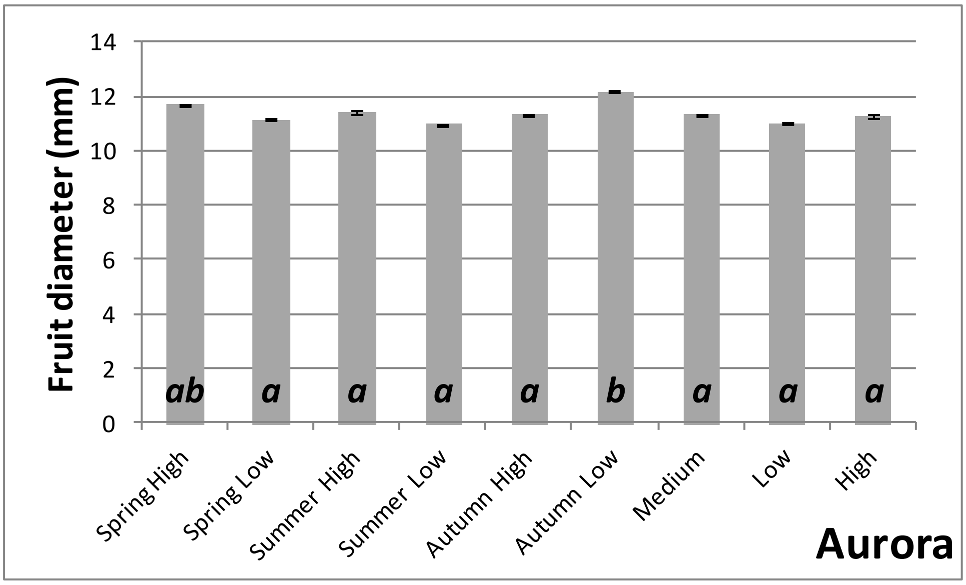

Figure 18. The effect of nitrogen treatment on the average berry diameter for the Aurora. Standard error bars are shown.

Duke

The high nitrogen treatment had a fruit diameter significantly less than the majority of the other treatments with the exception of spring high. The low treatment had the largest berry size of more than 15mm. The autumn low and summer high treatments also had larger fruit in comparison to the remaining treatments (see Figure 19).

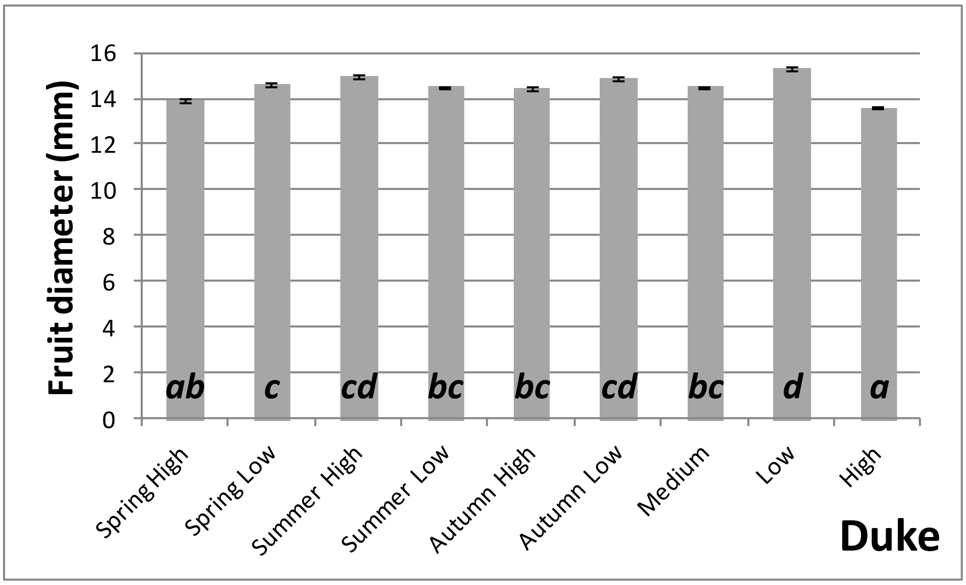

Figure 19. The effect of nitrogen treatment on the average berry diameter for the Duke. Standard error bars are shown.

Total soluble solids

A random sample of 25 ripe fruit were taken from each treatment for the testing of total soluble solids (Brix°) at the first pick of each variety, on 17 July and 4 October for the Duke and Aurora respectively.

Aurora

There was a significant effect of treatment upon the total soluble solids with a Brix of 10.5° from the autumn low treatment compared to the 12° of the spring high (see Figure 20).

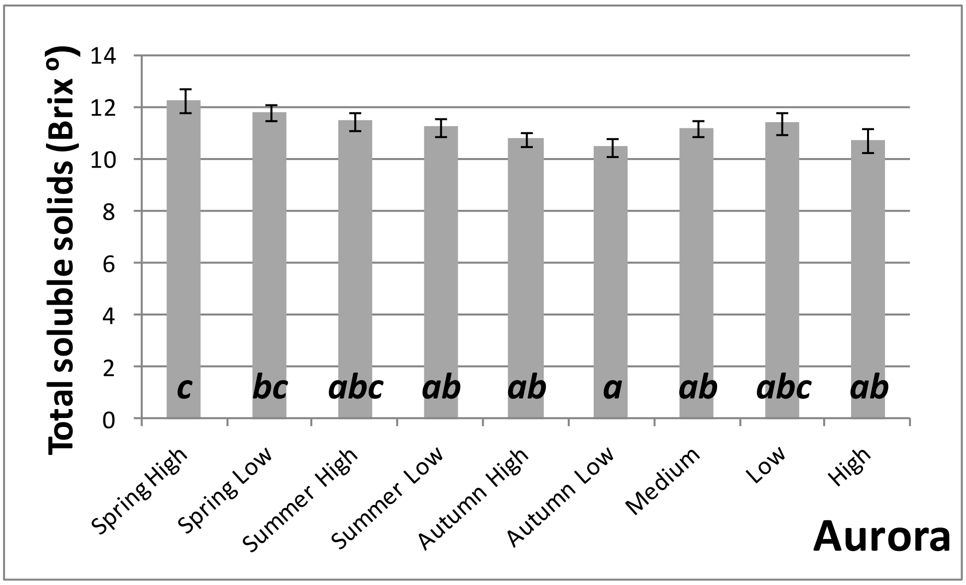

Figure 20. The effect of nitrogen treatment on the total soluble solids (Brix°) of the Aurora. Standard error bars are shown. The letters show significant differences between treatments.

Duke

Whilst the spring low treatment had a high Brix° for the Aurora, it was amongst the lowest readings from the Duke. The spring high treatment gave high readings in both of the varieties.

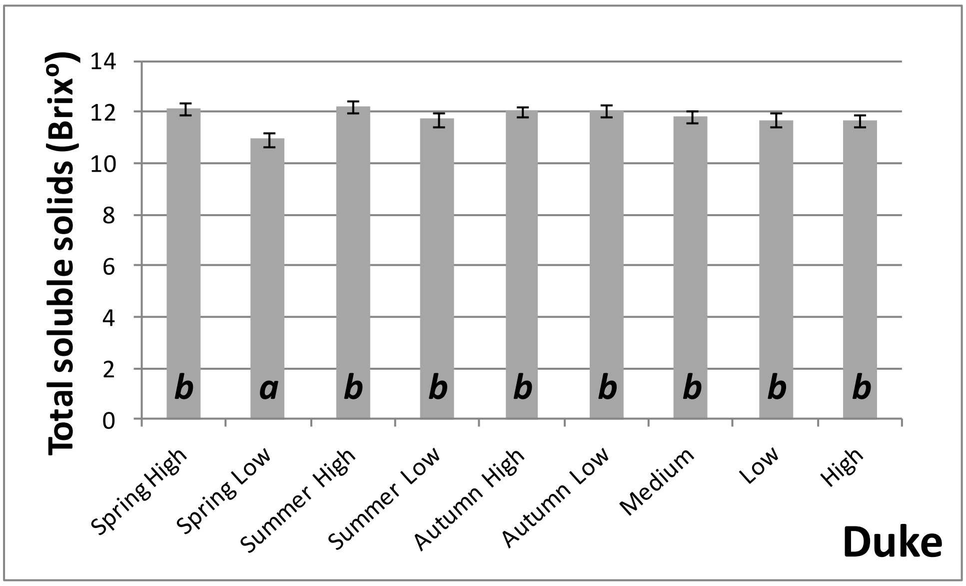

Figure 21. The effect of nitrogen treatment on the total soluble solids (Brix°) of the Duke. Standard error bars are shown. The letters show significant differences between treatments.

Fruit storability

The effect of nitrogen treatment on the storability of fruit was tested for the Aurora by placing a sample of 150g marketable fruit into an air cold store at 2°C at Brogdale and assessed fortnightly for eight weeks. Fruit was deemed to be non-marketable based on storage disorder symptoms such as wrinkled fruit, fruit collapse and *Botrytis*. When fruit became unmarketable, it was removed from the sample. The Duke also was placed into the air cold store and the same assessments made. In addition, 150g samples were also placed into a CA store at Hall Hunter Partnership and assessed at four and eight weeks.

Aurora

After four weeks in the air store, between 15 and 25% of the samples were non-marketable and this had increased to 50 to 70% by eight weeks (see Figure 22). Although not statistically significant, there were differences evident in storage potential with the autumn low having larger numbers of unmarketable fruit at the end of the eight weeks compared to the spring low treatment.

A considerable amount of the fruit classed as non-marketable occurred as a result of the dehydration of the fruit causing the skin to wrinkle and resulted in losses of up to 50% by week 8 (see Figure 23D). Differences in the number of fruit observed with wrinkles began to appear after four weeks of storage, and the medium and spring high treatments were particularly affected. Fruit collapse had also accounted for up to 20% of the original samples by the end of eight weeks storage. Losses in the low treatment were initially higher than the other treatments and by week 6 there were significant differences (see Table 6). Significant differences were also observed after eight weeks for the losses as a result of *Botrytis*, whereby the high nitrogen treatment developed the most infection and the low treatment significantly less (see Table 7).

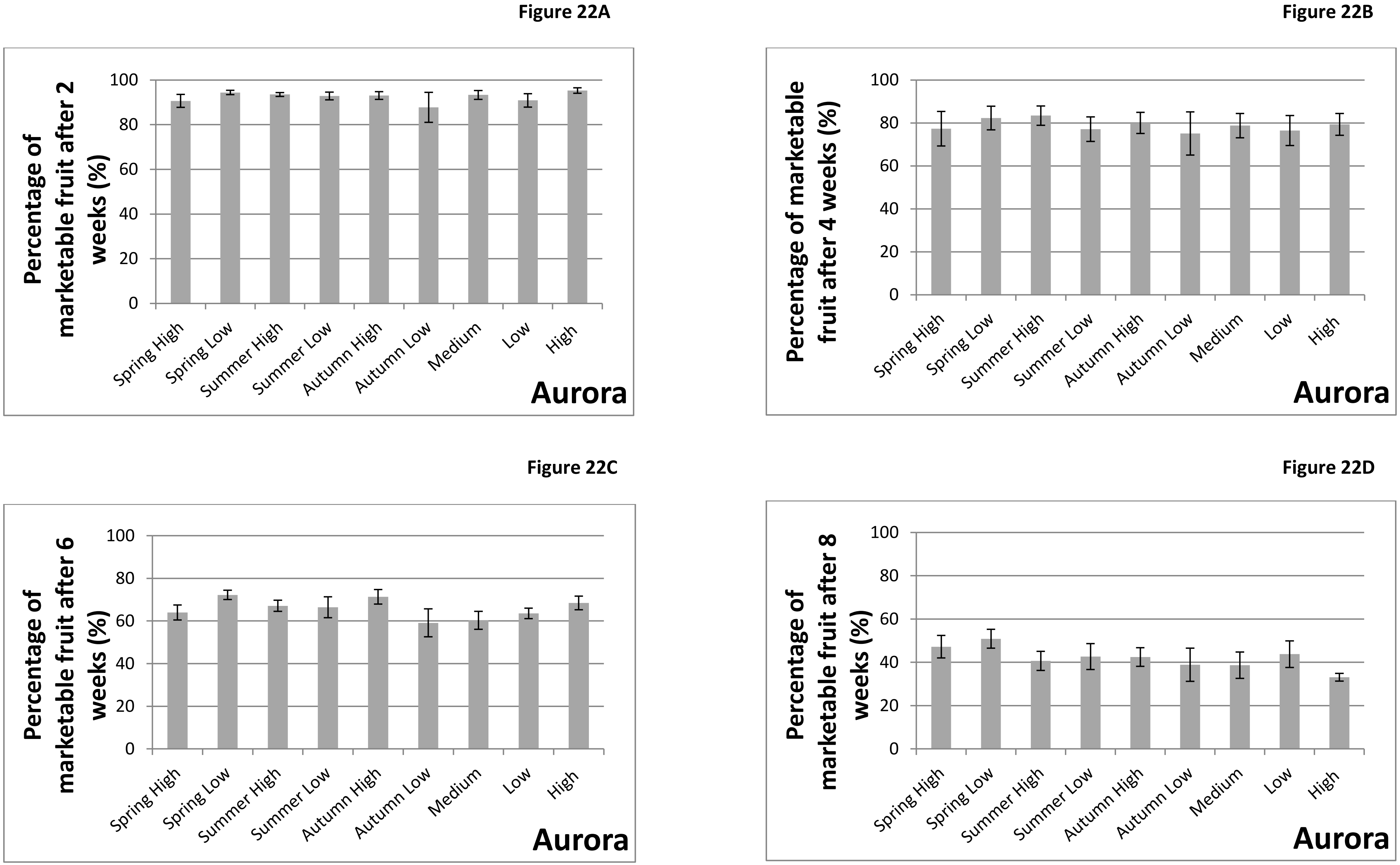

Figure 22. The effect of nitrogen treatment on the percentage of marketable fruit after 2, 4, 6 and 8 weeks of storage for Aurora. Standard error bars are shown.

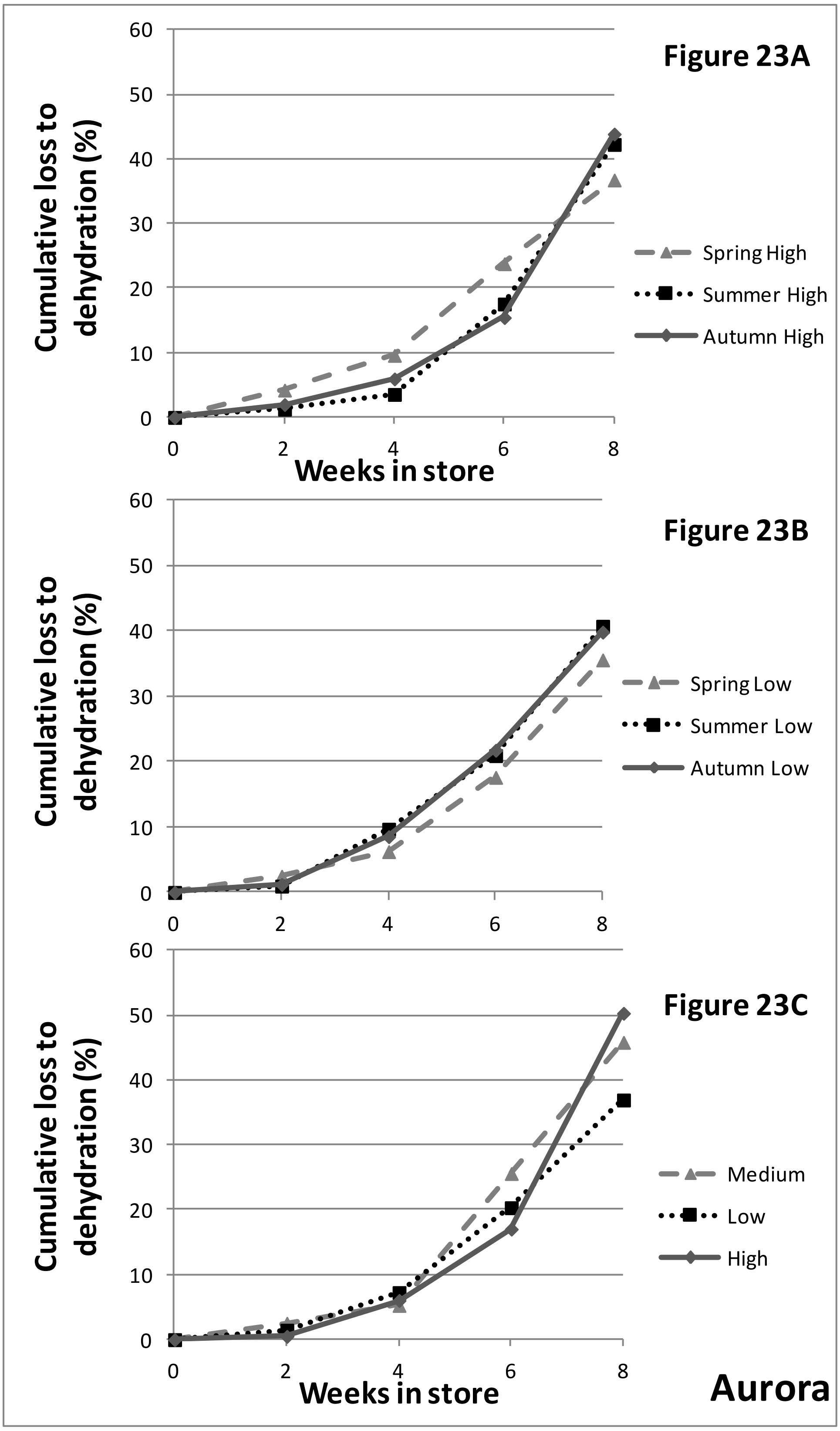

Figure 23. The effect of nitrogen treatment on the loss of Aurora storage samples due to fruit dehydration.

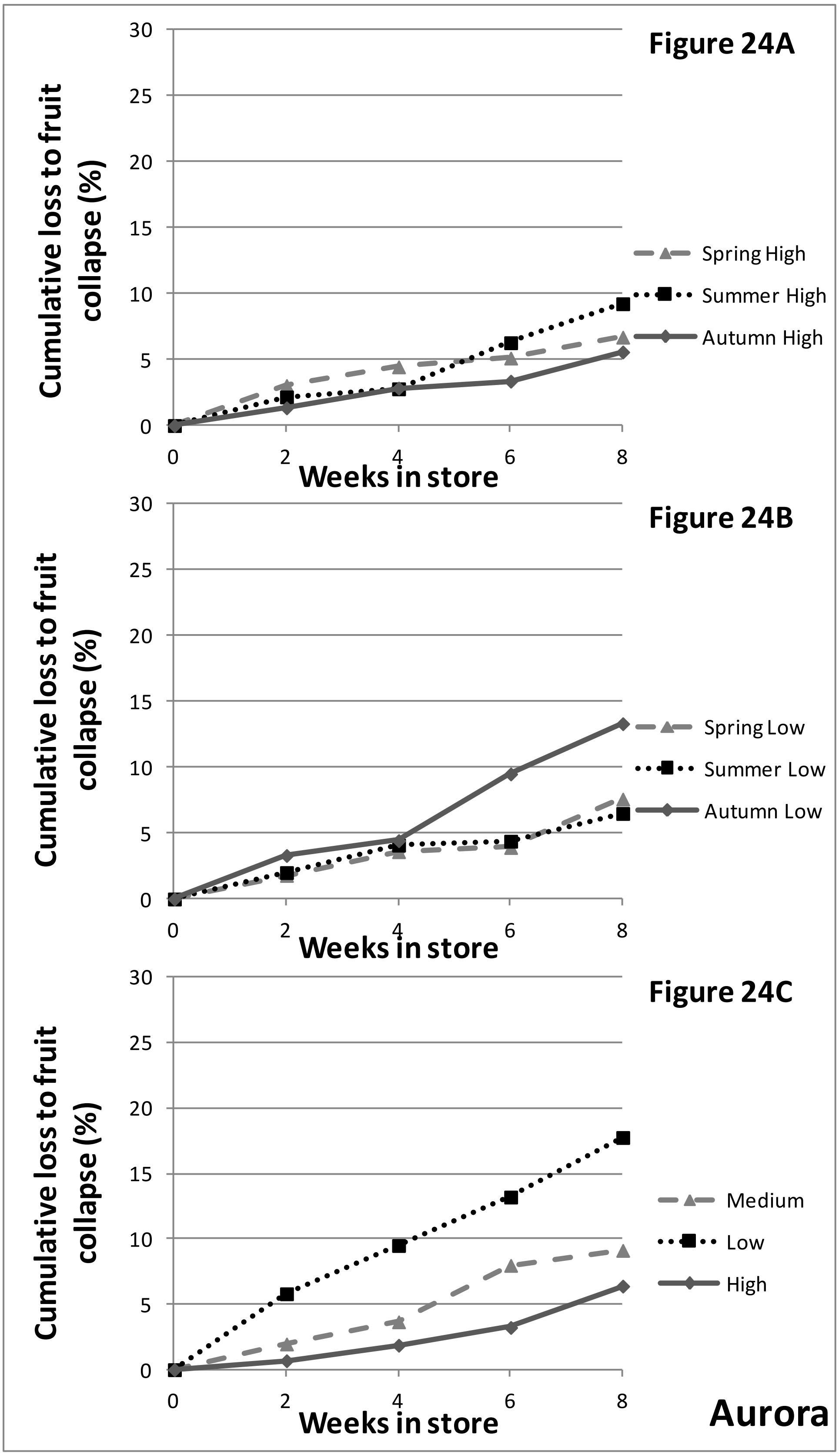

Figure 24. The effect of nitrogen treatment on the loss of Aurora storage samples due to fruit collapse.

Treatment	**Cumulative loss to fruit collapse by week 6 (%)**	**Cumulative loss to fruit collapse by week 8 (%)**
Spring High	5.1 ***(ab)***	6.7 ***(ab)***
Spring Low	3.9 ***(a)***	7.6 ***(ab)***
Summer High	6.3 ***(ab)***	9.2 ***(abc)***
Summer Low	4.4 ***(a)***	6.5 ***(a)***
Autumn High	3.4 ***(a)***	5.8 ***(a)***
Autumn Low	9.5 ***(bc)***	13.3 ***(cd)***
Medium	8.0 ***(bc)***	9.1 ***(bcd)***
Low	13.2 ***(c)***	17.8 ***(d)***
High	3.2 ***(a)***	6.4 ***(a)***
P value	*0.0015*	*0.0031*

Table 6. The effect of nitrogen treatment on the cumulative fruit collapse loss (%) for Aurora. The letters show the significance of differences between the treatments.

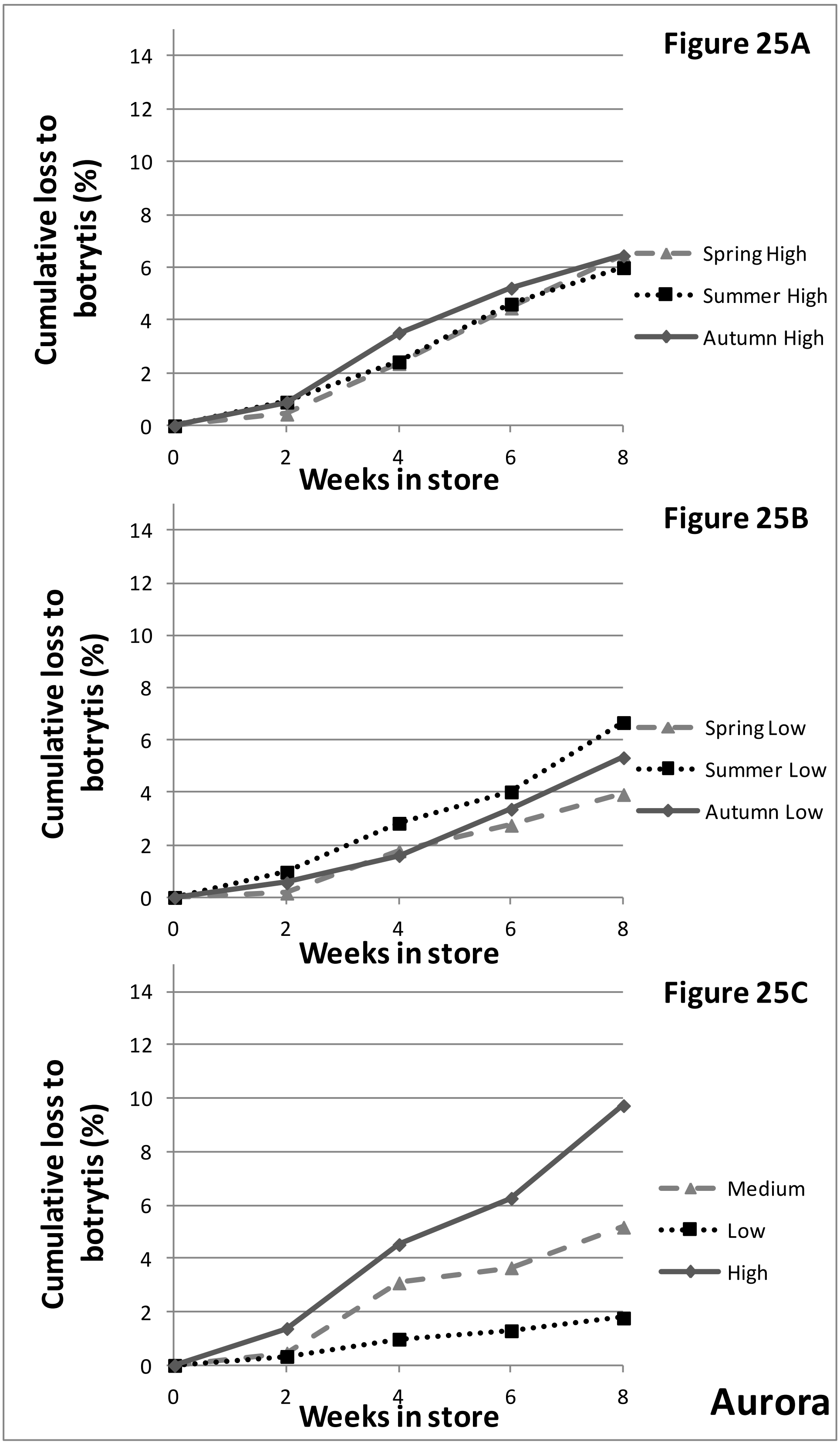

Figure 25. The effect of nitrogen treatment on the loss of Aurora storage samples due to *Botrytis*.

Treatment	Cumulative loss to *Botrytis* by week 8 (%)
Spring High	6.4 ***(bc)***
Spring Low	3.9 ***(ab)***
Summer High	6.0 ***(bc)***
Summer Low	6.7 ***(bc)***
Autumn High	6.5 ***(bc)***
Autumn Low	5.3 ***(bc)***
Medium	5.2 ***(ab)***
Low	1.8 ***(a)***
High	9.7 ***(c)***
P value	*0.0161*

Table 7. The effect of nitrogen treatment on the cumulative loss to *Botrytis* (%) for Aurora. The letters show the significance of differences between the treatments.

Duke

After 8 weeks of CA storage there were few unmarketable fruit in comparison to the air storage. Autumn low had the least non-marketable fruit averaging just 1.7% of the samples, significantly less than the spring high, summer high and low nitrogen and the medium treatments (see Table 8).

Treatment	Average fruit loss after 8 weeks (%)
Spring High	6.8 ***(c)***
Spring Low	3.5 ***(abc)***
Summer High	7.9 ***(c)***
Summer Low	6.1 ***(c)***
Autumn High	5.6 ***(bc)***
Autumn Low	1.7 ***(a)***
Medium	5.3 ***(c)***
Low	2.9 ***(ab)***
High	5.1 ***(bc)***

Table 8. The effect of nitrogen treatment on the percentage of the Duke samples which were non-marketable after eight weeks of CA storage. The letters show the significance of differences between the treatments (P=0.015).

Following eight weeks of air storage the samples had just 20-40% fruit remaining marketable (see Figure 26). Autumn low had the most marketable fruit remaining for the first six weeks of storage and the high treatment also stored better in comparison to the other treatments.

At four weeks, significant differences in the dehydration of fruit became evident with the low and medium having the smallest losses (see Table 9). However, the low nitrogen treatment lost a greater amount of berries to fruit collapse whist the high and summer high had less (see Table 10). There was initially very little incidence of *Botrytis* however after 4 weeks differences could be observed with the low treatment having significantly reduced losses (see Table 11).

Figure 26A

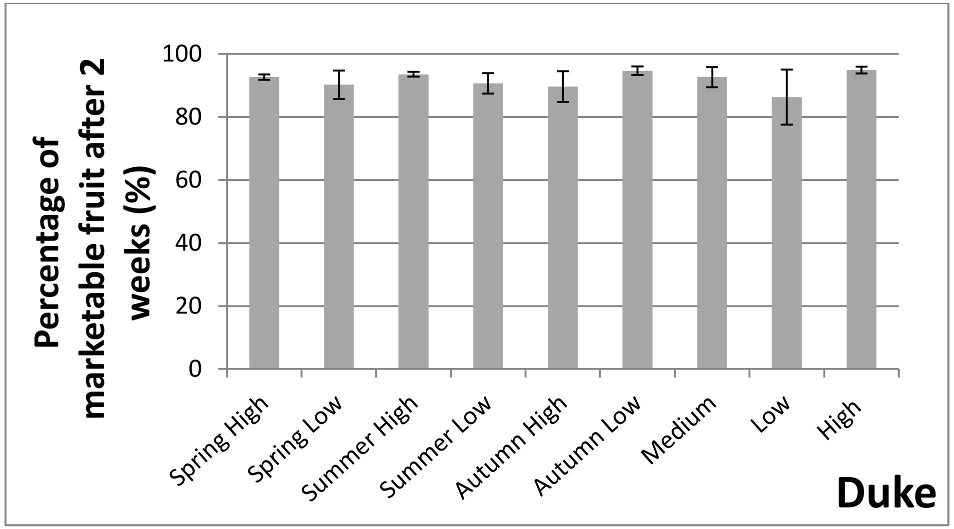

Figure 26B

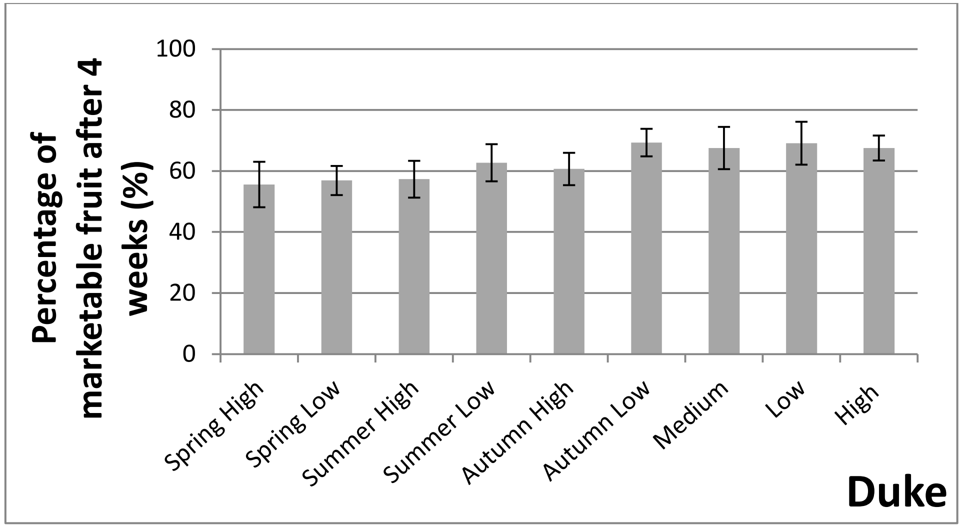

Figure 26C

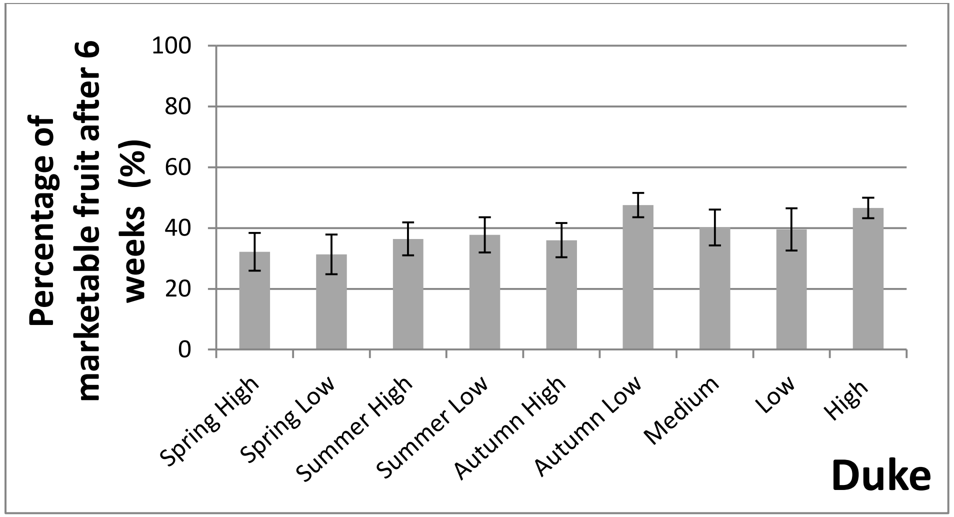

Figure 26D

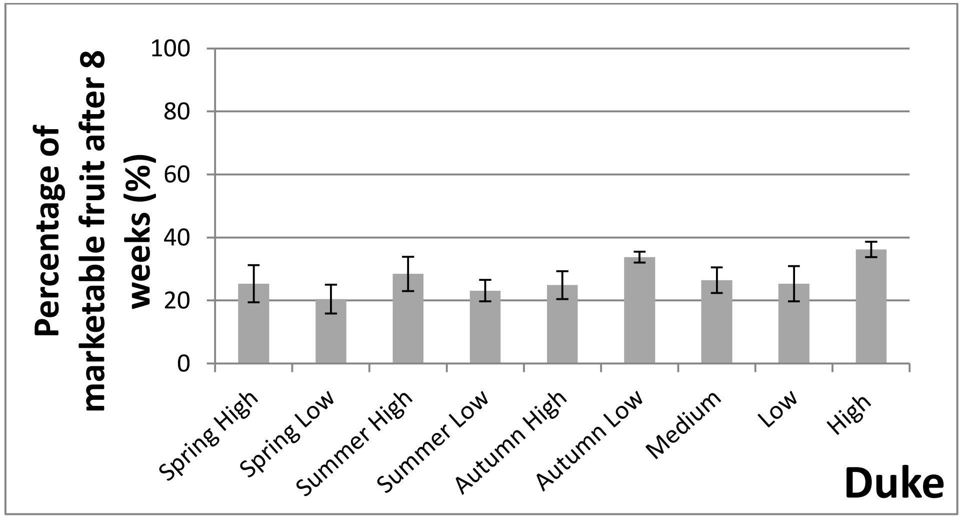

Figure 26. The effect of nitrogen treatment on the percentage of marketable fruit after 2, 4, 6 and 8 weeks of storage for Duke. Standard error bars are shown.

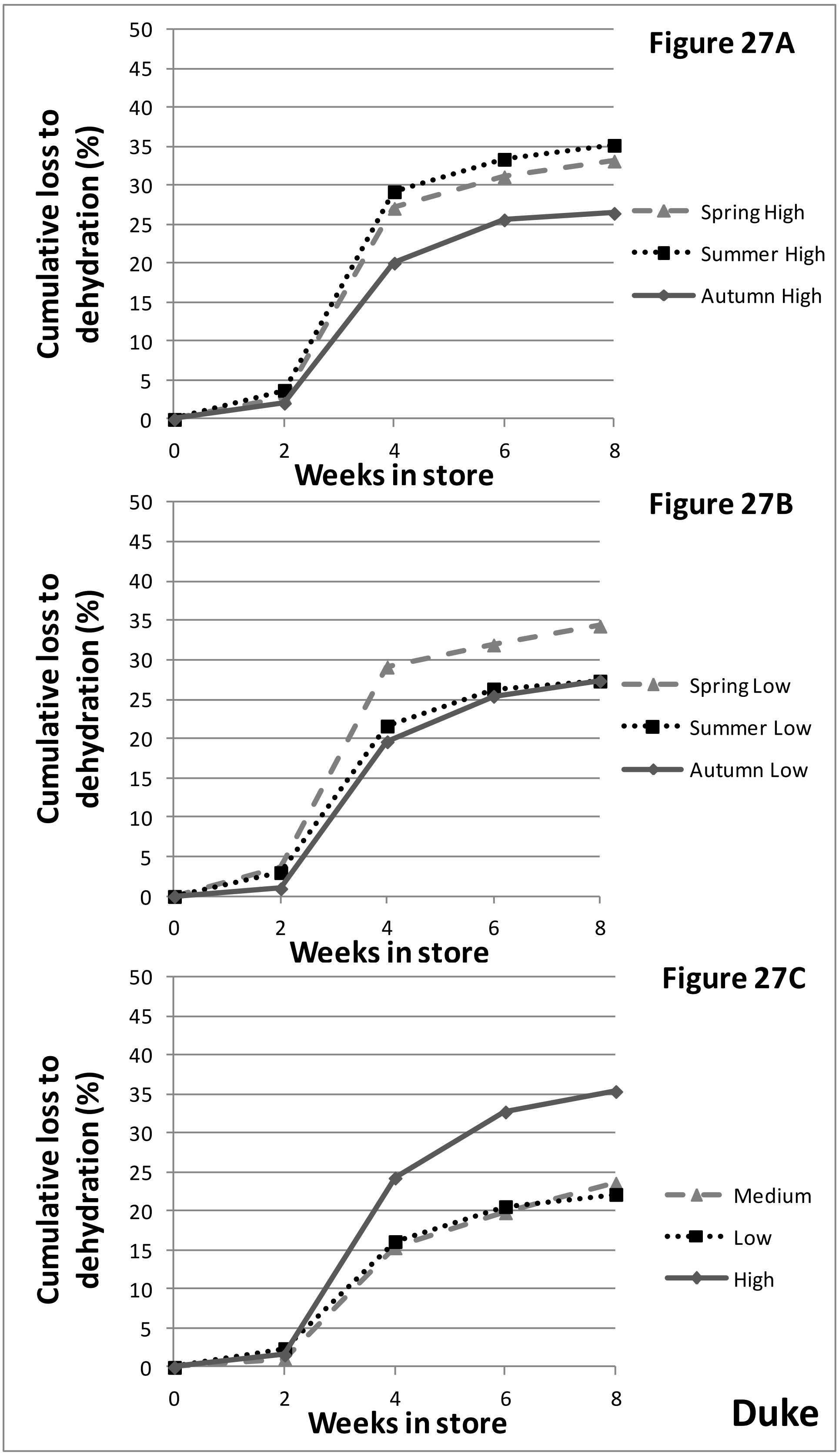

Figure 27. The effect of nitrogen treatment on the loss of Duke storage samples due to fruit dehydration.

Treatment	Cumulative loss to fruit dehydration by week 4 (%)	Cumulative loss to fruit dehydration by week 6 (%)
Spring High	27.1 ***(c)***	31.1 ***(b)***
Spring Low	29.1 ***(c)***	31.9 ***(b)***
Summer High	29.2 ***(c)***	33.4 ***(b)***
Summer Low	21.6 ***(bc)***	26.3 ***(ab)***
Autumn High	20.1 ***(abc)***	25.6 ***(ab)***
Autumn Low	19.6 ***(abc)***	25.4 ***(ab)***
Medium	15.3 ***(a)***	19.8 ***(a)***
Low	16.1 ***(ab)***	20.6 ***(a)***
High	24.3 ***(bc)***	32.8 ***(b)***
P value	*0.0132*	*0.0291*

Table 9. The effect of nitrogen treatment on the cumulative loss to fruit dehydration (%) following air storage for Duke. The letters show the significance of differences between the treatments.

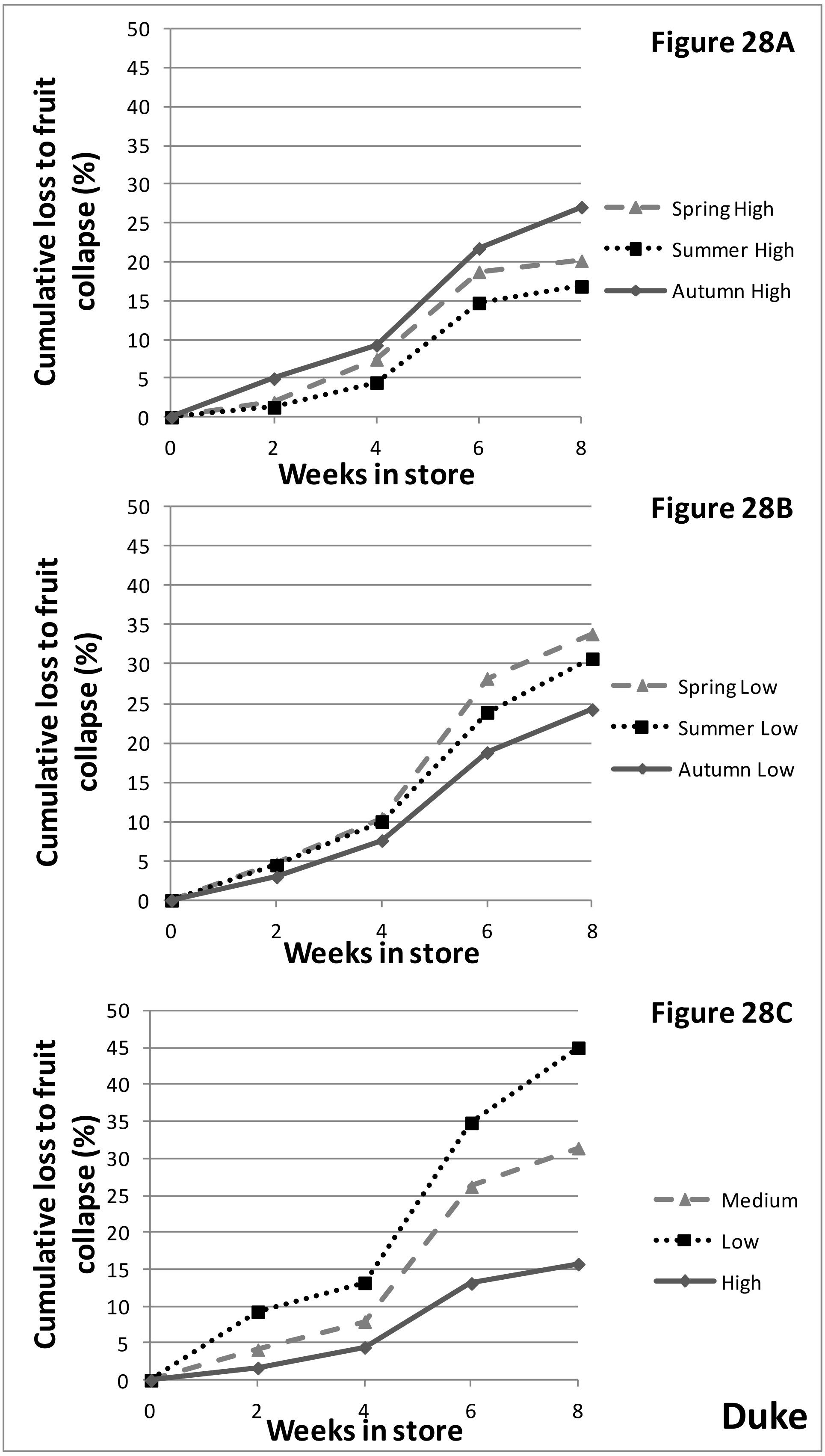

Figure 28. The effect of nitrogen treatment on the loss of Duke storage samples due to fruit collapse.

Treatment	**Cumulative loss to fruit collapse by week 6 (%)**	**Cumulative loss to fruit collapse by week 8 (%)**
Spring High	18.7 ***(ab)***	20.2 ***(ab)***
Spring Low	28.2 ***(bc)***	33.9 ***(cd)***
Summer High	14.7 ***(a)***	16.9 ***(a)***
Summer Low	23.90 ***(bc)***	30.7 ***(c)***
Autumn High	21.7 ***(ab)***	27.1 ***(bc)***
Autumn Low	18.8 ***(ab)***	24.3 ***(abc)***
Medium	26.2 ***(bc)***	31.4 ***(c)***
Low	34.8 ***(c)***	45.0 ***(d)***
High	13.1 ***(a)***	15.7 ***(a)***
P value	*0.0012*	*0.0000*

Table 10. The effect of nitrogen treatment on the cumulative loss due to fruit collapse (%) following air storage for Duke. The letters show the significance of differences between the treatments.

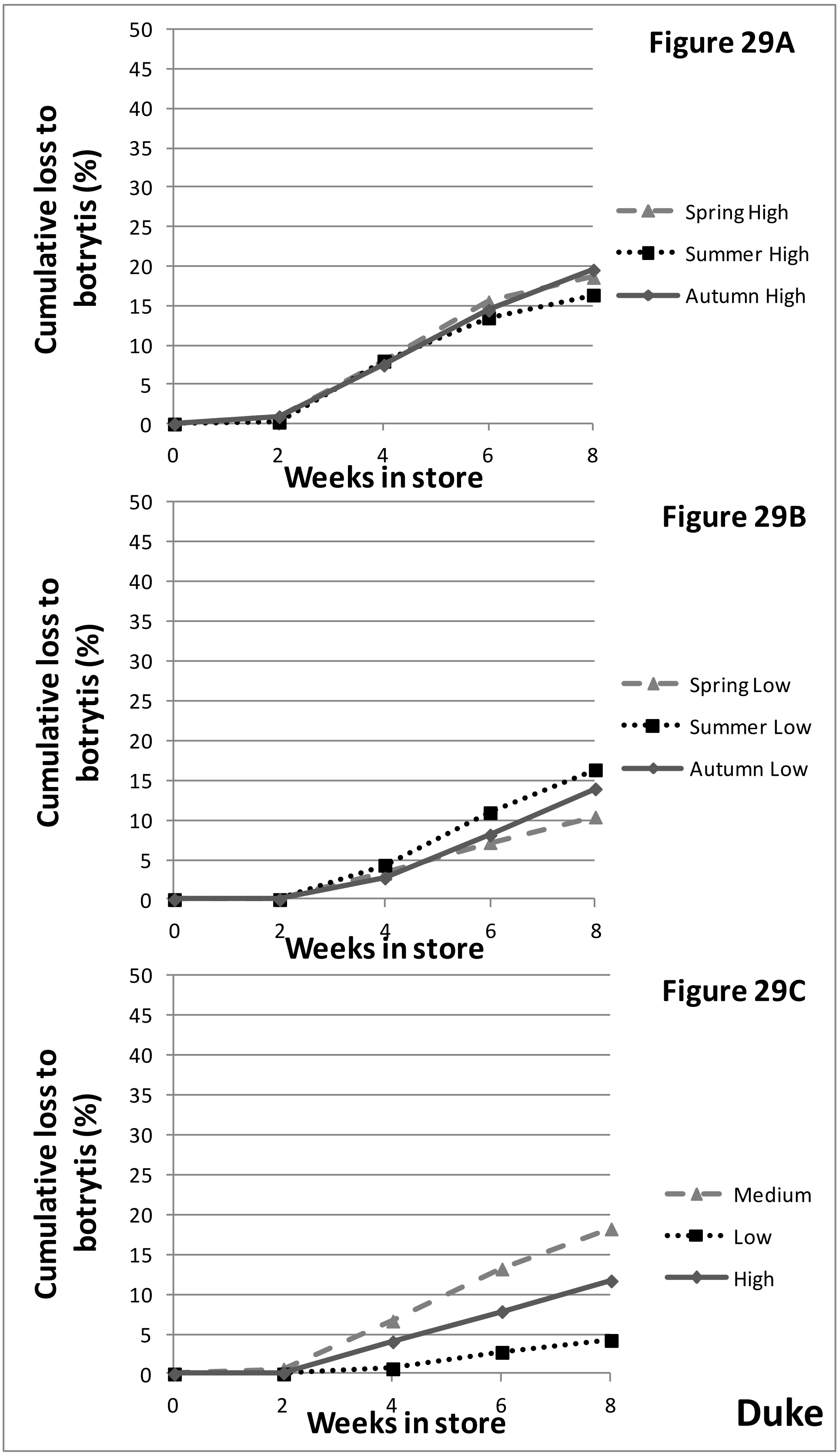

Figure 29. The effect of nitrogen treatment on the loss of Duke storage samples due to *Botrytis*.

Treatment	**Cumulative loss to *Botrytis* by week 4 (%)**	**Cumulative loss to *Botrytis* by week 6 (%)**	**Cumulative loss to *Botrytis* by week 8 (%)**
Spring High	7.9 ***(de)***	15.5 ***(d)***	18.6 ***(c)***
Spring Low	3.3 ***(bc)***	7.2 ***(b)***	10.4 ***(b)***
Summer High	8.0 ***(e)***	13.5 ***(d)***	16.4 ***(bc)***
Summer Low	4.3 ***(bcde)***	10.9 ***(bcd)***	16.3 ***(bc)***
Autumn High	7.5 ***(cde)***	14.4 ***(d)***	19.5 ***(c)***
Autumn Low	2.**7** ***(ab)***	8.1 ***(bc)***	13.9 ***(bc)***
Medium	6.7 ***(cde)***	13.2 ***(cd)***	18.2 ***(c)***
Low	0.6 ***(a)***	2.7 ***(a)***	4.2 ***(a)***
High	4.0 ***(bcd)***	7.8 ***(b)***	11.7 ***(b)***
P value	*0.001*	*0.0000*	*0.0002*

Table 11. The effect of nitrogen treatment on the cumulative loss to *Botrytis* (%) following air storage for Duke. The letters show the significance of differences between the treatments.

Vegetative growth

Three new shoots growing from the base of each blueberry bush were tagged during the spring and recorded when the nitrogen treatments were changed during the season.

Aurora

The low treatment had the least growth, significantly less than the other treatments at each recorded measurement (P=0.0014). The low treatment also had the smallest leaf number throughout the season.

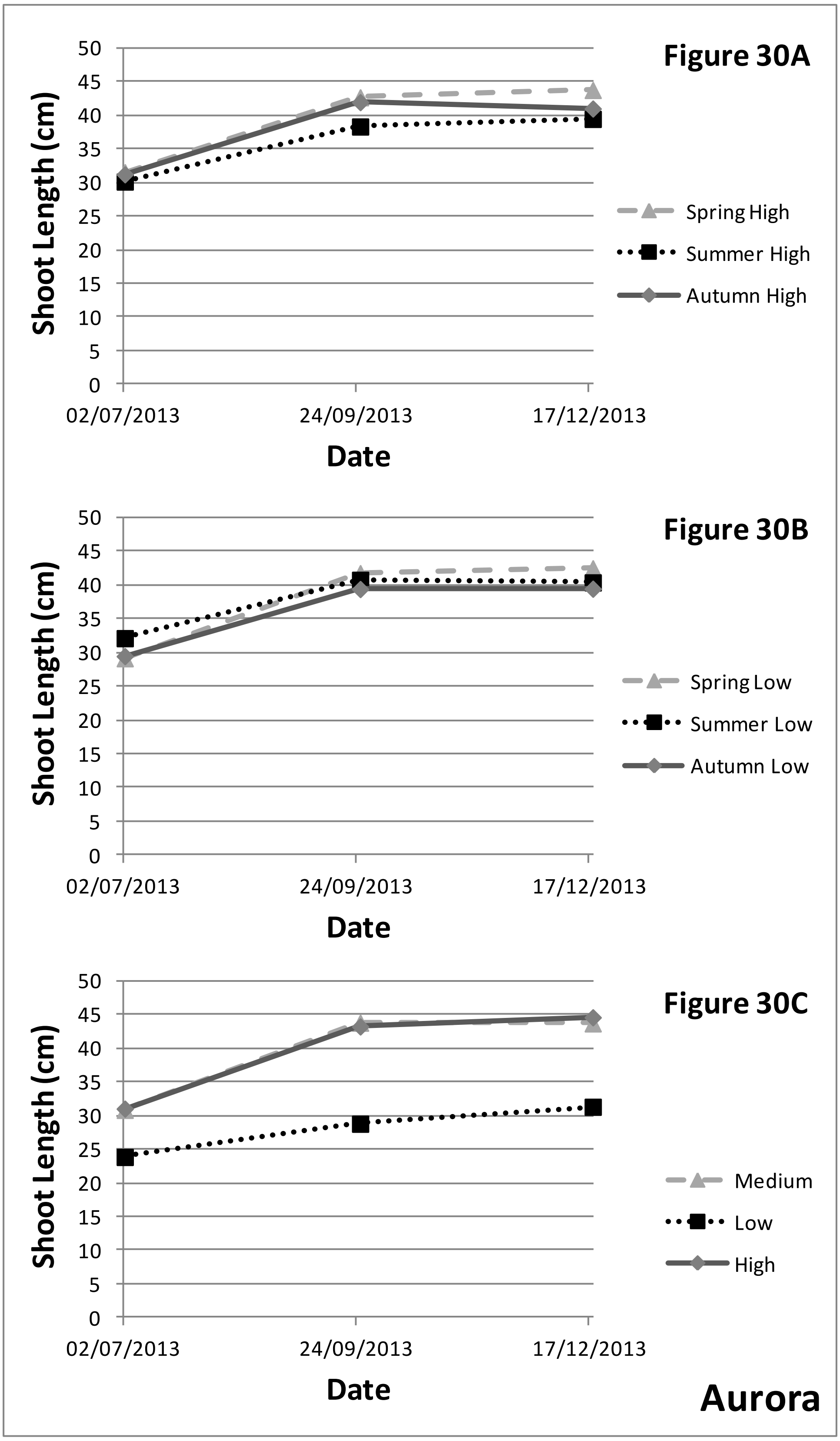

Figure 30. The effect of nitrogen treatment on the growth of tagged new shoots for Aurora.

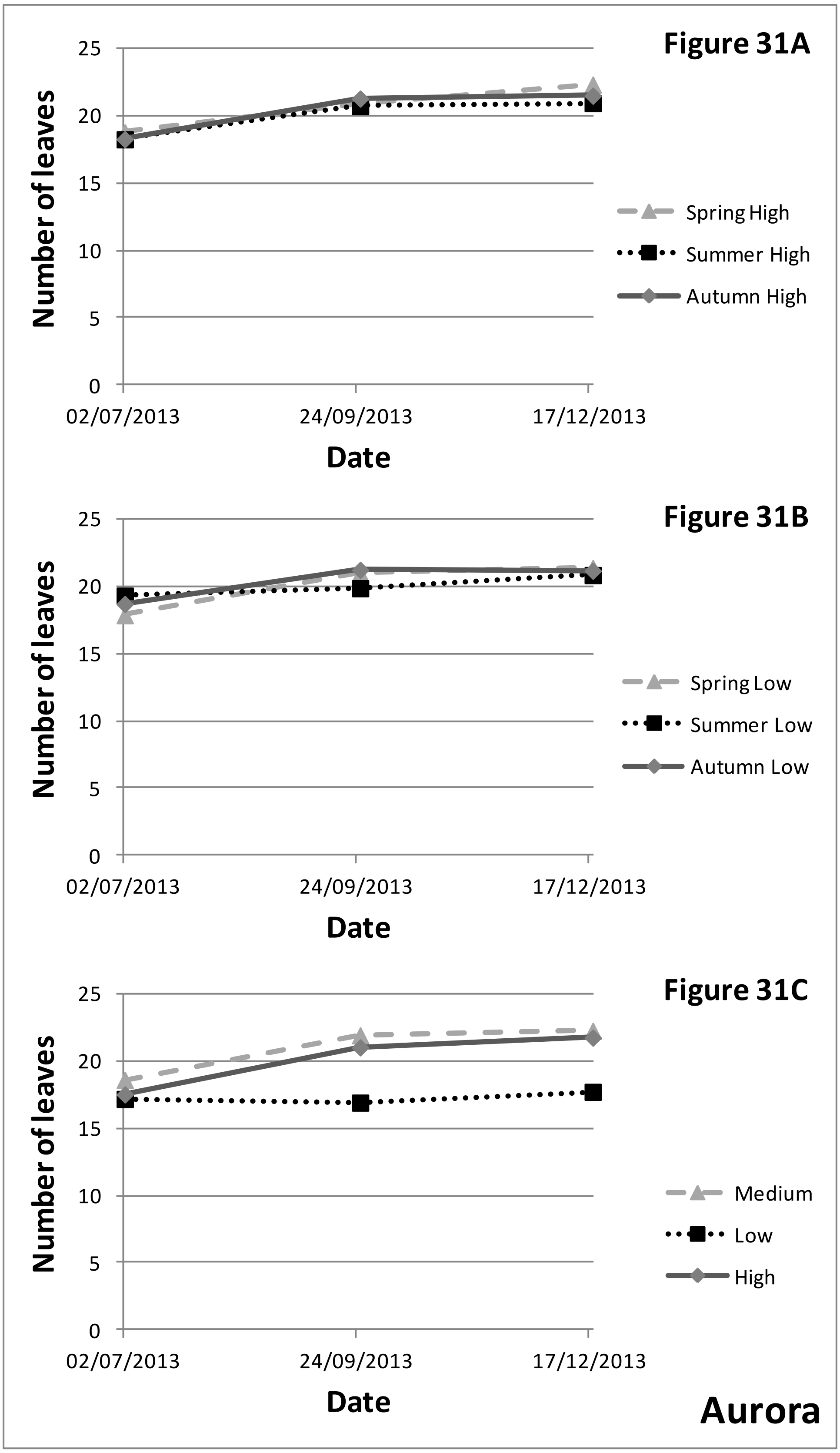

Figure 31. The effect of nitrogen treatment on the leaf number per tagged new shoots for Aurora.

Duke

Differences in the amount of extension growth became evident once the summer nitrogen treatments had been applied; however these differences were not significant. As in the Aurora, there was less growth in the low nitrogen treatment compared to the other treatments. Autumn low had the greatest extension growth from July to September, however the autumn high and spring high had the most throughout the season.

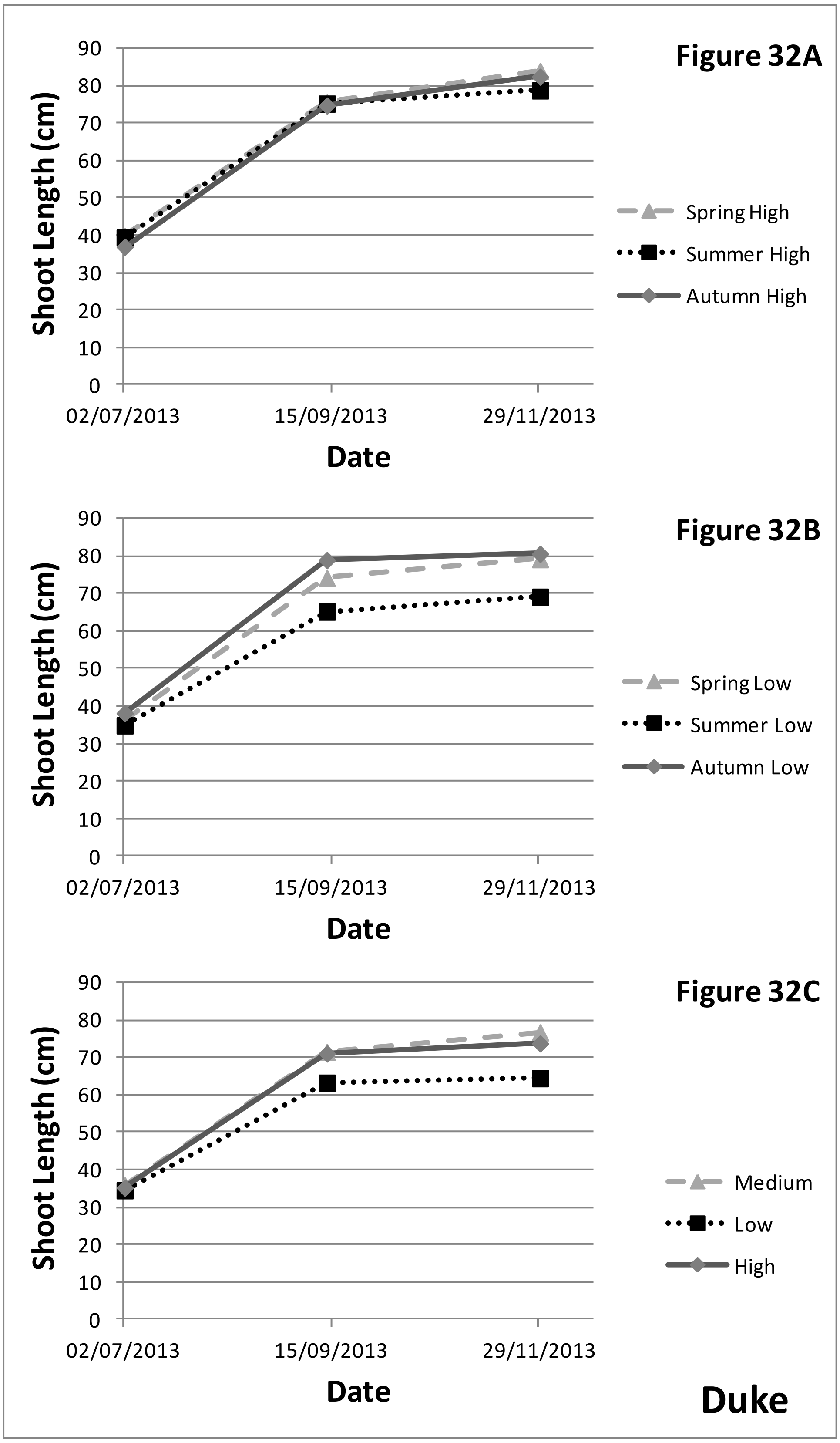

Figure 32. The effect of nitrogen treatment on the growth of tagged new shoots for Duke.

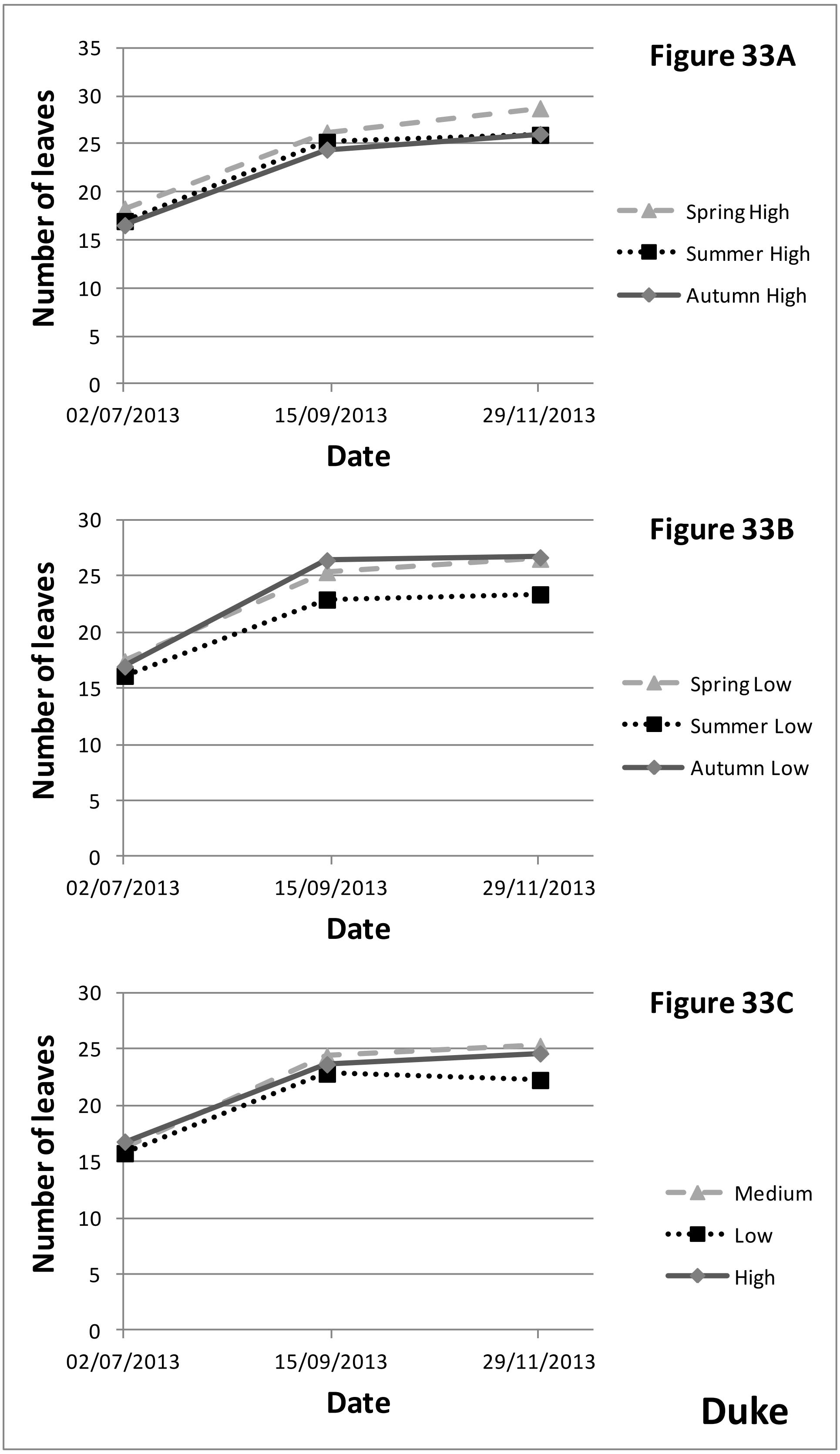

Figure 33. The effect of nitrogen treatment on the leaf number per tagged new shoots for Duke.

Feed analysis

The target nitrogen concentrations aimed for were 180, 120 and 60 mg/L for the high, medium and low respectively. Analysis showed the clear difference between the three nitrogen levels and very similar results to the previous year.

Nitrogen leaf analysis

Leaf samples were taken from each treatment for each variety in both July and September and the results can be seen in Table 12.

Aurora

The leaf nitrogen levels in July for the spring low and low treatments were lower in comparison to the other treatments. Larger variation could be seen in September where low and summer low had decreased nitrogen levels and spring high and summer high had larger values for leaf nitrogen.

Duke

The lowest nitrogen level seen in the July analysis was for the low nitrogen treatment, and the spring low was also relatively low in comparison to the other treatments. In the September analysis, the low treatment again had low levels for leaf nitrogen as did the summer low treatment.

	Aurora		**Duke**	
Treatment	**11 July**	**4 September**	**11 July**	**4 September**
Spring High	2.27	2.21	2.43	2.16
Spring Low	1.91	1.98	1.97	2.14
Summer High	2.13	2.12	2.35	2.19
Summer Low	2.14	1.65	2.34	1.64
Autumn High	2.13	1.92	2.28	2.15
Autumn Low	2.22	1.84	2.39	2.23
Medium	2.2	1.95	2.45	2.13
Low	1.9	1.5	1.64	1.53
High	2.24	1.93	2.37	2.34

Table 12. The effect of nitrogen treatment on nitrogen leaf analysis (% dry weight) for both the Aurora and Duke.

Discussion

Nitrogen usage by the plants varied according to treatment. There were differences observed in the total nitrogen in the inputs, runoff and also in the leaf analysis. There was a reduction in nitrogen in the leaf analysis taken in July for those treatments supplied with a low feed during the spring (low and spring low) and similarly, lower nitrogen was observed in the low and summer low samples in the September analysis. These levels of nitrogen are considered to be low when compared to industry leaf analysis ranges. Whether these levels are appropriate for all varieties of pot-grown blueberries in the UK remains to be seen.

There was a significant effect of treatment upon floral bud initiation in the Aurora whereby the low nitrogen treatment produced more floral buds. This suggests that increasing nitrogen concentration can inhibit floral bud production. Supplying low nitrogen levels during the autumn, when flower initiation occurs, resulted in some of the largest yields for both varieties, however these results were not significant. It is not clear as to whether these increases in yield were solely due to fruit size or fruit number.

Fruit quality was affected by nitrogen treatment, with significant differences seen in both Brix° and fruit size, dependent on nitrogen treatment. Although significant differences could be seen, the only consistent effect of treatment upon fruit diameter was that of the autumn low treatment, which was larger than most other treatments for both varieties. Although there were no significant differences seen in the percentage of non-marketable fruit following storage, there were differences in the cause of these losses. There were treatment differences in the losses from dehydration, collapse and *Botrytis*; the low nitrogen treatment particularly appeared to be more susceptible to fruit collapse and less prone to *Botrytis* than the other treatments.

Consistent with the results observed last year, the growth of Aurora shoots varied with nitrogen treatment, the low having significantly less growth than the other treatments. Although not significant, the Duke shoot growth also followed the same pattern. The low treatment showed reduced growth particularly during the summer and very little growth of any treatment occurred throughout the autumn. The high and medium nitrogen treatments produced similar amounts of vegetative growth, which may suggest that the medium treatment provides sufficient nitrogen for vegetative growth.

The effect of repeating the increasing and decreasing of nitrogen levels at different growth stages will be investigated over the next two seasons, and any cumulative effects of this may become apparent. Any differences in frost damage, if any occurs, will also be assessed during spring 2014 and 2015.

Conclusions

Floral bud production in the Aurora was affected by nitrogen treatment. Although there was no effect of treatment on marketable yield, there was an effect on the fruit quality of both varieties. Consistent with the findings from the previous season, lower nitrogen levels resulted in significantly decreased growth in the Aurora. The project will continue for another two seasons and it is likely that any cumulative effects of repeating nitrogen applications at these growth phases will become apparent.

Knowledge transfer

Holly Davies will be presenting a summary of the results of the project at the FAST Annual Growers Conference 2014.

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