Project title:	**Timing of nitrogen applications to optimise growth and yield without adversely affecting fruit storability and frost sensitivity**
Project number:	**SF 137**
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Report:	Annual Report January 2014
Previous report:	Annual Report January 2013 Annual Report January 2012
Key staff:	FAST Ltd
Location of project:	
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Date project commenced:	1st March 2012
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AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headline

Based on results so far there would seem to be little benefit in using higher levels of nitrogen throughout the season in container grown blueberry.

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).

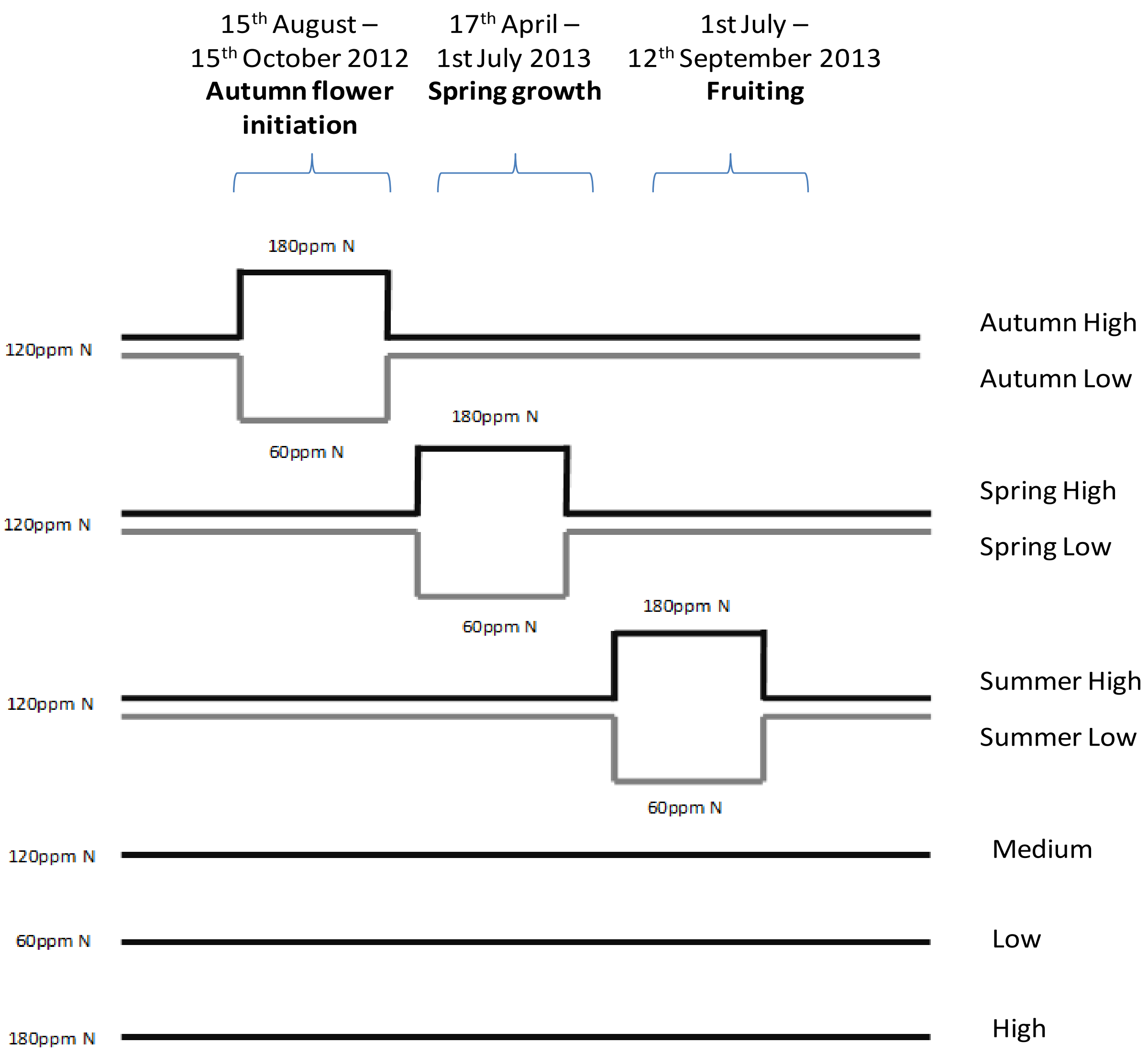


Figure 1 The treatments which were applied in Objective 2 of the project

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^{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.

Combined results for Objectives 1 and 2 in 2012 and 2013

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.

Results for Objective 2 in 2013 and 2014

The effect of increasing and decreasing nitrogen levels at different growth stages was repeated from autumn 2013 until autumn 2014.

The decrease in shoot growth in Duke observed for the low N treatment in 2012 and 2013 was not seen in 2014.

The differing nitrogen levels did not have an effect upon overall yield for either variety; however the high nitrogen treatment did produce a significant increase in fruit number for Duke. It also produced the smallest fruit in comparison to other treatments, whilst the low treatment produced significantly larger fruit. The high treatment had large early picks in comparison to other treatments, whilst the low nitrogen treatment had larger picks towards the end of the picking season.

The nitrogen treatment had an impact on storage potential for Aurora; the low nitrogen treatment had the most marketable fruit following a storage trial, as was seen in 2013. In 2014 this improvement in storage life was largely as a result of fewer incidences of fruit collapse and *Botrytis.* The high and summer high treatments were amongst those with the greatest Brix (°) for Duke.

Winter 2013/2014 and the subsequent spring were unusually mild in the south east of England with no harsh frosts, so conclusions could not be drawn on the impact of nitrogen nutrition on frost hardiness.

Main conclusions drawn from 2014

- There were no treatment effects on overall yield or quality class for the variety Aurora.
- There were impacts of nitrogen treatment on storage potential for Aurora.
- There was no effect of nitrogen treatment seen on shoot growth or total yield (kg) in 2014.
- There was a significant difference in berry weight and fruit size between treatments for Duke.
- There was a significant difference in cropping profile between treatments for Duke.
- There were differences in Brix (°) as a result of nitrogen treatment for Duke.

The project will continue for another season and it is likely that any cumulative effects of repeating nitrogen treatments will become apparent.

Financial benefits

The financial benefits of this project are very difficult to quantify with confidence at this stage. The reduced fertiliser costs and improved marketable yield through better storage life demonstrated in the work will offer some financial benefit. If the impact of low N on fruit size in Duke is repeated, it could offer a saving in picking costs.

Action points for growers

In view of the fact that this trial has one more season to run before completion, any conclusions and action points arising from them must be regarded as provisional. Based on results so far it would appear that:

- Low rates of nitrogen reduced growth rates in Duke during the first two years of the trial but had no effect in 2014. This effect on growth did not have any apparent impact on yield.
- The variety Aurora showed no response in terms of improved growth or yield to increasing levels of nitrogen.
- Low N reduced storage losses in 2013 and 2014.
- Increasing nitrogen levels to 180 mg/L during the summer gave higher Brix (º) in Duke berries in both 2013 and 2014.

Based on results so far there would seem to be little benefit in using higher levels of nitrogen throughout the season, though increasing N in the summer could improve Brix (º) levels in Duke. Lower nitrogen rates would lead to reductions in fertiliser costs and even less environmental impact.

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 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. Throop and Hanson (1997) suggest that as nitrogen is retained in the plants, increasing nitrogen levels late in the season may benefit bushes in the following season. However, 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 (Sønsteby *et al*, 2009).

The U.K is largely reliant on pot grown systems for blueberries, primarily because of problems associated with soil type and pH. Bushes are usually fed using drip irrigation with a specific blueberry feed. Manipulating feed in pot grown blueberries generally has more effect than on soil grown bushes due to the buffering capacity of the soil. This gives the grower 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 cultivars such as Duke and late production with cultivars 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 reductions in storage life, possibly through effects on fruit cell wall development 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. This 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. 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. Commercial experience suggests using at least 50% of nitrogen in the form of ammonium. In the project described here, a combination of potassium nitrate, monoammonium phosphate and ammonium sulphate was 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 and affect yield the following year. 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, a higher nitrogen level would favour growth and 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 has 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 will be 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) will be tested. Throughout the duration of the project, the growth, yield and fruit development will be 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 running at Brogdale Farm, Faversham, Kent. Three-year old blueberry bushes of the cultivars Duke and Aurora were sourced from Hall Hunter Partnership (HHP) in 25L pots on 6th 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-five main structural branches and for Aurora, plants with two-three main structural branches were selected.

On arrival at Brogdale, the pots of the cultivar Duke were placed on black Mypex floor covering in a Spanish Tunnel. 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 60mg/L N, 120mg/L N or 180mg/L N from March to October 2012. Ninety plants of each cultivar were arranged in a randomised block design with six blocks 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 cultivar along with shelf life.

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

Separate batches of 252 plants of each cultivar were 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 120mg/L N from April to August 2012. At this point, on 15th August 2012, the first nitrogen regimes started with the application of the autumn treatments. Timings were based on specific growth stages.

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 (see Figure 2). It should be noted that all dates vary according to the season (the 2014 season dates are mentioned in Table 1).

Treatments

'Autumn High'. A nitrogen level of 180mg/L was applied from the end of harvest until 90% leaf fall and then 120mg/L was applied from bud break until the end of harvest.

'Autumn Low'. A nitrogen level of 60mg/L was applied from the end of harvest until 90% leaf fall and then 120mg/L was applied from bud break until the end of harvest.

'Spring High'. A nitrogen level of 120mg/L was applied from the end of harvest until 90% leaf fall. 180mg/L was then applied from bud break until first green fruit and then decreased again to 120 mg/L until the end of harvest.

'Spring Low'. A nitrogen level of 120mg/L was applied from the end of harvest until 90% leaf fall. 60mg/L was then applied from bud break until first green fruit and then increased again to 120mg/L until the end of harvest.

'Summer High'. A nitrogen level of 120mg/L was applied from the end of harvest until 90% leaf fall and from bud break until first green fruit. This was then increased to 180mg/L from first green fruit until the end of harvest.

'Summer Low'. A nitrogen level of 120mg/L was applied from the end of harvest until 90% leaf fall and from bud break until first green fruit. This was then reduced to 60mg/L from first green fruit to the end of harvest.

'Medium'. A standard nitrogen concentration of 120mg/L was applied from the end of harvest until 90% leaf fall and then from bud break until end of harvest.

'Low'. A nitrogen concentration of 60mg/L was applied from the end of harvest until 90% leaf fall and then from bud break until end of harvest.

'High'. A nitrogen concentration of 180mg/L was applied from the end of harvest until 90% leaf fall and then from bud break until end of harvest.

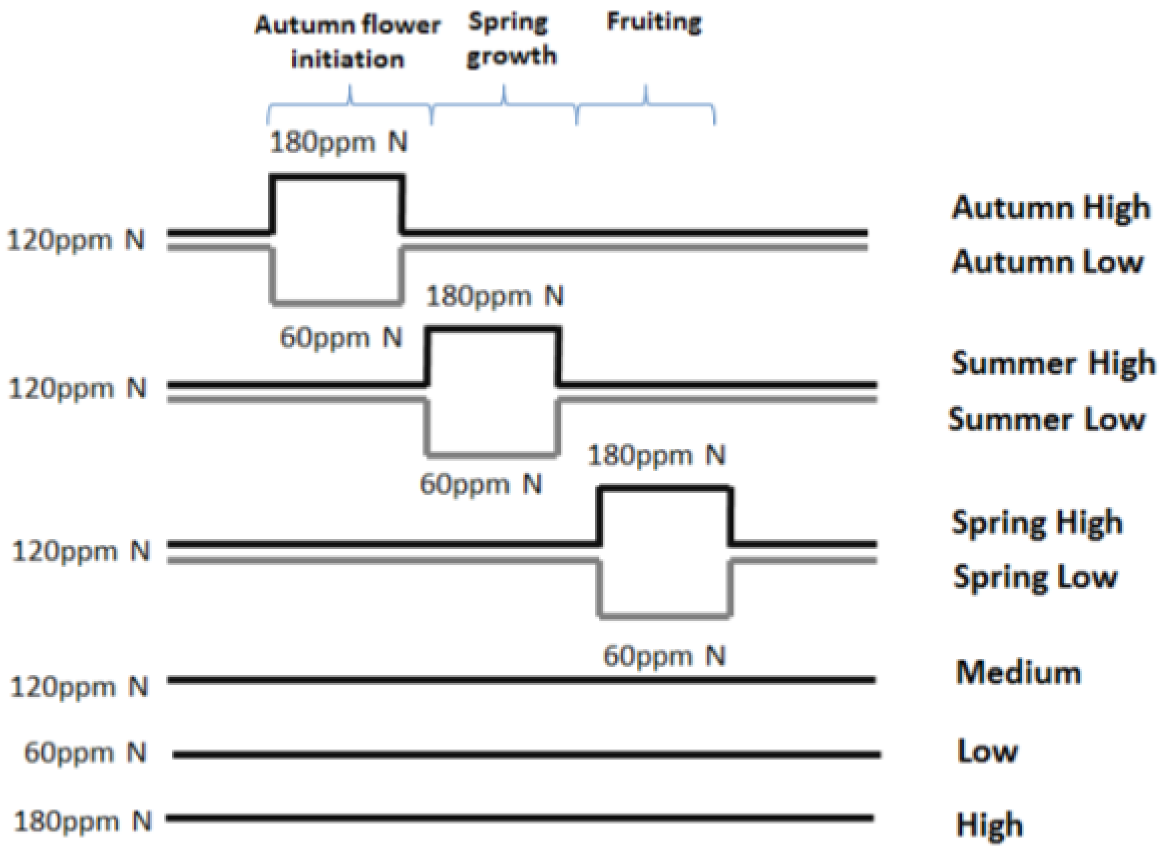


Figure 2. The nitrogen regimes which were applied in Objective 2 of the project.

Table 1. The timing of changes in the nitrogen regime for 2013/2014. Dates for Aurora and Duke are shown.

	2013 / 2014 treatments	
Growth period/ Year	Aurora	Duke
Autumn flower initiation 2013	12th September- 28th November 2013	12th September- 28th November 2013
Spring growth 2014	28th March- 27th May 2014	28th March- 19th May 2014
Fruiting 2014	27th May- 29th September 2014	19th May- 22nd July 2014

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

The assessments which were made include:

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

Cropping Fruit from each treatment was harvested by block, a representative sample created and separated into Class I, Class II and Waste fruit. These categories were then counted and weighed to determine the effect of treatment on yield and overall fruit quality.

Storability Following picking, a sample of both the Aurora and the Duke were placed into an air store at 2°C at Brogdale and assessed fortnightly until deemed non-marketable. Assessments made fortnightly were as follows:

- Percentage fruit with shrivel
- Weight loss during storage
- Fruit collapse

- Incidence of *Botrytis*
- In addition, a sample of Duke was also placed into a CA store at Hall Hunter Partnership on 25th July 2014 and assessed after four weeks for overall marketability

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. Irrigation inputs and outputs were also monitored.

Pesticide applications and biological control

An application of Calypso was made mid-May in response to aphid and honeydew secretions for both cultivars. A further application of Calypso and Aphox was made at the beginning of July to Aurora where sooty mould could be seen. In mid-May, an increase in the number of light brown apple moth catches was observed for Aurora, and so an ovicide was applied. In addition Hallmark was applied to target the larvae. Hallmark was applied again in September as a post-harvest spray for spotted wing drosophila for both cultivars. Topas was used in conjunction as a penetrative spray for leaf spot. Nematop was applied through drip irrigation in August and October to control vine weevil larvae.

Table 2. Pesticide applications and biological control used throughout the 2014 season. The cultivar which received treatment is indicated in the table.

Date	Trade name	Active ingredient	Application rate	Approval status	Aurora	Duke
19th May 2014	Calypso	Thiacloprid	250ml/Ha	This product has an Extension of Authorisation for minor use (EAMU) on this crop: Authorisation number 20142133	✓	✓

Date	Trade name	Active ingredient	Application rate	Approval status	Aurora	Duke
	Dimilin Flo	Diflubenzuron	0.3L/2000L	This product has an EAMU for use on this crop: Authorisation number 20060573	✓	
	Hallmark	Lambda-cyhalothrin	17.5ml/100L	This product has an EAMU for use on this crop: Authorisation number 20140521	✓	
4th Jul 2014	Calypso	Thiacloprid	250ml/Ha	This product has an EAMU for use on this crop: Authorisation number 20142133	✓	
	Aphox	Pirimicarb	280g/Ha	This product has an EAMU for use on this crop: Authorisation number 20102319	✓	
18th Aug 2014	Nematop	*Heterorhabditis bacteriophora*	133,334 per plant	N/A	✓	✓
19th Sep 2014	Hallmark	Lambda-cyhalothrin	17.5ml/100L	This product has an EAMU for use on this crop: Authorisation number 20140521	✓	✓
	Topas	Penconazole	0.5L/ha	This product has an EAMU for use on this crop: Authorisation number 20142528	✓	✓
15th Oct 2014	Nematop	*Heterorhabditis bacteriophora*	133,334 per plant	N/A	✓	✓

Statistical analysis

Analysis of Variance (ANOVA) has been used to determine the significance of treatment effects. Least Significant Differences (LSDs) are used to determine the significance of differences between individual treatments. A 95% confidence interval was used and so a P value of less than 0.05 indicates a statistically significant treatment effect. The data for cvs. Duke and Aurora have been analysed separately.

Results

Flower initiation and bud break

Frost damage

The 2013/2014 winter in Kent whilst very wet, was also mild. The lowest temperature at Brogdale throughout the autumn and winter was -7.0ºC, which was recorded mid-November. Buds of certain cultivars, when fully dormant, can survive temperatures of -40ºC (Gough, 1994) and so the plants suffered very little frost damage.

Percentage bud break

The number of buds along the length of new shoots were counted and categorised according to whether or not dormant buds had opened. The percentage of bud break along new shoots was then calculated and the average made for each treatment. These assessments were made on 16th April and 24th April 2014 for Duke and Aurora respectively.

There were no significant differences between the percentage of bud break across treatments for either Aurora (P=0.35) or Duke (P=0.11). Aurora bushes had between 50 and 60% of open buds whilst Duke showed slightly more variation. The low nitrogen treatment was amongst the treatments with the highest rate of bud break (see Figures 3A and 3B).

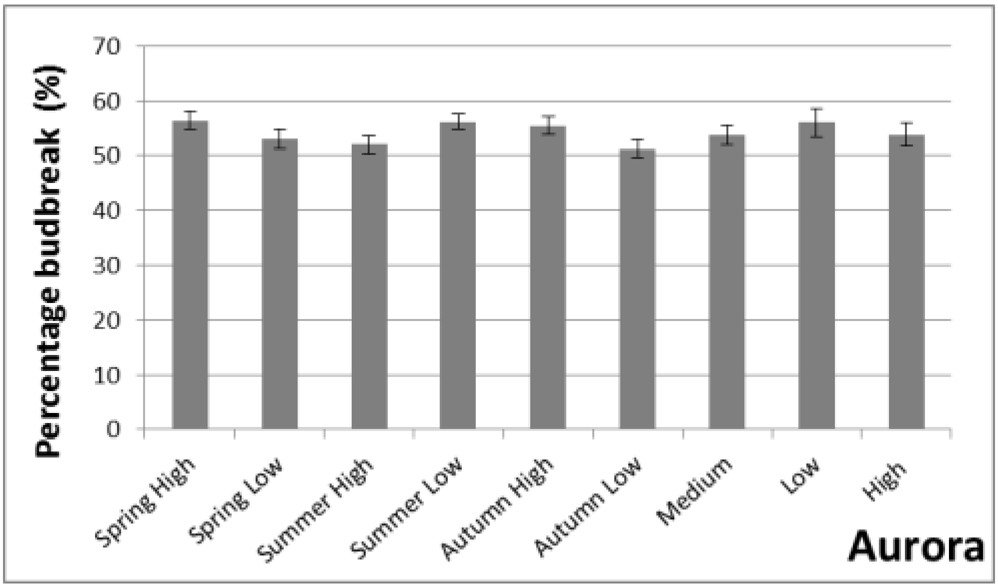


Figure 3A. The effect of nitrogen treatment on the percentage bud break for Aurora. Standard error bars are shown.

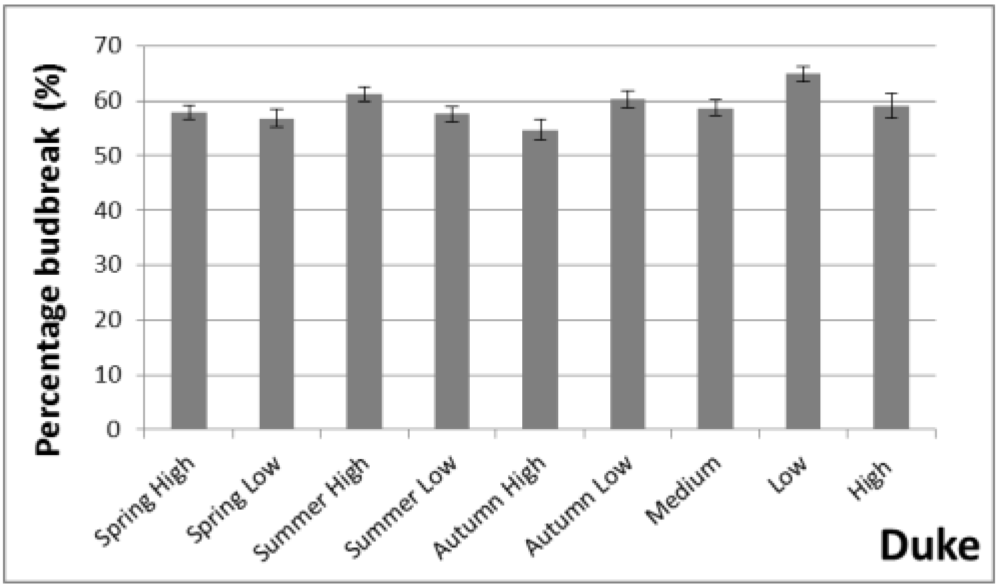


Figure 3B. The effect of nitrogen treatment on the percentage bud break for Duke. Standard error bars are shown.

Floral bud production

The proportion of floral buds in relation to the total bud number was recorded from three shoots per bush, the percentage calculated, and the average made per treatment. This was also assessed on 25th March and 31st March 2014 for Duke and Aurora respectively.

The high nitrogen treatment had the greatest percentage of floral buds for Aurora; however this was not of statistical significance. Whilst Duke bushes produced more floral buds than the Aurora on average, there were similar results, with the most flower buds in the high nitrogen treatment (see Figures 4 and 5).

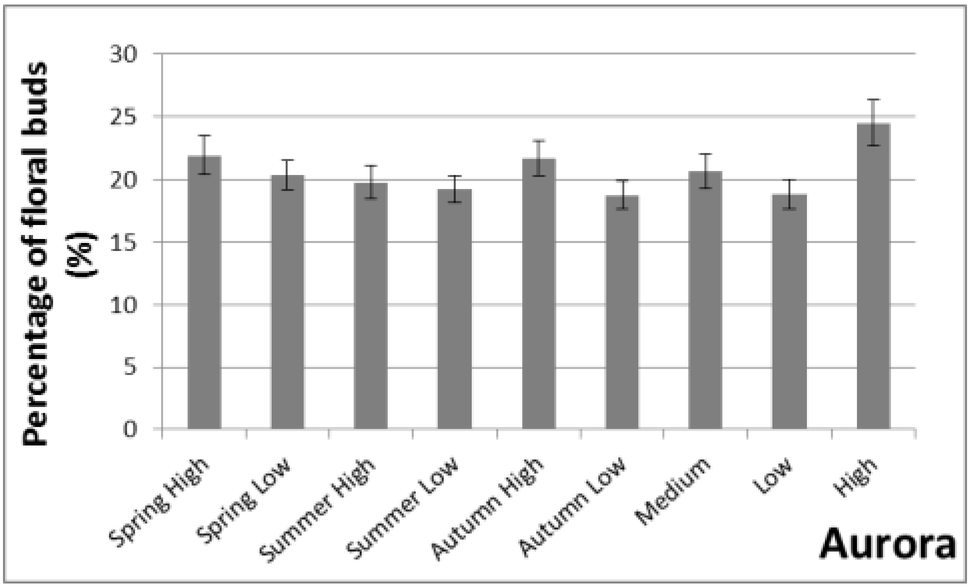


Figure 4. The effect of nitrogen treatment on the percentage of floral buds for Aurora. Standard error bars are shown.

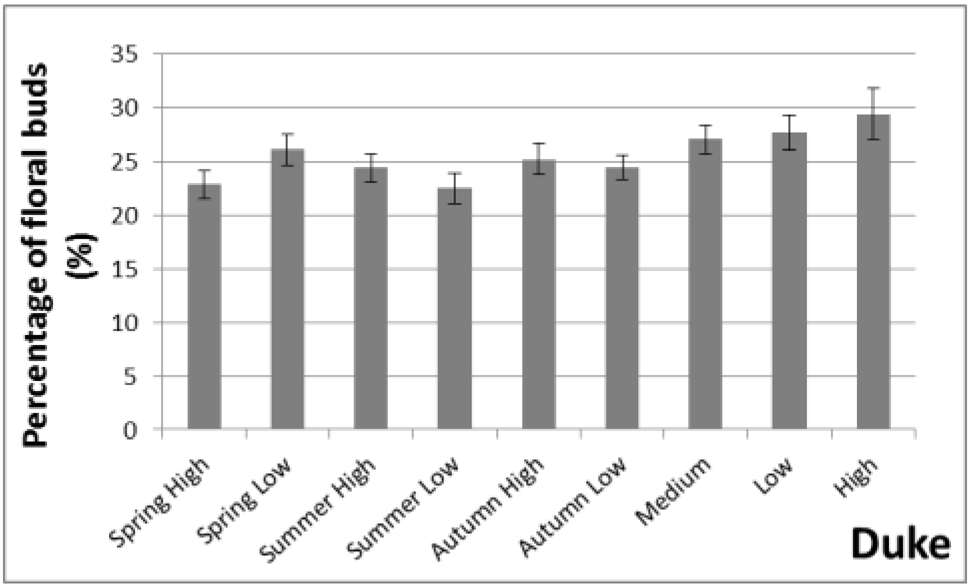


Figure 5. The effect of nitrogen treatment on the percentage of floral buds for Duke. Standard error bars are shown.

Flower number

The number of flowers per flower cluster of a representative sample of each treatment was assessed and the average calculated. Assessments were made for Duke on 16th April and Aurora on 24th April 2014.

There was little variation in the average number per flower cluster and no significant differences were found between treatments for either cultivar (see Figures 7 and 8). Low nitrogen was amongst the treatments with the least flowers per cluster for Aurora.

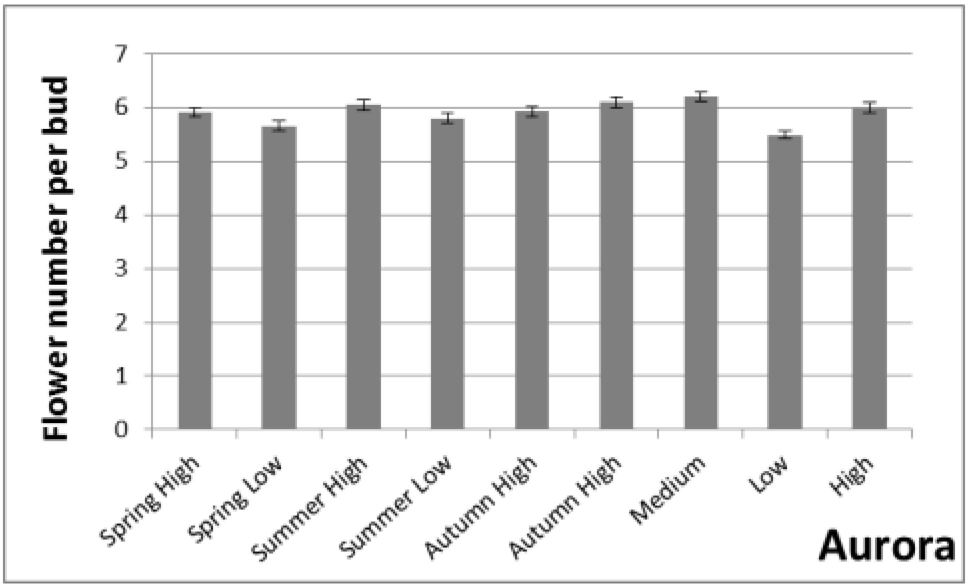


Figure 6. The effect of nitrogen treatment on the flower number per cluster for Aurora. Standard error bars are shown.

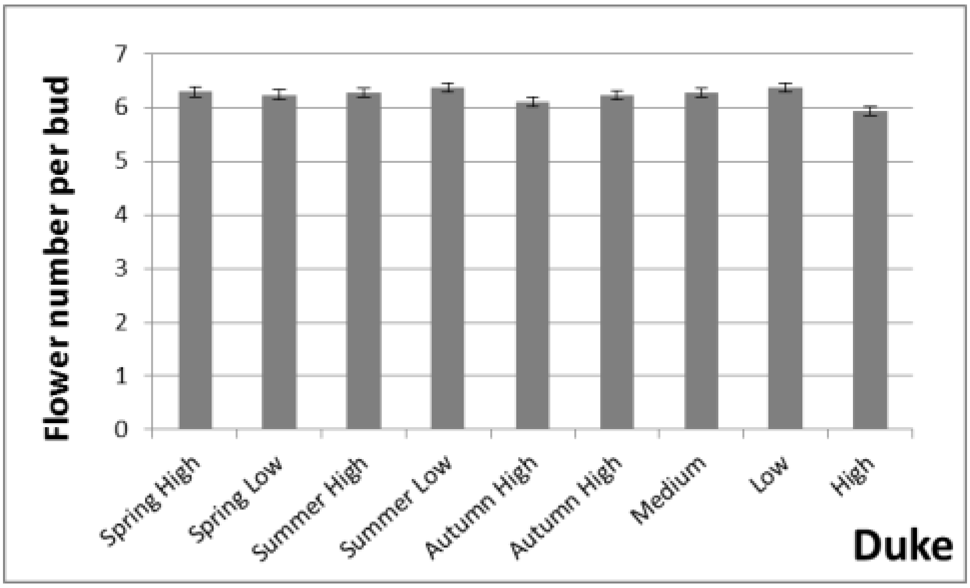


Figure 7. The effect of nitrogen treatment on the flower number per cluster for Duke. Standard error bars are shown.

Cropping

Yield

Due to high volumes of fruit set, sampling methods were used to obtain a representative sample of fruit to grade from each block per treatment. Berries were then categorised as Class I, Class II or waste fruit. The classes were then counted and weighed.

Figure 8. Methods of recording yields, sampling and grading.

Aurora

Picking commenced on 20th August and finished on 18th September. Aurora bushes averaged total yields of 1.63kg per bush throughout the season; however the individual treatments ranged between 1.45kg and 1.85kg. Amongst the greatest yields were the spring high and autumn low treatments, however there were no significant differences between treatments for total yield (see Figures 9 and 10).

There was however a significant effect of treatment on final pick yield, whereby the spring high treatment had the greatest pick (P=0.0067). Spring high and autumn low had the greatest total number of fruit harvested throughout picking, whilst spring low produced the fewest fruit (see Table 4). There were also no statistical differences found between individual quality classes (see Table 3).

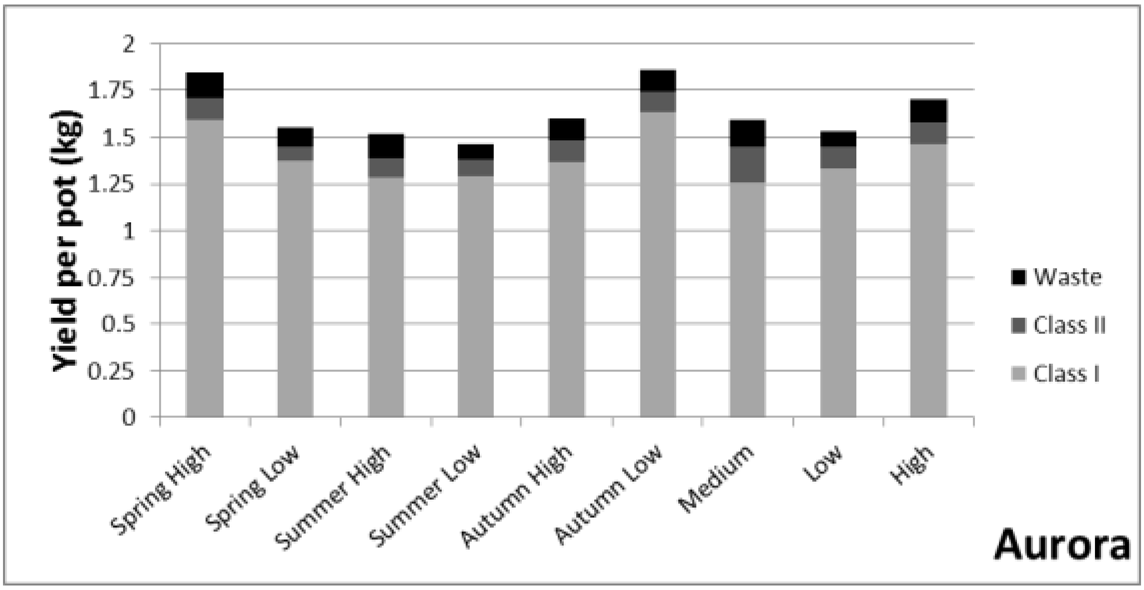


Figure 9. The effect of nitrogen treatment on the average yield per bush (kg) for Aurora. The shading of bars represents the different quality classes.

Table 3. The effect of nitrogen treatment on the amount of fruit categorised in each quality class (%) for Aurora.

Treatment	Class I yield per bush (%)	Class II yield per bush (%)	Waste yield per bush (%)
Spring High	79	11	10
Spring Low	80	10	10
Summer High	78	11	11
Summer Low	76	15	9
Autumn High	78	12	10
Autumn Low	80	10	10
Medium	73	16	11
Low	81	12	7
High	79	11	10
P value	*0.46*	*0.32*	*0.15*

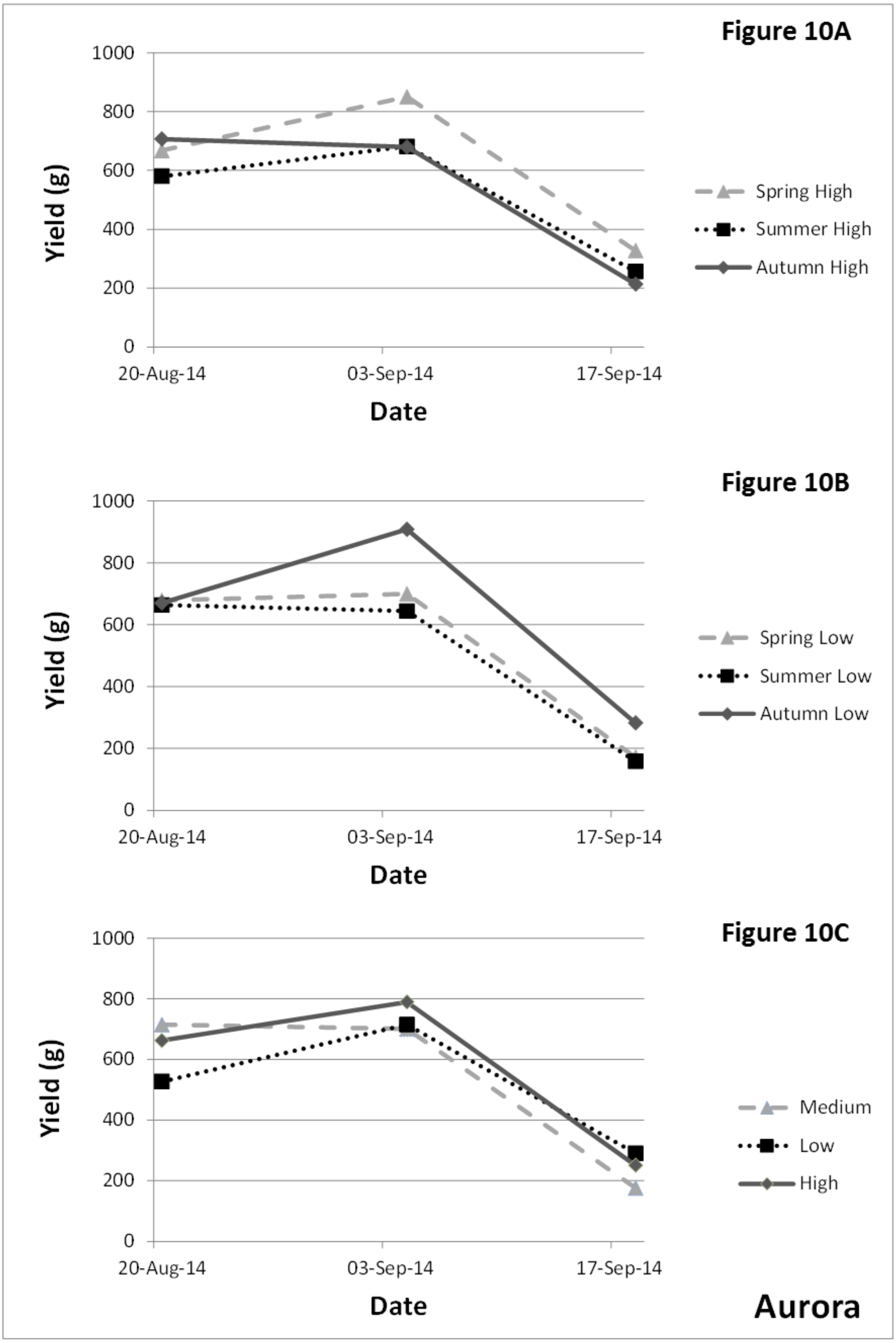


Figure 10 A-C. The effect of nitrogen treatment on the yield profile per bush for Aurora.

Table 4. The average for total fruit number harvested per bush for Aurora.

Treatment	Total fruit number per bush
Spring High	1326
Spring Low	996
Summer High	1107
Summer Low	1110
Autumn High	1134
Autumn Low	1276
Medium	1094
Low	1185
High	1209
P value	*0.1306*

Duke

Duke was picked from 12th June until 15th July 2014 across 5 picks with an average yield per bush of 2.35kg. The majority of treatments averaged between 2 and 2.5kg per pot with the exception of summer high which had a smaller yield of 1.95kg per bush (see Figure 11). The high nitrogen treatment had a significantly larger number of fruit harvested per bush (P=0.0309), in excess of 600 fruit more than any of the other treatments (see Table 6). 86% of the crop from the high nitrogen treatment was Class I fruit, which was significantly less than produced by any other treatment. It also produced the greatest proportion of Class II fruit across the treatments (see Table 5). In contrast, the low treatment produced the most Class I fruit relative to total yield, and the least Class II.

Although there was no statistical difference in total yield per treatment, there were significant differences between treatments for the first and last individual picks (see Figure 12). The high treatment had a significantly greater first pick than any other treatment, whilst the low nitrogen treatment had the smallest first pick (P=0.0003). However, the low treatment had the largest final pick of all treatments, statistically similar to only the autumn high treatment (P=0.0328).

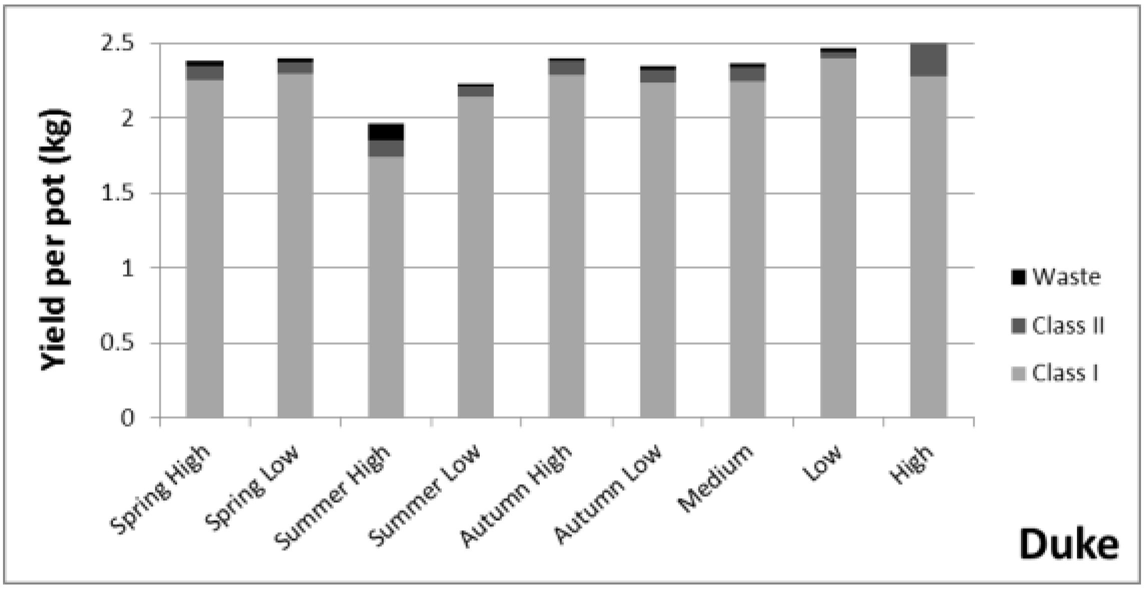


Figure 11. The effect of nitrogen treatment on the average yield per bush (kg) for Duke. The shading of bars represents the different quality classes.

Table 5. The effect of nitrogen treatment on the amount of fruit categorised in each quality class (%) for Duke. The letters show significant differences between treatments.

Treatment	Total Class I yield per bush (%)	Total Class II yield per bush (%)	Total waste yield per bush (%)
Spring High	94 ***b***	4 ***b***	2
Spring Low	95 ***b***	4 ***b***	1
Summer High	91 ***b***	6 ***b***	3
Summer Low	96 ***b***	3 ***b***	1
Autumn High	94 ***b***	5 ***b***	1
Autumn Low	95 ***b***	4 ***b***	1
Medium	95 ***b***	4 ***b***	1
Low	98 ***c***	1 ***a***	1
High	86 ***a***	13 ***c***	1
*P value**	***0.0001***	***0.0000***	*0.24*

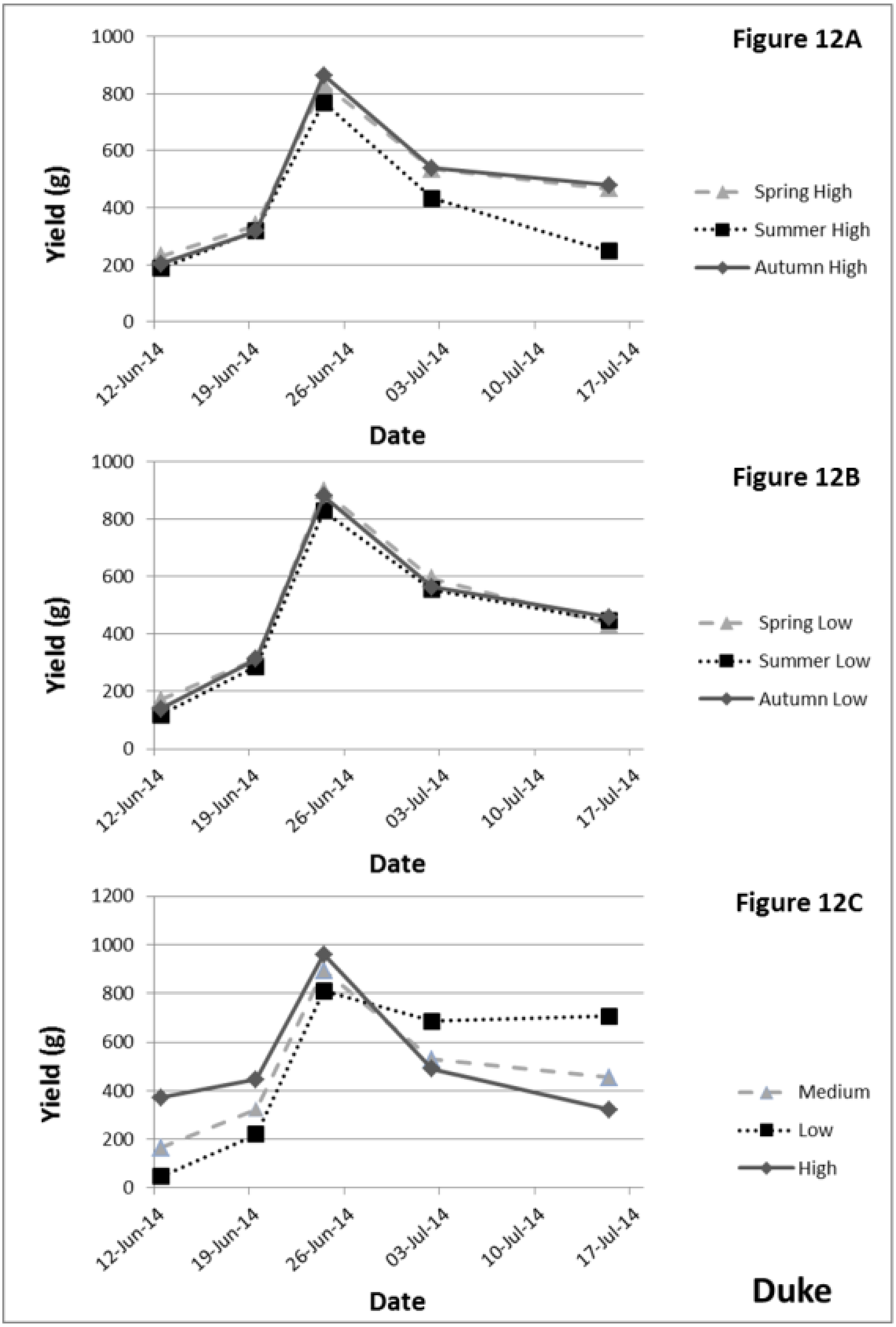


Figure 12. The effect of nitrogen treatment on the yield profile per bush for Duke.

Table 6. The average for total fruit number harvested per bush for Duke

Treatment	Total fruit number per bush
Spring High	1813 ***a***
Spring Low	1754 ***a***
Summer High	1459 ***a***
Summer Low	1585 ***a***
Autumn High	1851 ***a***
Autumn Low	1762 ***a***
Medium	1779 ***a***
Low	1542 ***a***
High	2560 ***b***
*P value**	***0.0309***

Berry weight

From the sampled fruit at each pick, the total weight and number were used to calculate the average berry weight (g). There was some variation in berry weight (g) for treatments for Aurora, ranging between 1.3 and 1.5g per berry, however there was no statistical significance (see Figure 13). More variation was seen in berry weight (g) for Duke, with both the low and high treatments having significantly different average weights, as well as having significant differences from all other treatments. (P=0.0000). The low treatment produced berries which were at least 0.2g larger than the other treatments whilst the high treatment produced berries at least 0.2g smaller than the others (see Figure 14).

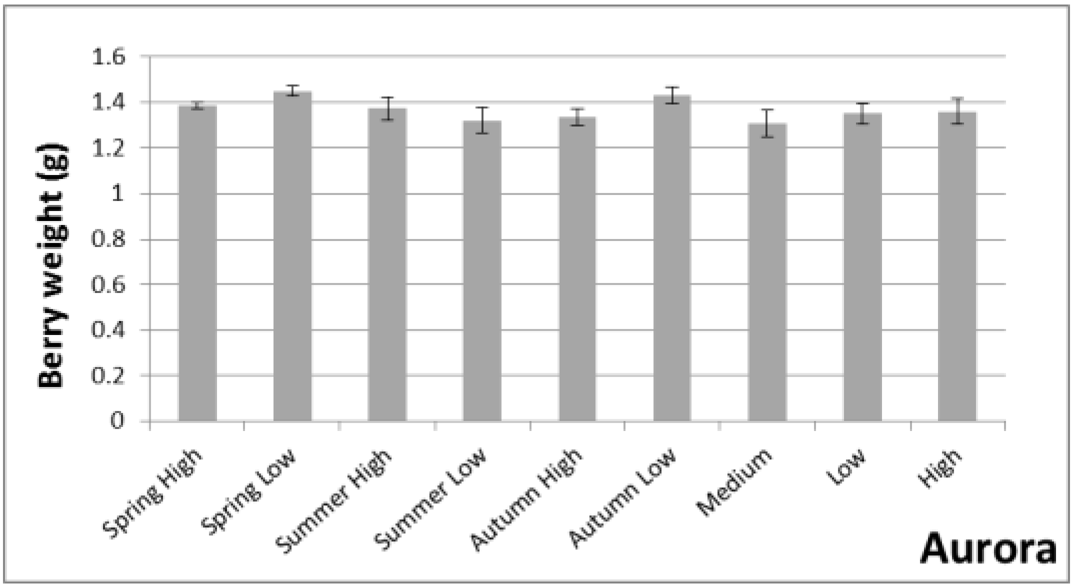


Figure 13. The effect of nitrogen treatment on the average berry weight for Aurora. Standard error bars are shown.

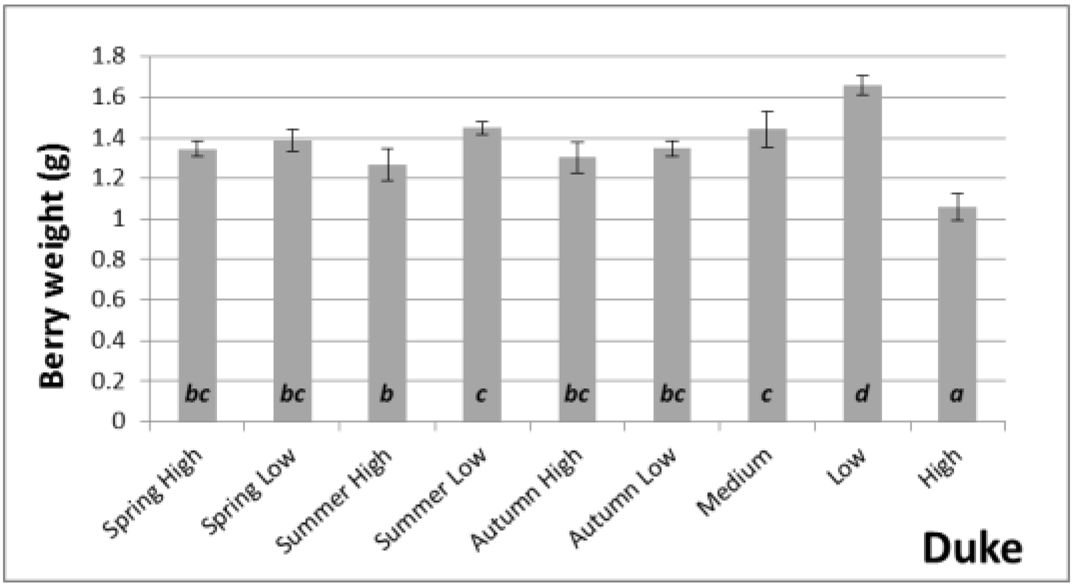


Figure 14. The effect of nitrogen treatment on the average berry weight for Duke. Standard error bars are shown and the letters show significant differences between treatments.

Fruit size

Fruit size was in excess of 15mm for Aurora with the exception of the high nitrogen treatment (see Figure 15). This was however statistically similar to most other treatments, with the exception of summer high and spring low which had a larger fruit size of 15.6 and 16.1mm respectively (P=0.0192). Similar to Aurora, the high treatment had the smallest fruit size for Duke, with a diameter of 12.9mm. This was significantly less than all other treatments (P=0.0000). The low treatment had berries of 15.2mm, which was significantly larger than all other treatments (see Figure 16).

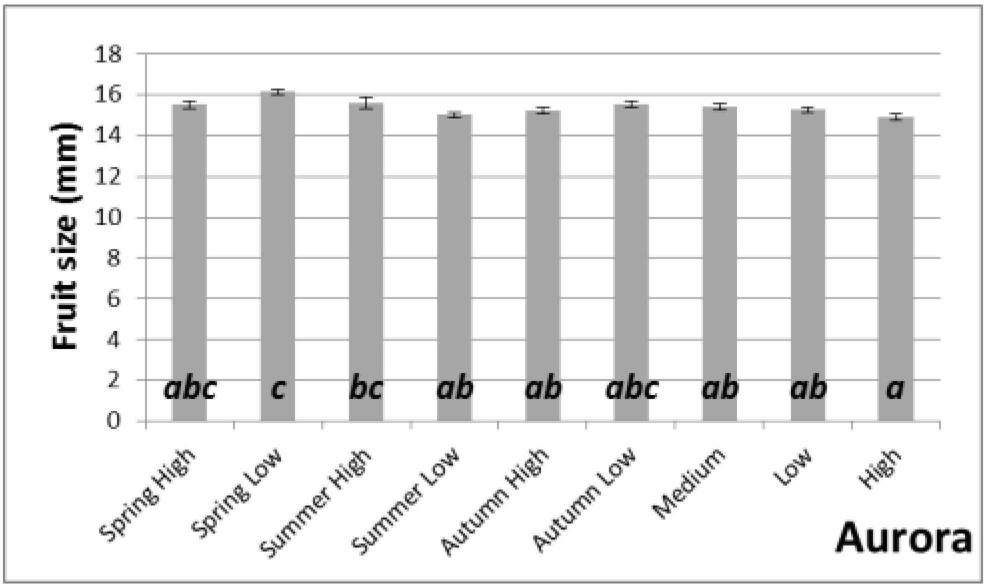


Figure 15. The effect of nitrogen treatment on the average fruit size for the Aurora. Data taken from 21st August 2014. Standard error bars are shown and the letters show significant differences between treatments.

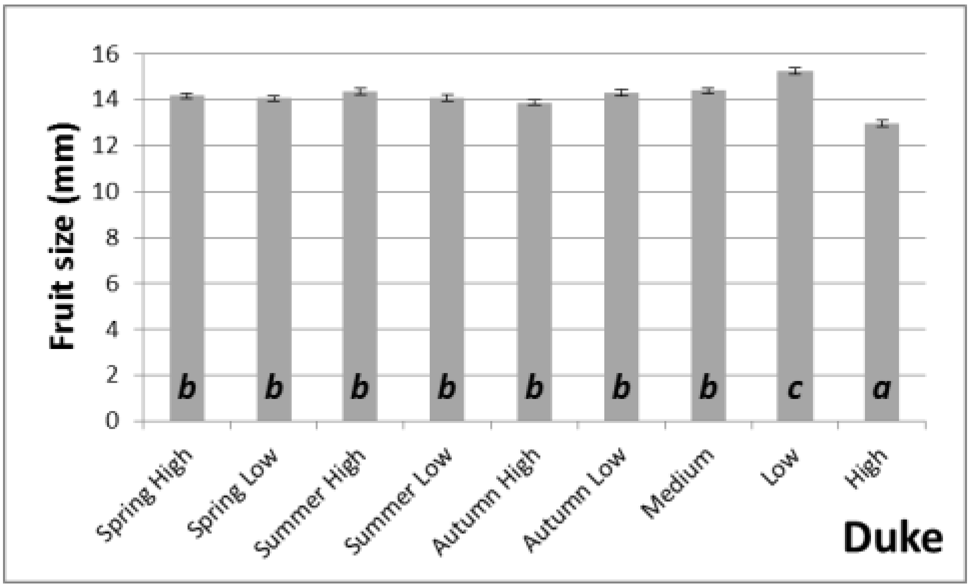


Figure 16. The effect of nitrogen treatment on the average fruit size for the Duke. Data taken from 3rd July 2014. Standard error bars are shown and the letters show significant differences between treatments.

Total soluble solids

A random sample of 25 ripe fruit was taken from each treatment for the testing of total soluble solids (Brix°) at the first pick. This was 19th June and 21st August for the Duke and Aurora respectively.

The Brix ranged on average between 10.6 and 11.5^{o} for the Aurora with little variation between treatments (see Figure 17). Brix levels were higher in the Duke with the highest value of 13.4^{o} for the summer high treatment. This was significantly more than all treatments except high (P=0.0021). The lowest Brix was from the low treatment (see Figure 18).

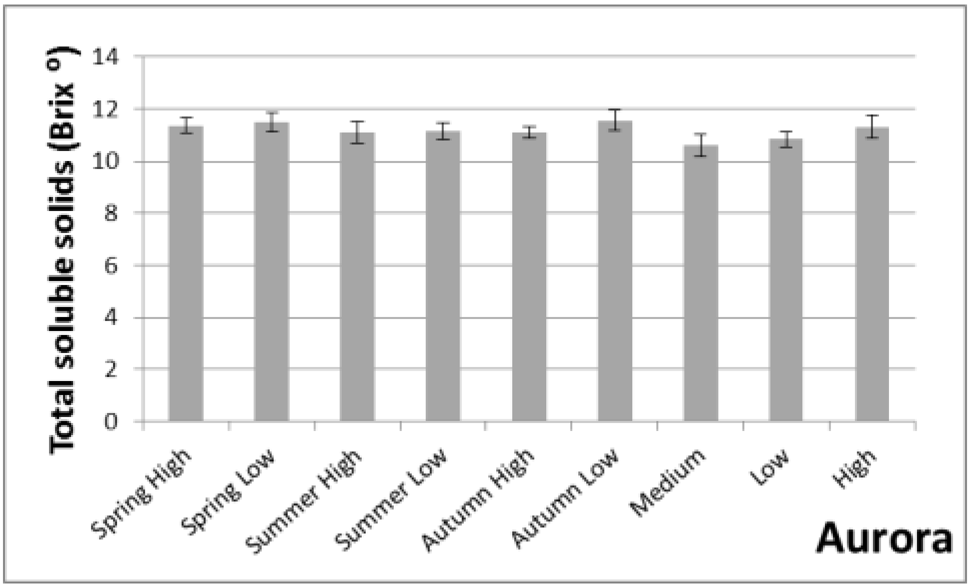


Figure 17. The effect of nitrogen treatment on the total soluble solids (°Brix) of the Aurora. Standard error bars are shown.

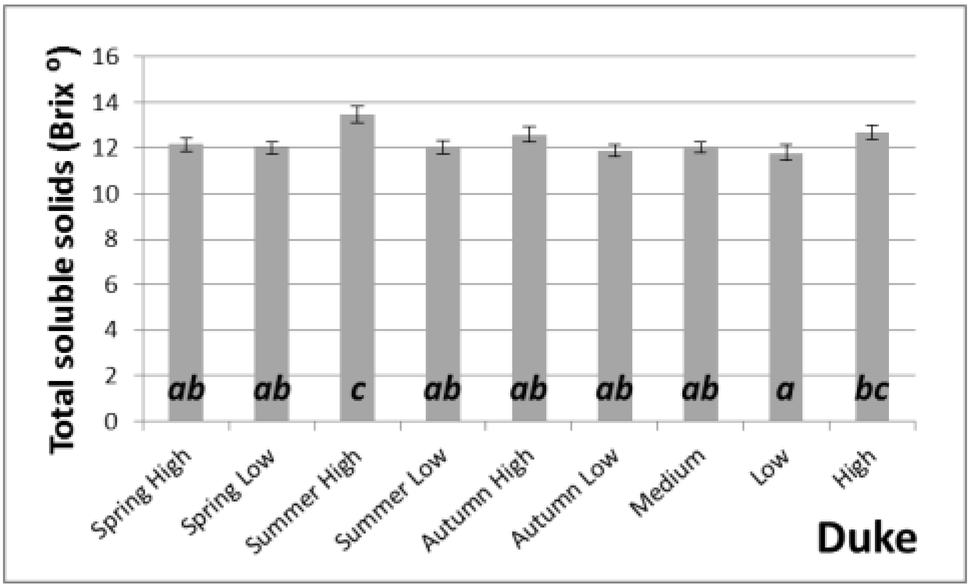


Figure 18. The effect of nitrogen treatment on the total soluble solids (°Brix) of the Duke. Standard error bars are shown. The letters show significant differences between treatments.

Fruit storability

The effect of nitrogen treatment on the storability of fruit was tested by placing a sample of 150g marketable fruit into an air cold store at 2ºC at Brogdale and assessed fortnightly for eight weeks. Duke samples were placed into store on 26th June, and the Aurora on the 3rd September 2014. 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. In addition, 150g samples of the Duke were also placed into a CA store at Hall Hunter Partnership on 25th July 2014 and a general assessment made at four weeks.

Aurora

After four weeks in the air cold store, the samples had lost between 19 and 33% of the original sample, and this had increased to 51 and 76% by week 8. The low nitrogen treatment lost the least fruit throughout testing, significantly less than some of the other treatments (see Table 7). Summer high and spring low had some of the largest losses by week 4. However, after eight weeks of storage, the summer high had the least marketable fruit remaining (see Figure 19).

Losses due to fruit dehydration were the greatest, and botrytis, the least. Whilst the low treatment had relatively low losses to fruit dehydration throughout storage, the differences between treatments were not considered significant (see Figure 20C). Statistically significant results, however, were found between the treatments for losses to fruit collapse and botrytis (see Tables 8 and 9). The low nitrogen treatment had low levels of fruit collapse throughout storage, as did the autumn low treatment (see Figure 21). The least incidence of botrytis was found in the low nitrogen treatment with few treatments with statistically similar results. By the end of eight weeks, summer high had the greatest losses to botrytis (see Figure 22).

Table 7. The effect of nitrogen treatment on the percentage sample considered non-marketable throughout storage. The letters show the significance of differences between the treatments.

Treatment	Cumulative loss after 2 weeks (%)	Cumulative loss after 4 weeks (%)	Cumulative loss after 6 weeks (%)	Cumulative loss after 8 weeks (%)
Spring High	9	28 ***abcd***	40	60 ***bc***
Spring Low	11	33 ***a***	52	71 ***ab***
Summer High	9	33 ***a***	54	76 ***a***
Summer Low	8	22 ***cd***	38	63 ***bc***
Autumn High	9	30 ***abc***	48	73 ***ab***
Autumn Low	9	24 ***bcd***	38	66 ***abc***
Medium	11	31 ***ab***	51	70 ***ab***
Low	10	19 ***d***	35	51 ***c***
High	9	31 ***ab***	48	69 ***ab***
*P value**	*0.8158*	***0.0068***	*0.0608*	***0.0343***

* A P value of less than 0.05 indicates a statistically significant treatment effect.

Figure 19. The effect of nitrogen treatment on the percentage of marketable fruit after 2, 4, 6 and 8 weeks of air storage for Aurora. Standard error bars are shown.

Figure 19A

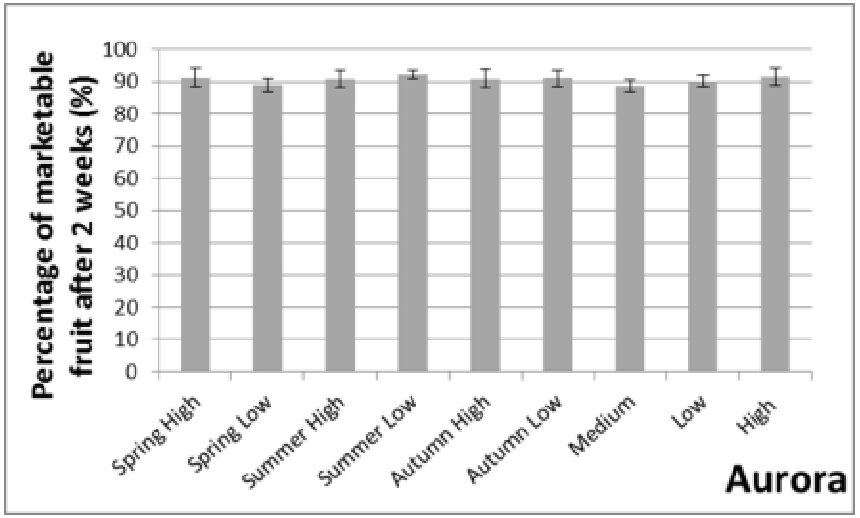


Figure 19C

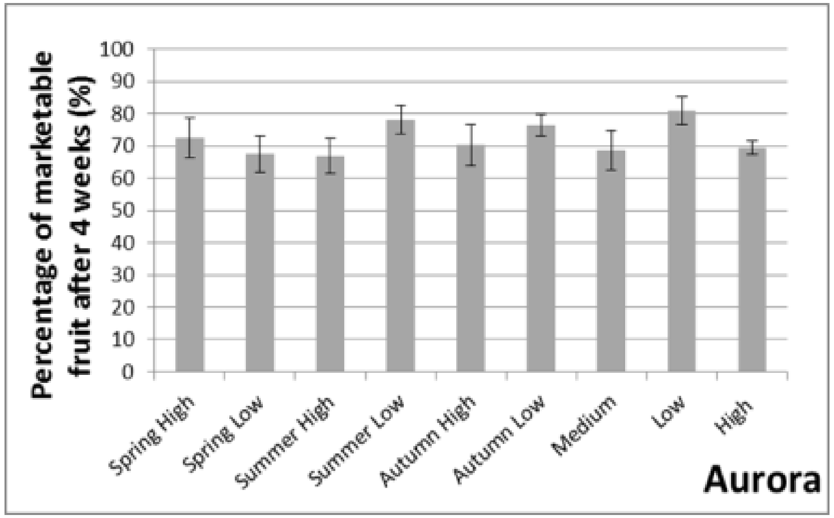


Figure 19B

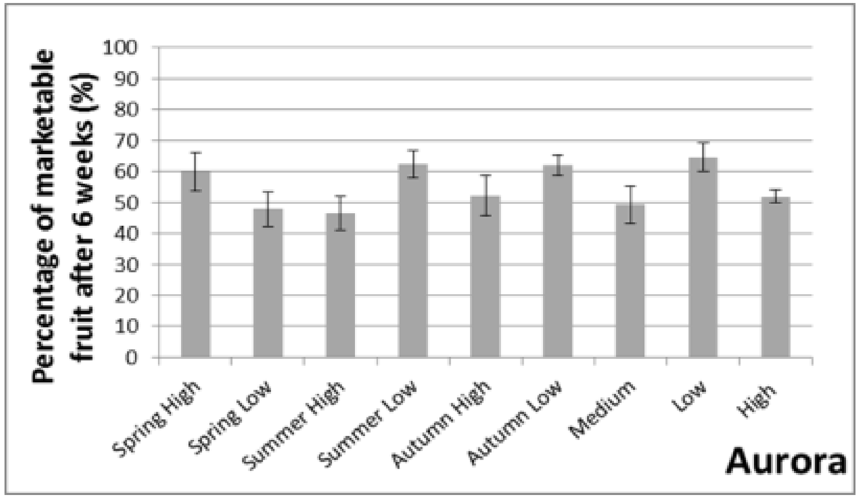
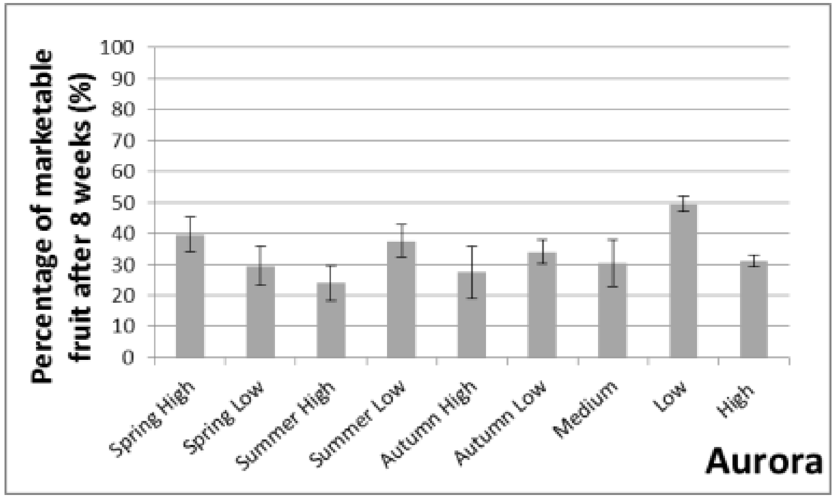


Figure 19D



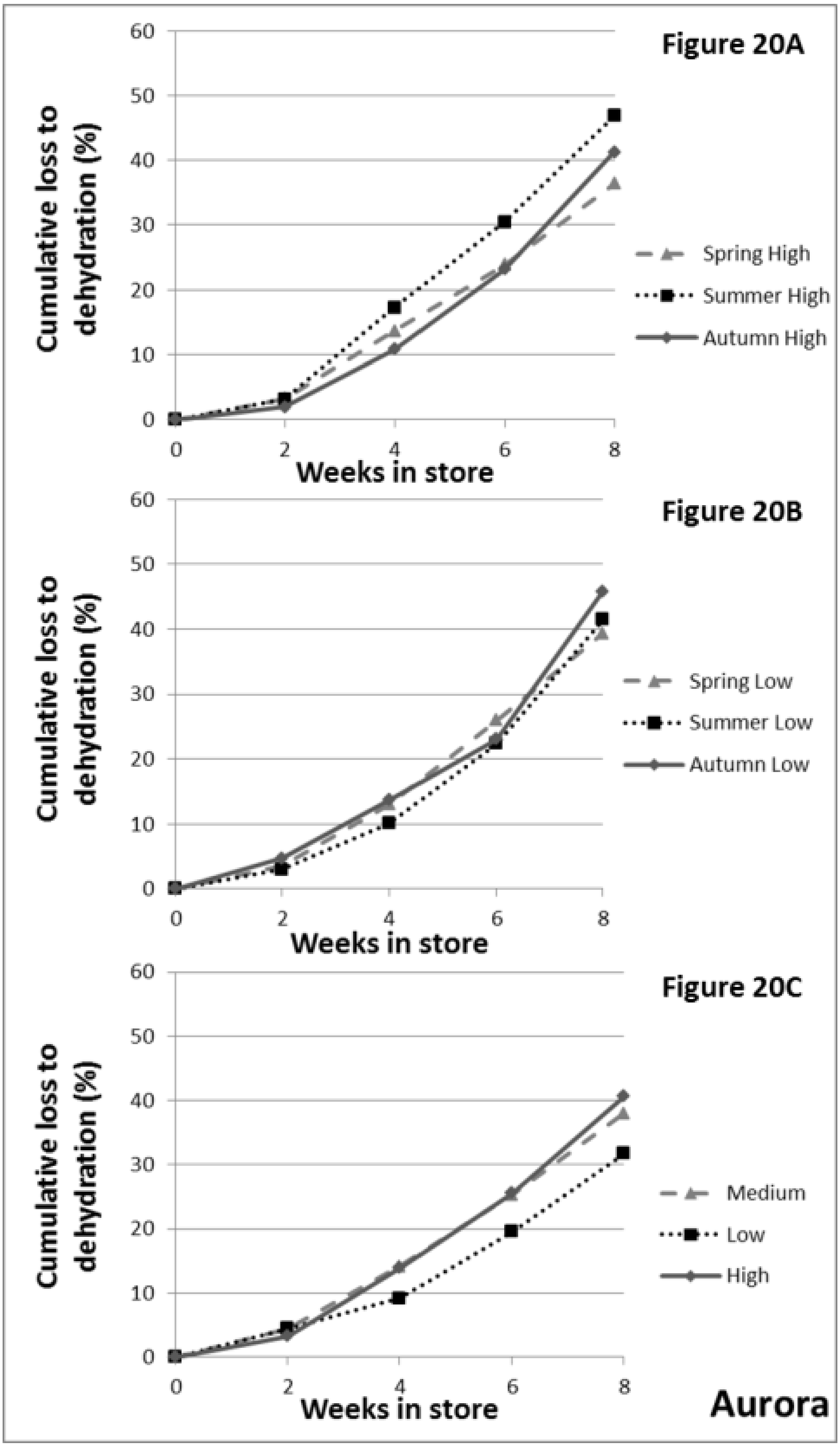


Figure 20. The effect of nitrogen treatment on the loss of storage samples due to fruit dehydration for Aurora.

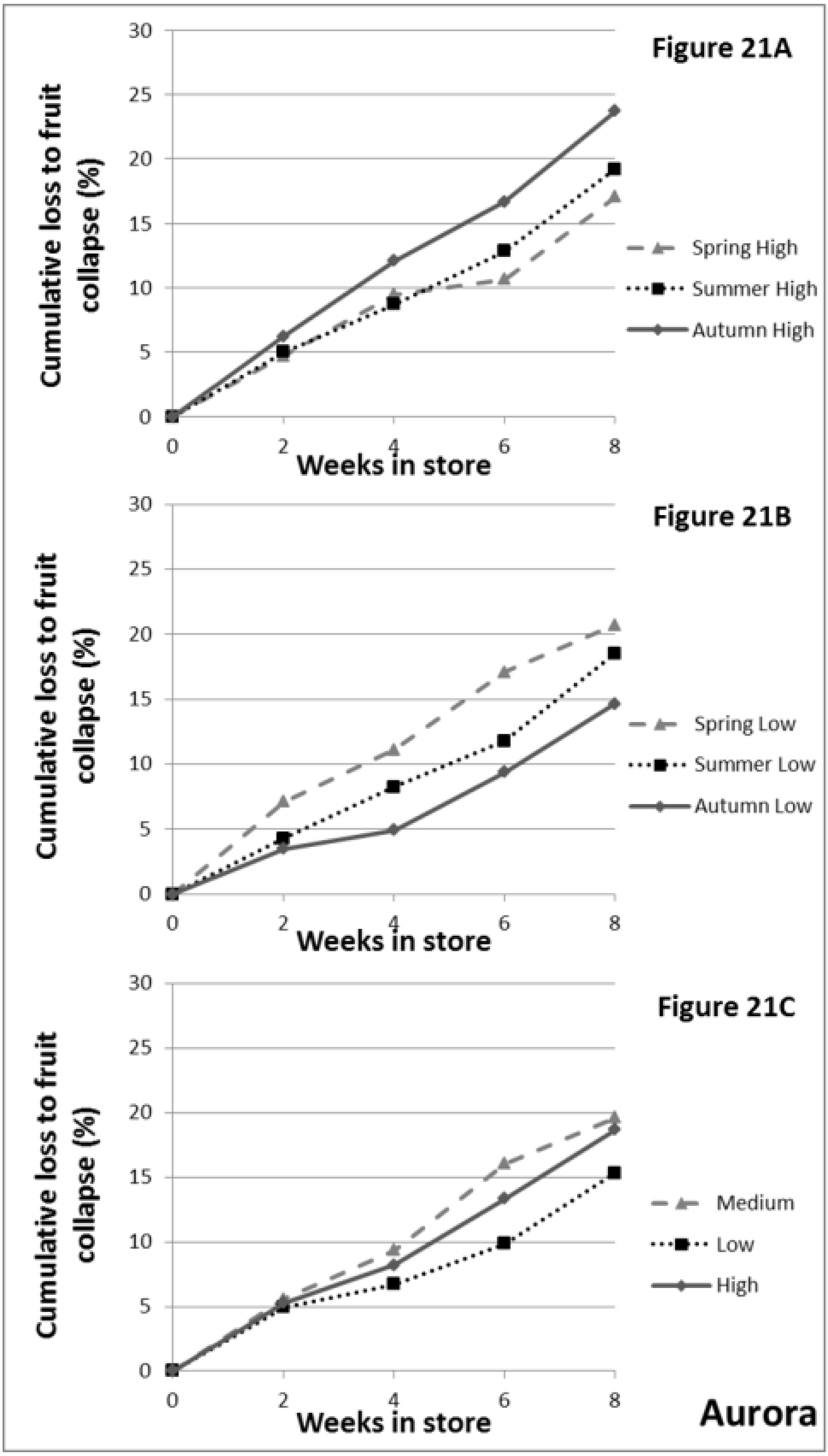


Figure 21. The effect of nitrogen treatment on the loss of storage samples due to fruit collapse for Aurora.

Table 8. The effect of nitrogen treatment on cumulative fruit collapse loss (%) for Aurora. The letters show the significance of differences between the treatments.

Treatment	Cumulative fruit collapse loss by week 2	Cumulative fruit collapse loss by week 4	Cumulative fruit collapse loss by week 6	Cumulative fruit collapse loss by week 8
Spring High	4.7	9.5	10.6 ***ab***	17.1
Spring Low	7.1	11.1	17.1 ***c***	20.7
Summer High	5.0	8.7	12.8 ***abc***	19.2
Summer Low	4.3	8.2	11.8 ***abc***	18.5
Autumn High	6.2	12.1	16.7 ***c***	23.7
Autumn Low	3.5	4.9	9.4 ***a***	14.7
Medium	5.6	9.4	16.0 ***bc***	19.6
Low	4.9	6.7	9.9 ***a***	15.3
High	5.3	8.7	13.3 ***abc***	18.7
P value	*0.5644*	*0.0754*	***0.0394***	*0.3545*

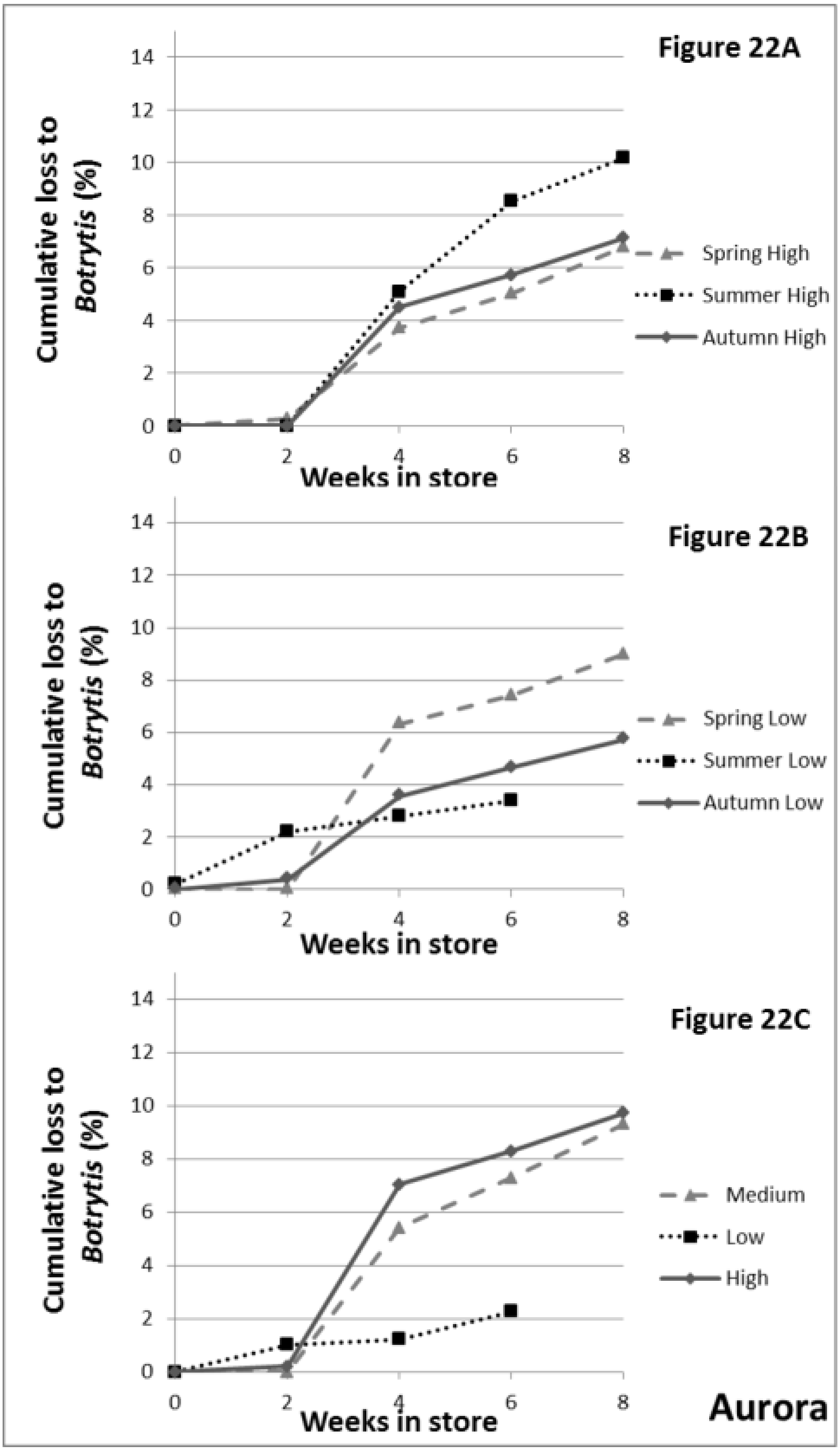


Figure 22. The effect of nitrogen treatment on the loss of Aurora storage samples as a result of *Botrytis*.

Table 9. The effect of nitrogen treatment on the cumulative *Botrytis* losses (%) for Aurora. The letters show the significance of differences between the treatments.

Treatment	Cumulative loss to *Botrytis* by week 2	Cumulative loss to *Botrytis* by week 4	Cumulative loss to *Botrytis* by week 6	Cumulative loss to *Botrytis* by week 8
Spring High	0.3	3.7 ***bc***	5.0 ***bc***	6.8 ***bc***
Spring Low	0.0	6.3 ***c***	7.4 ***bc***	9.0 ***c***
Summer High	0.0	5.1 ***bc***	8.5 ***abc***	10.2 ***c***
Summer Low	0.2	2.2 ***ab***	2.8 ***ab***	3.4 ***ab***
Autumn High	0.0	4.5 ***bc***	5.7 ***bc***	7.1 ***abc***
Autumn Low	0.4	3.6 ***bc***	4.7 ***bc***	5.7 ***abc***
Medium	0.0	5.4 ***bc***	*7.3* ***c***	9.3 ***c***
Low	0.0	1.0 ***a***	1.2 ***a***	2.3 ***a***
High	0.2	7.0 ***c***	8.3 ***c***	9.7 ***c***
P value	*0.7698*	***0.0142***	***0.0029***	***0.0149***

Duke

Following four weeks in an air store, between 79 and 87% of the original samples remained marketable, and this decreased to just 9 and 32% by week 8 (see Figures 23B and 23D). The spring low treatment had 10% greater losses than the other treatments after just two weeks, with just 75% of fruit remaining marketable. However, this effect was not sustained throughout storage. The low treatment was amongst the treatments with the most marketable fruit at every assessment, and at the end of eight weeks had the most marketable fruit. These differences however were not of statistical significance.

The increase in the marketability for the low treatment appeared to be as a result of a reduction in the incidence of dehydration and *Botrytis* throughout storage. It showed consistently lower levels of fruit dehydration, particularly from week 4 onwards (See Figure 24C). After eight weeks, the low treatment had shown less than half the *Botrytis* than most other treatments (see Figure 26C). The spring low and autumn low treatments experienced large losses to fruit collapse in comparison to most other treatments, however there were no significant differences between treatments for any storage disorder (see Figure 25B).

A brief assessment of samples stored in CA facilities for four weeks revealed little incidence of fruit collapse. Moulds were more noticeable in the medium, low and spring high treatments.

Figure 23A

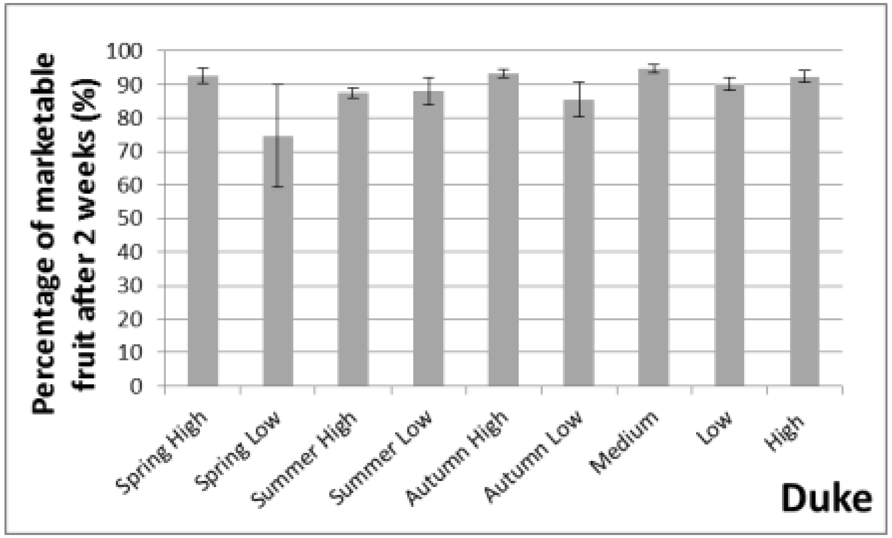


Figure 23B

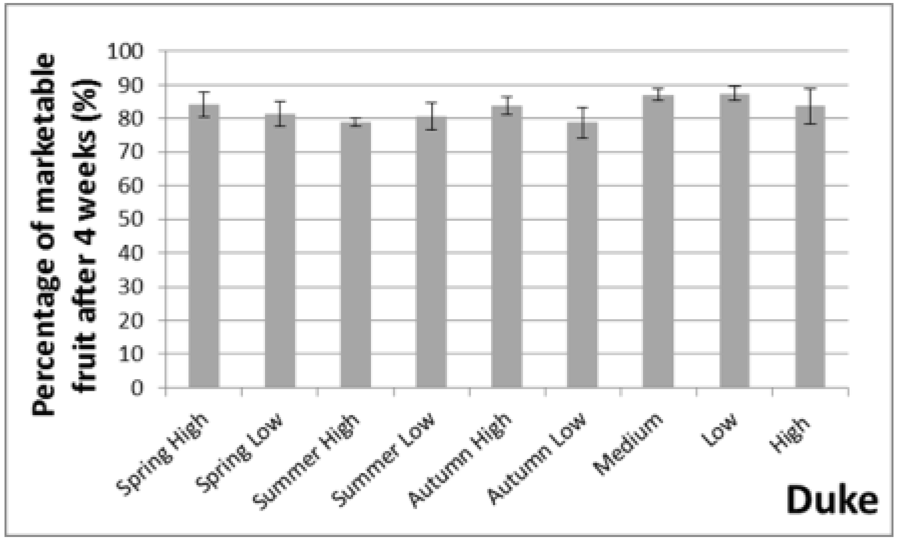


Figure 23C

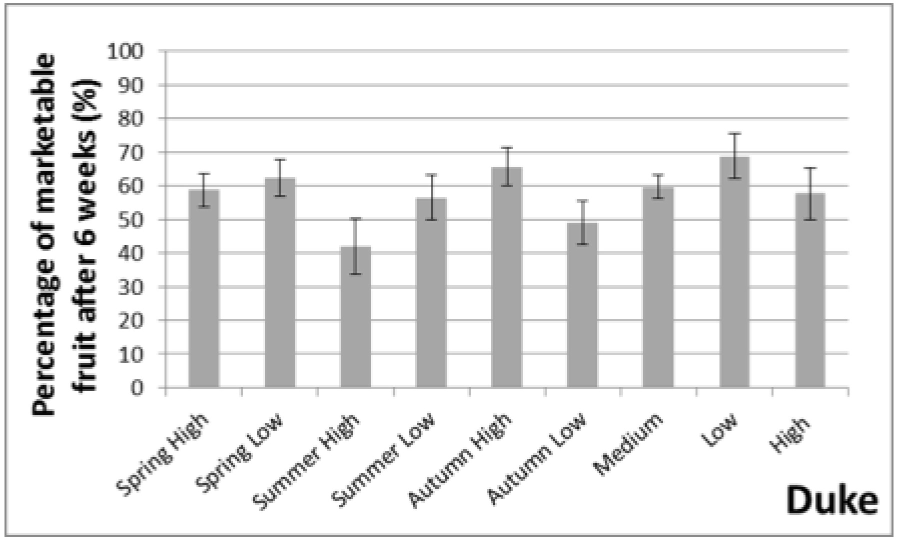


Figure 23D

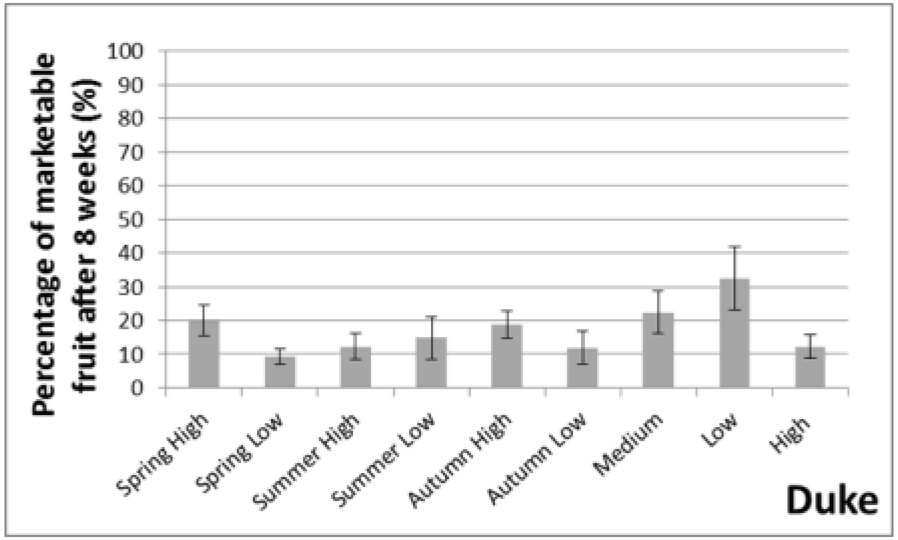


Figure 2

Figure 23. The effect of nitrogen treatment on the percentage of marketable fruit after 2, 4, 6 and 8 weeks of air storage for Duke. Standard error bars are shown.

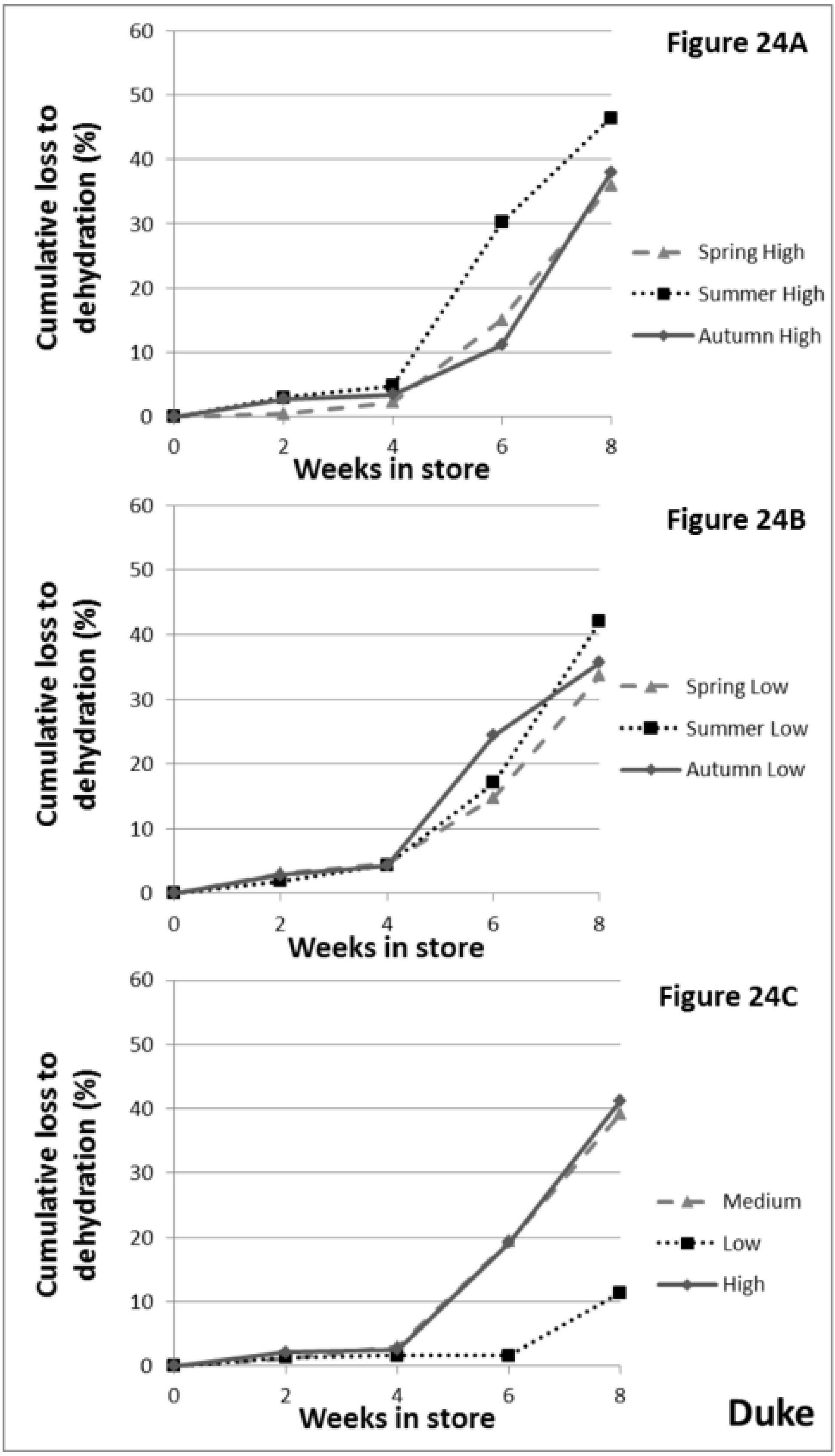


Figure 24. The effect of nitrogen treatment on the loss of Duke storage samples as a result of fruit dehydration.

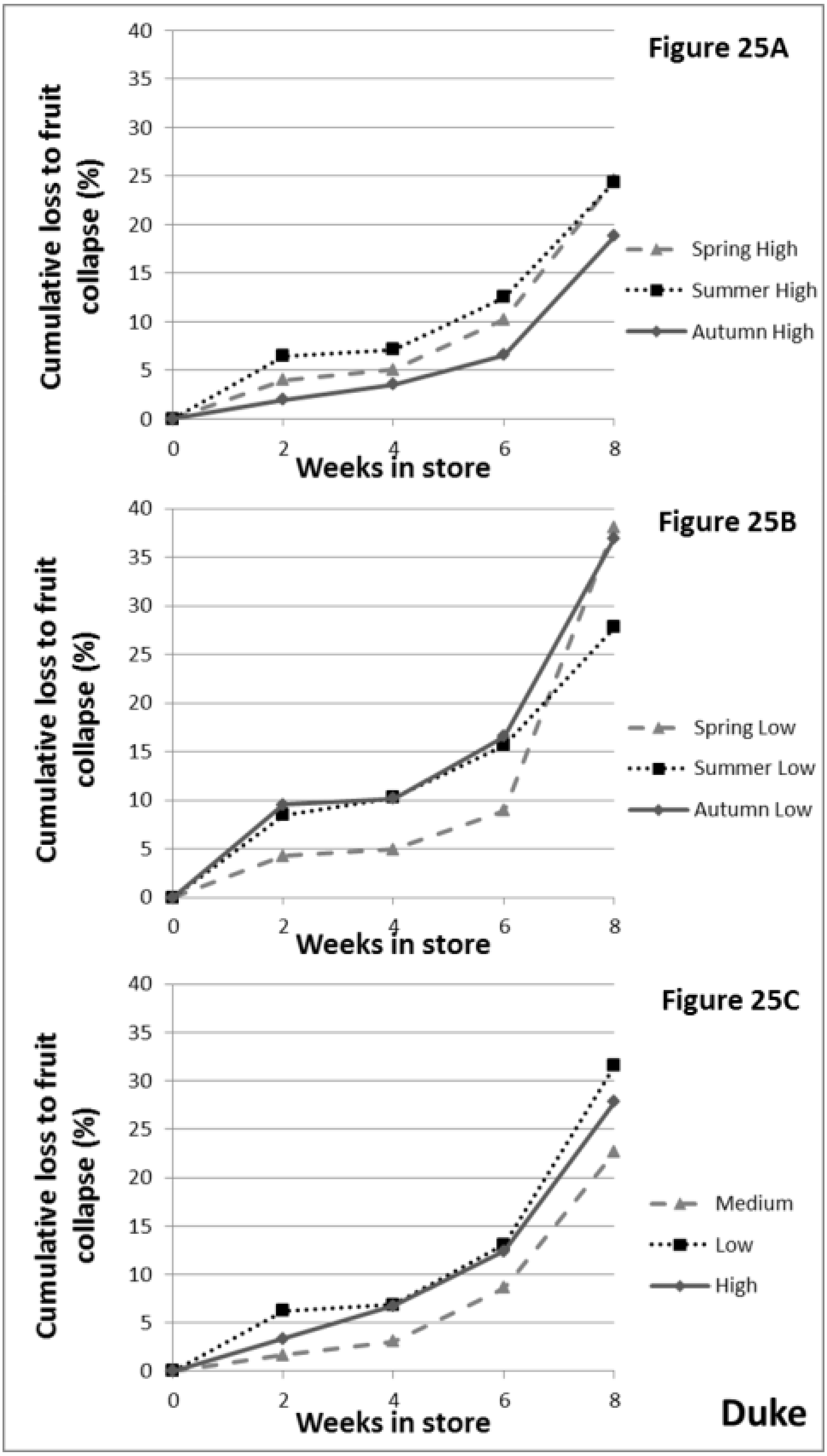


Figure 25. The effect of nitrogen treatment on the loss of storage samples due to fruit collapse for Duke.

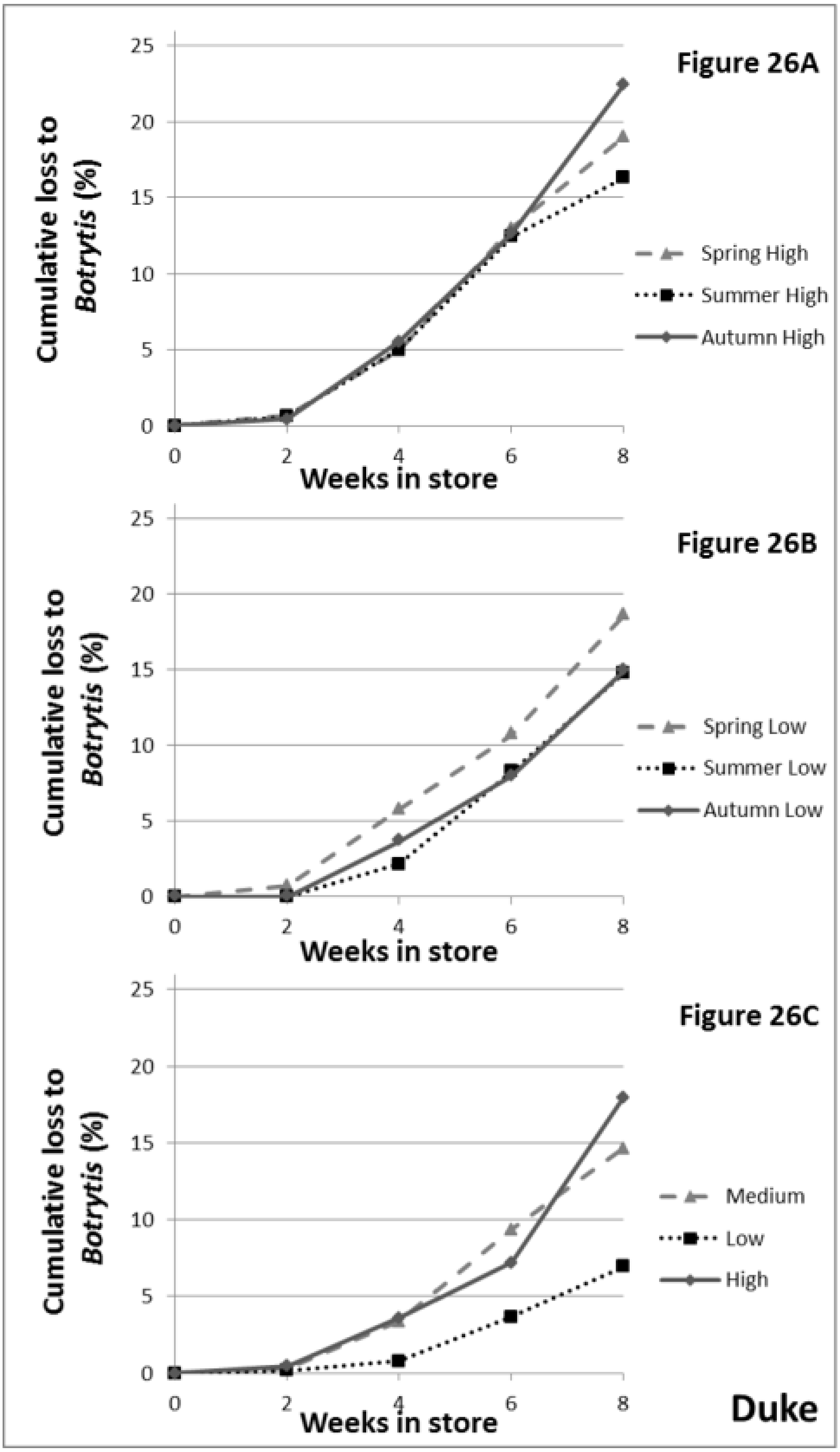


Figure 26. The effect of nitrogen treatment on the loss of Duke storage samples as a result of botrytis.

Vegetative growth

The three strongest new shoots growing from the base of each blueberry bush were tagged during the spring. The length of these was recorded at three points during the season when the nitrogen regimes were changed.

Aurora

Shoot measurements and leaf counts were made at first green fruit, the end of harvest and at 90% leaf fall on 28th May, 30th September and 11th December respectively.

Most shoot growth occurred during fruit ripening and very little growth occurred after harvest. Most treatments had post-harvest shoot growth of less than another 1cm, with the exception of autumn low (see Figure 27). There was also little variation in growth prior to harvest where 16 to 20cm growth was measured between May and September. Changes in leaf number throughout the season were similar for all treatments (See Figure 28).

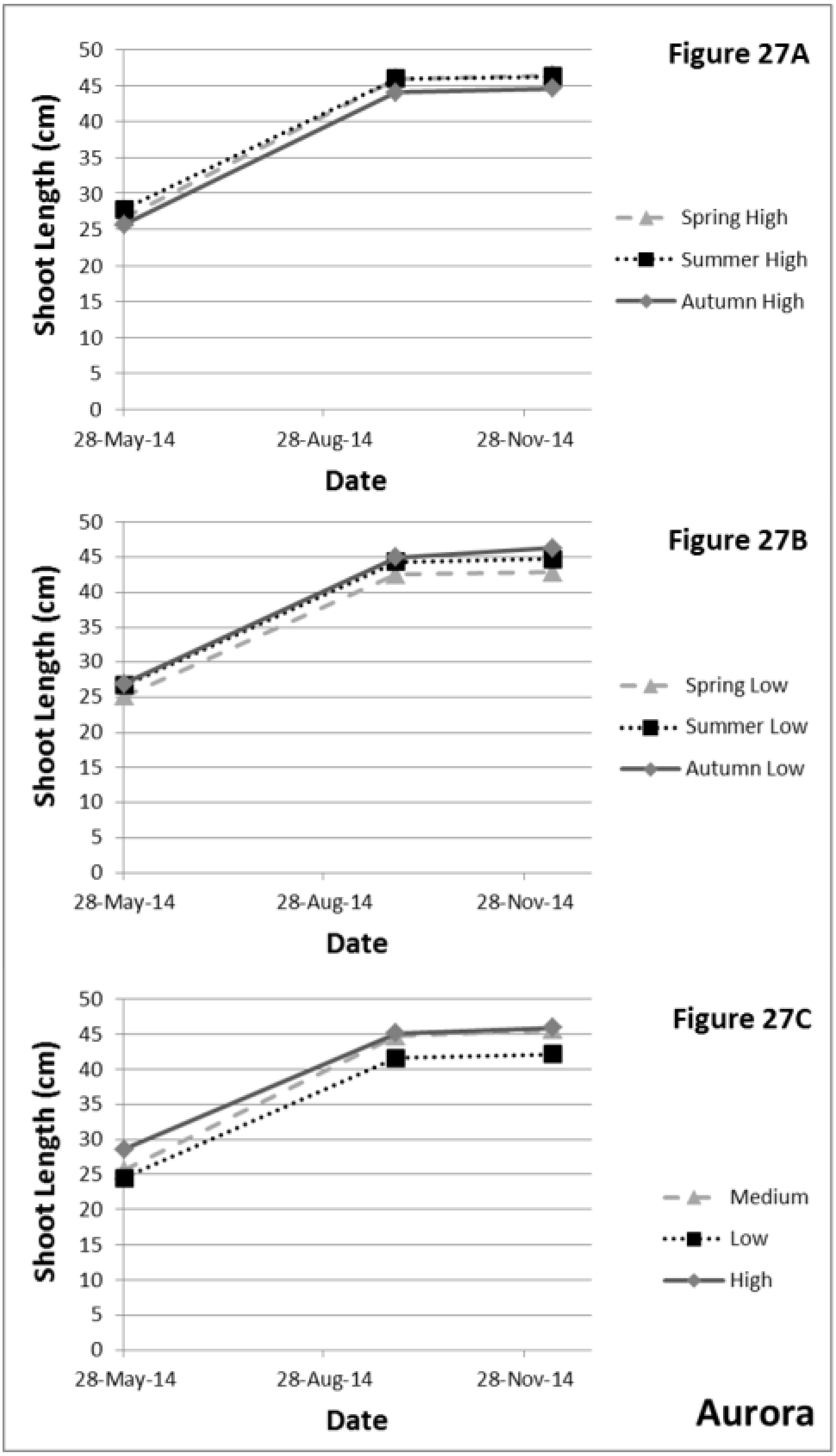


Figure 27. The effect of nitrogen treatment on the growth of tagged new shoots for Aurora.

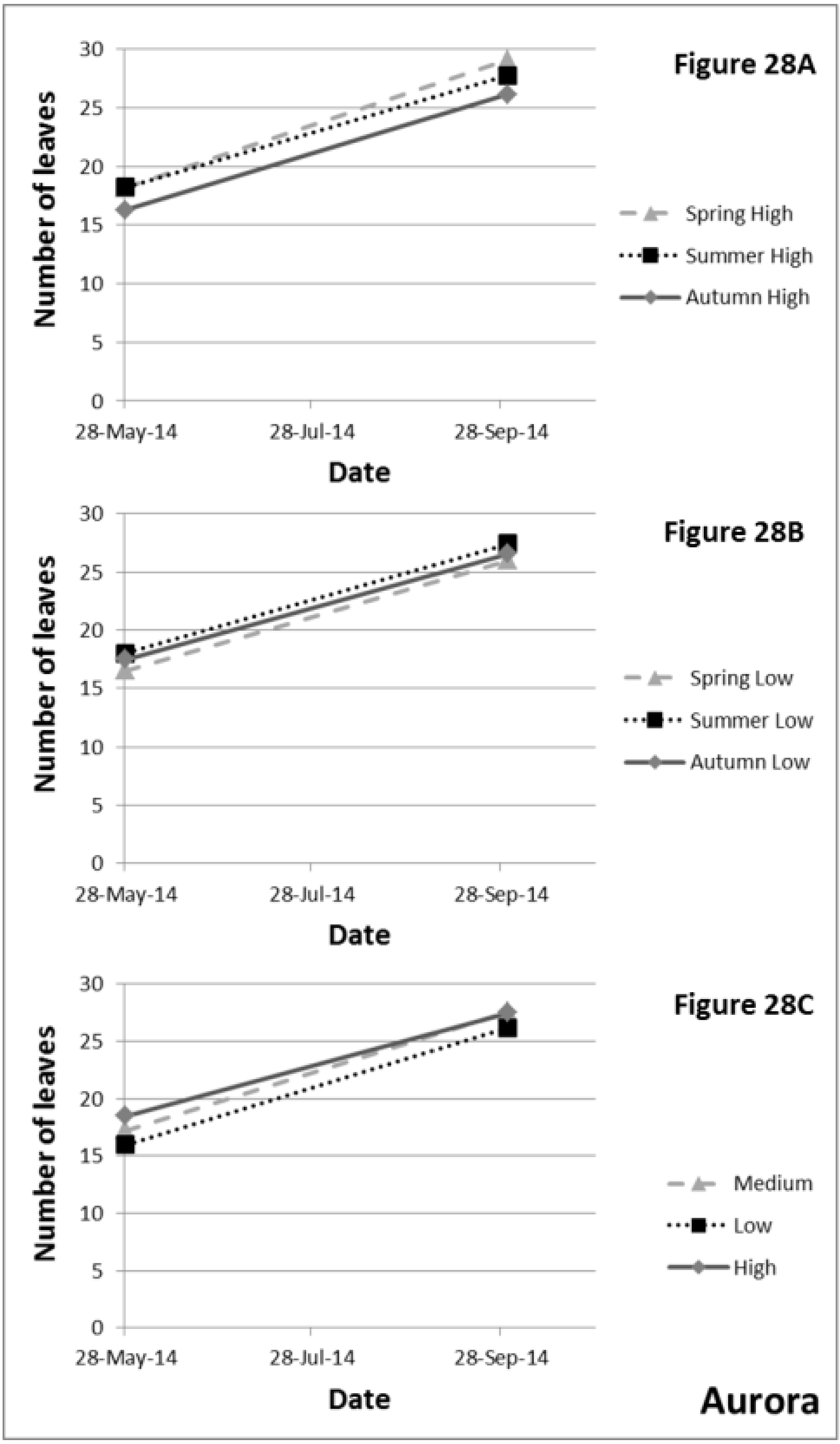


Figure 28. The effect of nitrogen treatment on the number of leaves per tagged new shoot for Aurora.

Duke

Shoot measurements for Duke were also made at first green fruit, the end of harvest and at 90% leaf fall. These assessments occurred on 19th May, 23rd July and 4th December respectively.

Similar to the Aurora, most growth occurred during fruit ripening. However, growth after harvest was greater for the Duke, extending between 6 and 10cm (see Figure 29). The most variation in growth between treatments came prior to harvest. The autumn low treatment had the most growth; however this difference was not of statistical significance. The high treatment had the least growth throughout the season and also the fewest leaves.

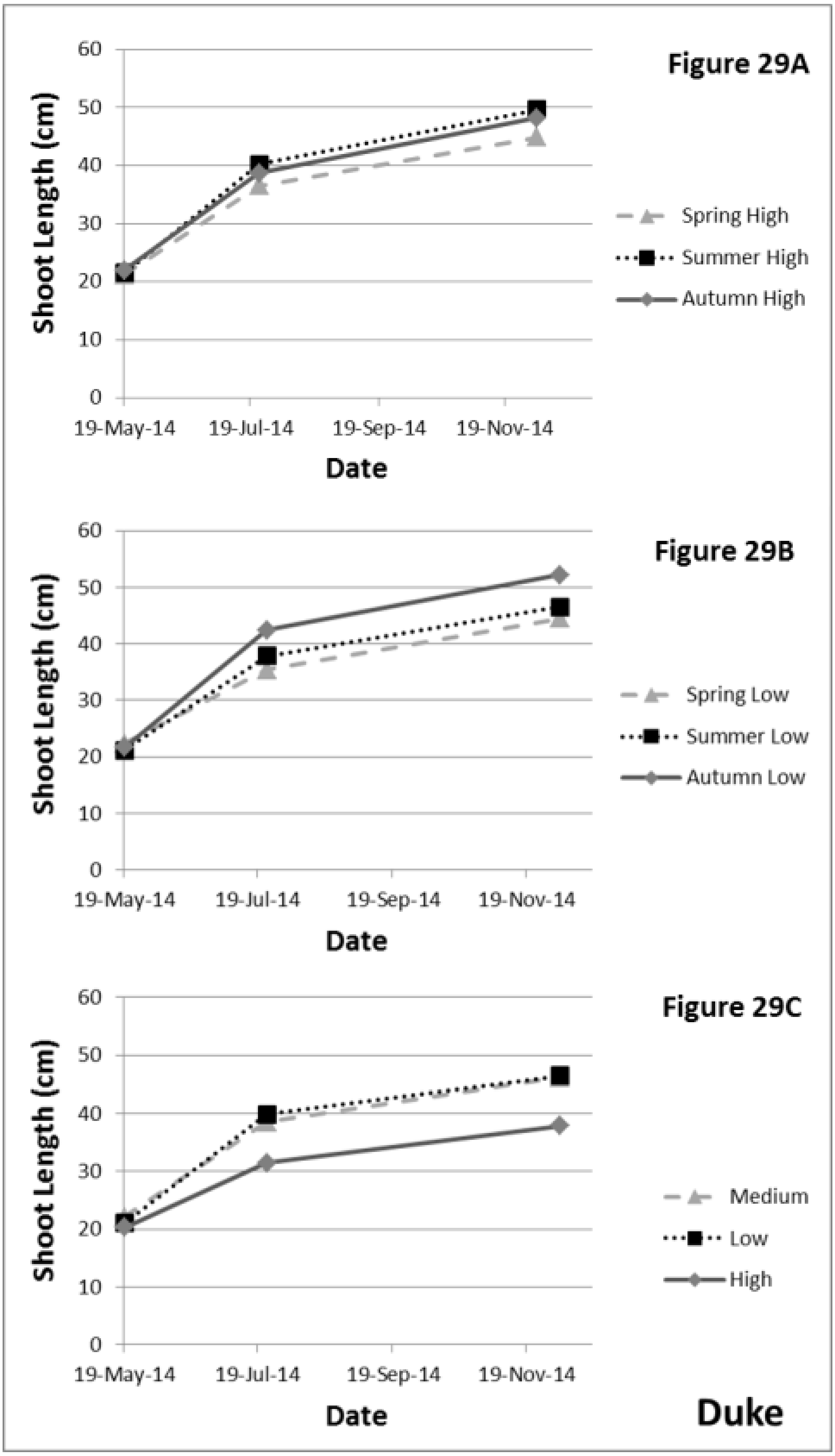


Figure 29. The effect of nitrogen treatment on the growth of tagged new shoots for Duke.

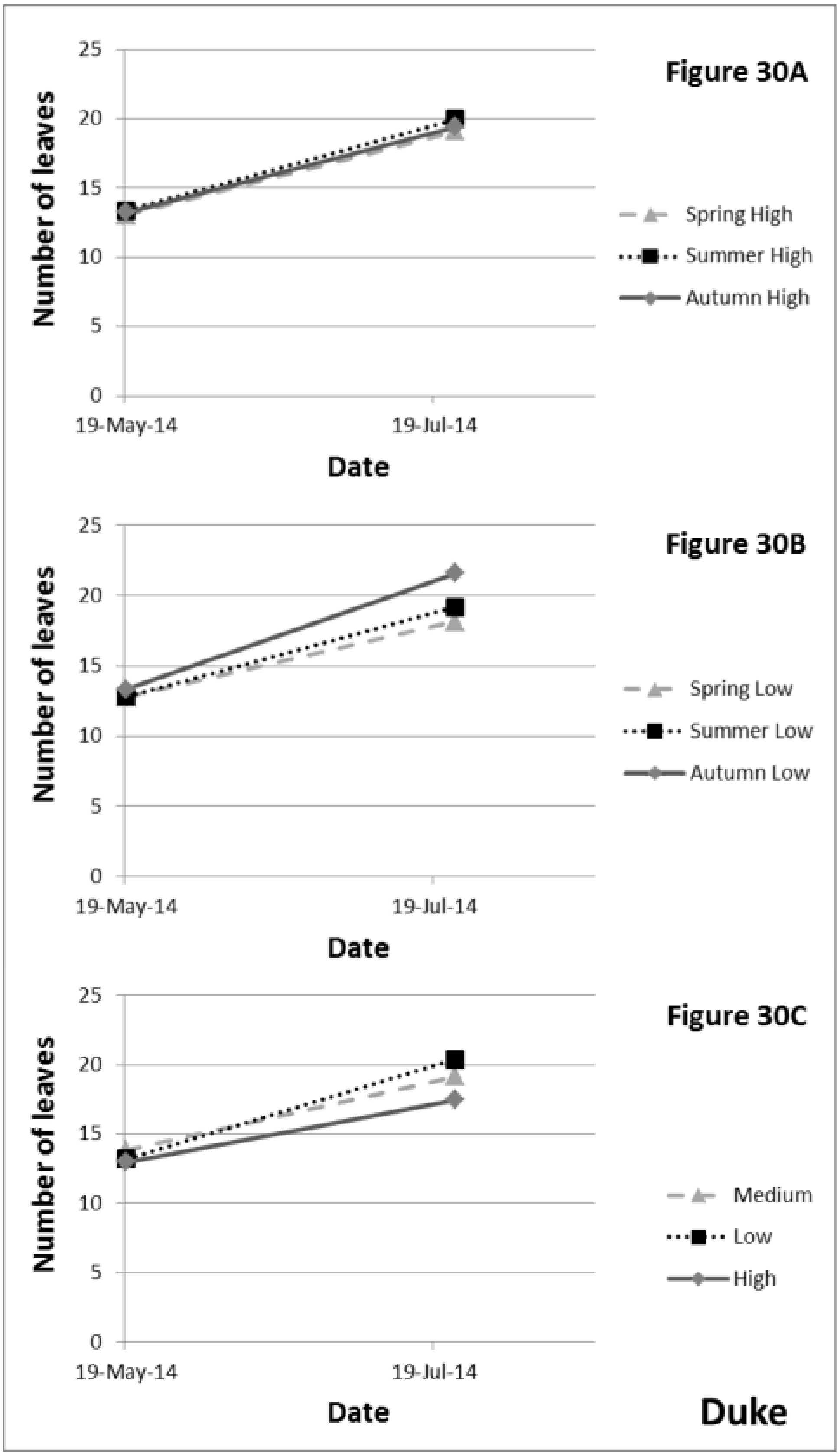


Figure 30. The effect of nitrogen treatment on the number of leaves per tagged new shoots for Duke.

Feed analysis

The targets for nitrogen concentration were 60, 120 and 180 mg/L for the low, medium and high nitrogen regimes. The same feed recipes were used for high, medium and low throughout the season and at the same target ECs. As is often the case with feeding systems, there was variation in the nitrogen levels achieved (see Figures 31 and 32). Clear differences, however, were maintained between low, medium and high regimes.

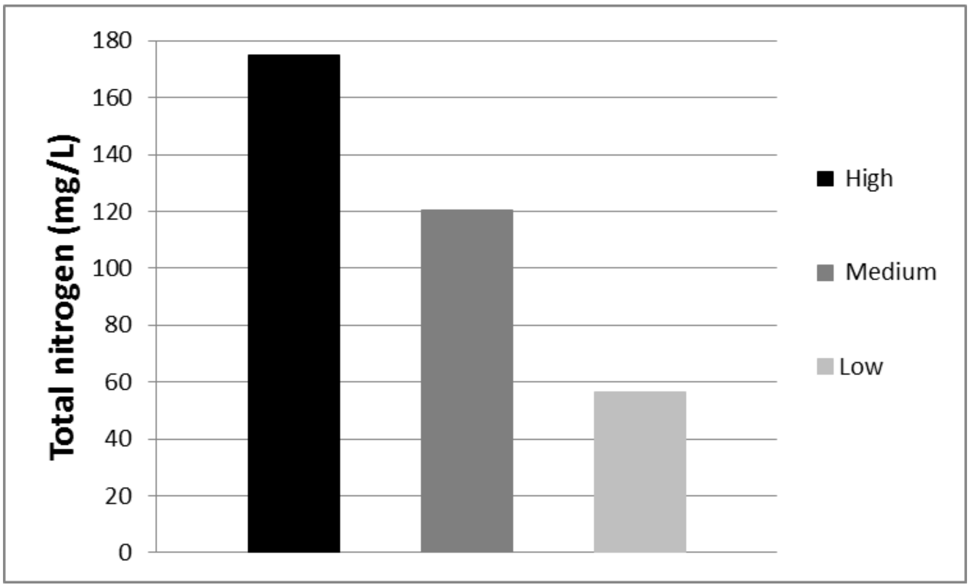


Figure 31. The nitrogen concentration of the three feed regimes. This analysis is from 24th July 2014.

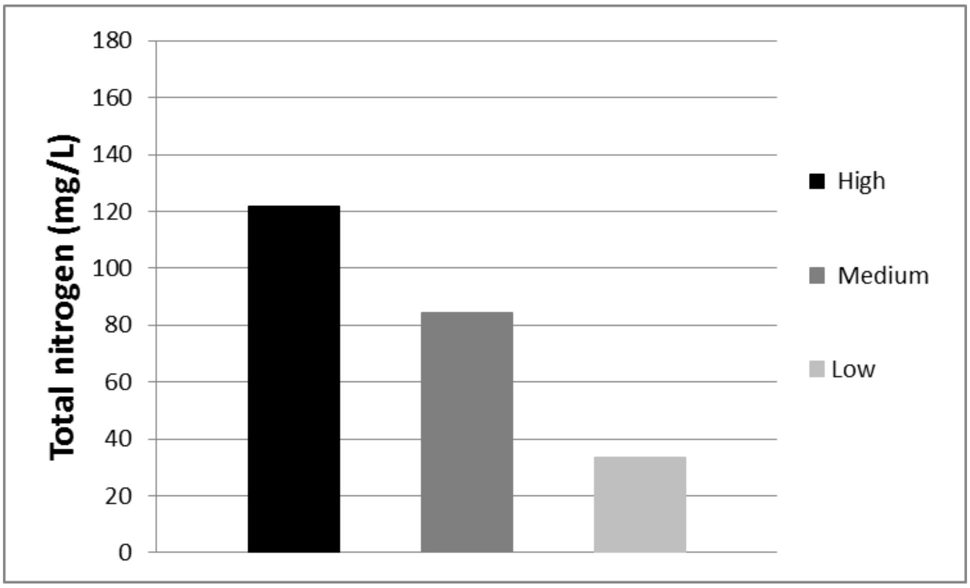


Figure 32. The nitrogen concentration of the three feed regimes. This analysis is from 8th August 2014.

Nitrogen leaf analysis

Leaf samples were taken from each treatment at the end of May/ beginning of July for each cultivar. This was shortly after the feed had been switched to 'summer' regimes. The results can be seen in Table 10.

Aurora

There were only small differences between the leaf nitrogen of the treatments. The spring low and summer low treatments were amongst the lowest leaf nitrogen, whilst the high treatment had the greatest leaf nitrogen level.

Duke

The spring low, summer high and high treatments were amongst those with the lowest leaf nitrogen, whilst the autumn high and high treatments had the greatest nitrogen levels.

Table 10. The effect of nitrogen treatment on nitrogen leaf analysis (% dry weight) for both the Aurora and Duke.

	Aurora	**Duke**
Treatment	**1st June**	**26th May**
Spring High	2.05	2.20
Spring Low	1.99	2.10
Summer High	2.07	2.15
Summer Low	1.97	2.21
Autumn High	2.03	2.25
Autumn Low	2.07	2.25
Medium	2.03	2.22
Low	2.02	2.21
High	2.10	2.17

Discussion

Whilst there was no effect of treatment on overall yield or quality class for Aurora, there were significant effects observed for Duke. There was no effect seen on total yield (kg) for Duke, however there was a significant increase in the total number of fruit harvested from the high treatment. There were also significant impacts on the quality of the fruit. In comparison to all other treatments, the high treatment had greater percentages of Class II and smaller proportions of Class I fruit. The significant decrease in both berry weight (g) and fruit size (mm) for Duke further suggests that feeding high nitrogen resulted in the large quantity of smaller fruit.

The cropping profile for Duke revealed a significant difference in pick sizes for the first and last picks. Feeding high nitrogen throughout the season resulted in greater early picks and a decline in pick size towards the end of the season. The opposite effect was seen for the low treatment where the early picks were small, whilst the final picks of the season were much greater than any other treatment. This indicates that there may be an effect of nitrogen treatment upon fruit ripening. This may explain the difference in berry weight and size between the low and high nitrogen treatments, as berries which ripen more slowly are likely to become larger.

Fruit quality was affected by nitrogen treatment for Duke, with effects seen on the º Brix levels. The summer high treatment produced the highest º Brix levels, with similar results seen for the high treatment only. These results were similar to the previous season, in which the summer high treatment was also amongst the treatments with the highest º Brix. This may suggest that feeding high nitrogen during fruit ripening may increase º Brix levels. This is likely to be as a result of increased photosynthetic rates, which may allow for improved accumulation of sugars.

Impacts of nitrogen treatment were found in storage potential for Aurora. The summer high treatment had the least marketable fruit remaining after eight weeks of storage, whilst the low treatment stored the best, with approximately 50% of the original sample remaining. This appeared to be as a result of low incidences of both fruit collapse and botrytis. Low levels of botrytis in this treatment were observed in the previous season, however the storage results of the previous year indicated increased susceptibility to fruit collapse. Similar to the 2013 results, the high and summer high treatments were amongst those which had high incidences of botrytis. This indicates that feeding high nitrogen levels, particularly during the ripening process, may lead to more botrytis.

Previous years' data have shown the low nitrogen treatment to result in reduced growth throughout the season, significantly so for Aurora. Growth throughout the 2014 season, however, did not follow the same trend. No significant differences were observed in growth between treatments; however the high nitrogen treatment had the least growth from bud break until green fruit. The growth results of the coming season may confirm the effect of high nitrogen on growth or give an indication whether the effect was seasonal.

Conclusions

Feeding high nitrogen throughout the season resulted in a greater number of total berries, which were of smaller size, whilst low nitrogen produced significantly larger fruit. The cropping profiles for these treatments were also considerably different. Larger yields were recorded early in the picking season for the high nitrogen. In contrast, higher yields were observed further into picking for the low nitrogen treatment. Berries from bushes supplied with high nitrogen, particularly during the summer, achieved higher ^{o}Brix levels, whilst those with low levels of nitrogen stored considerably better. No significant differences were observed in total yield, shoot growth or leaf number between the various nitrogen treatments.

Knowledge transfer

Dan Chiuian presented a summary of the 2014 season results at the FAST Members Annual Conference on 5th February 2015.

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