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| **Project title:** | Optimising the light recipe for maximum photosynthesis, yield and quality in strawberry |
| **Project number:** | |
| **Project leader:** | Keiri Swann University of Reading |
| **Report:** | Annual report, 10/2020 |
| **Previous report:** | NA |
| **Key staff:** | Paul Hadley<br>Carrie Twitchen<br>Simon Pearson |
| **Location of project:** | University of Reading |
| **Industry Representative:** | Richard Harnden |
| **Date project commenced:** | 01/04/2019 |

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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

Over 100 tonnes of strawberries per hectare is achievable with multi-tiered farming. First fruit can be produced by valentine's day. However, electricity costs are prohibitive without higher yields per unit area and greater efficiencies in the use of artificial light.

## Background

There is an expanding market for out of season strawberries in the UK which is, currently met by importation from warmer countries such as Spain or UK glasshouse production under High Pressure Sodium (HPS) lights. LED lighting offers a far more efficient alternative to HPS lights for UK production. My research explores the potential for LEDs in strawberry production and how they could be used most efficiently with regards to light intensity, spectrum and duration.

## Summary

Out-of-season production of strawberries is possible using a multi-tiered growing system using supplementary LED lighting. An everbearer cultivar produced a larger overall crop but production was two weeks later that an early season Junebearer. Supplementary LED light increased yield to over 100 tonnes per hectare but with high associated electricity costs. Yields decrease down the tiers with the reduced availability of natural light. Light intensity significantly increases yield at intensities above 227 µmol/$m^2$/s.

## Financial Benefits

Despite high out-of-season yields produced in this experiment the multi-tiered system has not yet been optimised to be cost effective when electricity costs were considered. Table 1 indicates how the different lighting treatments and associated costs relate to the yield and profitability of the system.

*Table 1: Cost yield analysis per meter for each cultivar and lighting treatment with an averaged effect of tier. Strawberry price based on early season strawberry prices (*(DEFRA, 2020b).

| Variety | Photo-duration | Intensity (µmol $m^{-2}s^{-1}$) | Energy Cost (£) | General Cost (£) | Total Cost (£) | Yield (kg) | Price (£/kg) | Income (£) | Profit (£) |
|---|---|---|---|---|---|---|---|---|---|
| Junbearer | 11 | 344 | 29.43 | 31.58 | 61.01 | 2.908 | 8 | 23.27 | -37.74 |
| Junbearer | 11 | 227 | 23.54 | 31.58 | 55.12 | 2.554 | 8 | 20.43 | -34.69 |
| Junbearer | 16 | 344 | 42.81 | 31.58 | 74.39 | 3.076 | 8 | 24.61 | -49.78 |
| Junbearer | 16 | 227 | 34.25 | 31.58 | 65.82 | 2.886 | 8 | 23.09 | -42.74 |
| Junbearer | 22 | 344 | 58.86 | 31.58 | 90.44 | 3.263 | 8 | 26.10 | -64.34 |
| Junbearer | 22 | 227 | 47.09 | 31.58 | 78.67 | 2.935 | 8 | 23.48 | -55.18 |
| Everbearer | 11 | 344 | 29.43 | 31.58 | 61.01 | 3.321 | 8 | 26.56 | -34.44 |
| Everbearer | 11 | 227 | 23.54 | 31.58 | 55.12 | 3.222 | 8 | 25.78 | -29.35 |
| Everbearer | 16 | 344 | 42.81 | 31.58 | 74.39 | 3.968 | 8 | 31.75 | -42.64 |
| Everbearer | 16 | 227 | 34.25 | 31.58 | 65.82 | 3.193 | 8 | 25.54 | -40.28 |
| Everbearer | 22 | 344 | 58.86 | 31.58 | 90.44 | 4.089 | 8 | 32.71 | -57.73 |
| Everbearer | 22 | 227 | 47.09 | 31.58 | 78.67 | 4.054 | 8 | 32.43 | -46.24 |

## Action Points

The use of supplementary light produces higher and earlier strawberry yields. However, a lower light intensity than seen here is likely to be more profitable, due to lower associated energy costs. Furthermore, higher planting densities and the addition of $CO_2$ could dramatically increase yield and profitability. Also, there is a potential for vertical farms to achieve a higher price for the fruit due to increased consumer demand for a novel product with less pesticide use, low food miles and cleaner production methods.

# SCIENCE SECTION

## Introduction

There is increasing demand for strawberries in the UK through the winter months with imports valued at £166m per annum (DEFRA, 2020a). The alternative to importation is local greenhouse production with supplementary lighting, where the yield per unit area can be maximized with intensive multi-tiered production systems (Beacham, Vickers and Monaghan, 2019). Previously, High Pressure Sodium (HPS) lamps were the principal lighting system used in greenhouse production. However, HPS lamps are not energy efficient and produce too much radiant heat to be placed close enough to plants to be used in a multi-tiered system or to reach high intensities (Mitchell and Stutte, 2015). In contrast, LED lights are cooler, making it possible for them to produce higher irradiances by being positioned closer to plants. Different blends of colours are possible with LED lights, they have a high energy efficiency and their cost is declining.

Fruit development in Junebearing varieties occur under long days at high temperatures (Konsin, Voipio and Palonen, 2001; Yamasaki, 2013), whilst, short days are required for flower initiation. A prolonged period of long days can inhibit further flower initiation and instead promote vegetative runner production (Dennis, Lipecki and Kiang, 1970). In contrast, fruit development occurs in Everbearers over a wide range of photoperiods and these varieties are considered to be insensitive to photoperiod for flower bud initiation (Savini *et al.*, 2005). However, periods of short days and high temperatures can inhibit flowering (Nishiyama and Kanahama, 2002) and long days have been shown to promote earlier flowering (Okimura and Igarashi, 1997; Yoshida *et al.*, 2012). Both Junebearers and Everbearers are used for out of season production often with low chill Junebearing varieties forced for an early spring crop and Everbearers used to prolong the summer season into the autumn (Neri *et al.*, 2012).

Out of season production of Junebearers is best achieved in short photoperiods with a high light intensity leading to greater yields, plant size photosynthetic rate, improved crop quality, earlier flowering and faster ripening (Miura, Yoshida and Yamasaki, 1993; Hidaka *et al.*, 2014). In Everbearers, long photoperiods lead to earlier and more abundant flowering (Yoshida *et al.*, 2012), whereas in Junebearers longer photoperiods cause excessive runnering (Dennis, Lipecki and Kiang, 1970). Miyazawa *et al.,* 2009 found that Everbearers performed best at a high daily light integral (DLI) and temperature, with no effect of photoperiod. Increased light intensity has been found to increase plant growth and yield (Nestby and Trandem, 2013). However, Tang *et al.,* 2020 found a positive effect of shading at (387–437µmol) on fruit quality and yield.

This PhD project explores the efficiency of a three-tiered LED lit growing system for out of season strawberry production focusing on the lighting duration and intensity, comparing Everbearer and Junebearer strawberry cultivars. on yield and fruit quality.

## Materials and methods

The experiment was conducted in the winter of 2019-2020 on a three-tiered planting system lit by 300 µmol $m^{-2}$ $s^{-1}$ white LEDs (KropTek, Woking, UK) in a heated glasshouse at the Crops and Environment Laboratory at the University of Reading. A premium Everbearing (Variety A) and Junebearing strawberry (Variety B) variety were obtained as tray plants and planted on the 18th of December 2019, at a rate of eight plants per 1 metre coir filled strawberry bags (Legro, Helmond, The Netherlands). Planting occurred across three tiers each consisting of a 10m row of strawberry tabletop guttering (Single Row Substrate System, Haygrove Ltd, Ledbury, UK) in two randomised blocks, the first and last metre of each gutter acting as a guard giving 567 test plants. Each row had a different light duration, 11, 16, and 22hrs, with fully lit and 80% treatments in a randomised block design. A standard commercial strawberry mix (Strawberry Special, Solufeed Ltd., Barnham, UK) was used to fertigate the plants with additional potassium added at fruiting (Solupotassse, Solufeed Ltd., Barnham, UK). pH and EC were set at 5.5 and 1.8 mS/cm respectively and plants were irrigated to 10-20% daily run-off. The glasshouse was maintained at an average temperature of 17°C and relative humidity of 70%. Biological control for glasshouse western flower thrips (*Frankliniella occidentalis*), two-spotted spider mite (*Tetranychus urticae*), white fly (*Trialeurodes vaporariorum*) and a range of aphid species were also introduced regularly (Bioline Agrosciences, Little Clacton, UK). Bees were introduced every six weeks for pollination.

Yield data was collected biweekly on a total bag basis then averaged to estimate yield per plant. Fruit was categorised into 1st Class (over 8g), 2nd Class (8g and under) and waste fruit. Fruit quality was recorded on ripe fruit pooled for each treatment replicate at three harvest dates to show fruit sweetness, flavour and maturity. The °Brix (sugar content)/ acid ratio was determined using a handheld digital refractometer (Strawberry °Brix / Acidity Meter, Atago, Tokyo, Japan). For the brix measurement, 1 ml of the liquid juice was placed on the refractometer and the brix recorded. For the acid content 1ml juice was diluted with 50ml of deionised water then placed on the refractometer and the acid content expressed as % citric acid. Statistical analysis was carried out using ANOVA (Genstat, 18th edition) with the least significant difference calculated at 5%. A regression analysis was also conducted.

## Results

Reducing the light intensity from an average of 344µmol to 227µmol reduced the Class 1 yield (averaged across both varieties) by 13% ($p<0.001$). Increasing the lighting duration also increased yield but not in proportion to increased energy input ($p=0.001$). The yield increased by over 200g/plant up the multi-tiered system in response to the increased availability of natural light ($p<0.001$) (Figure 1).

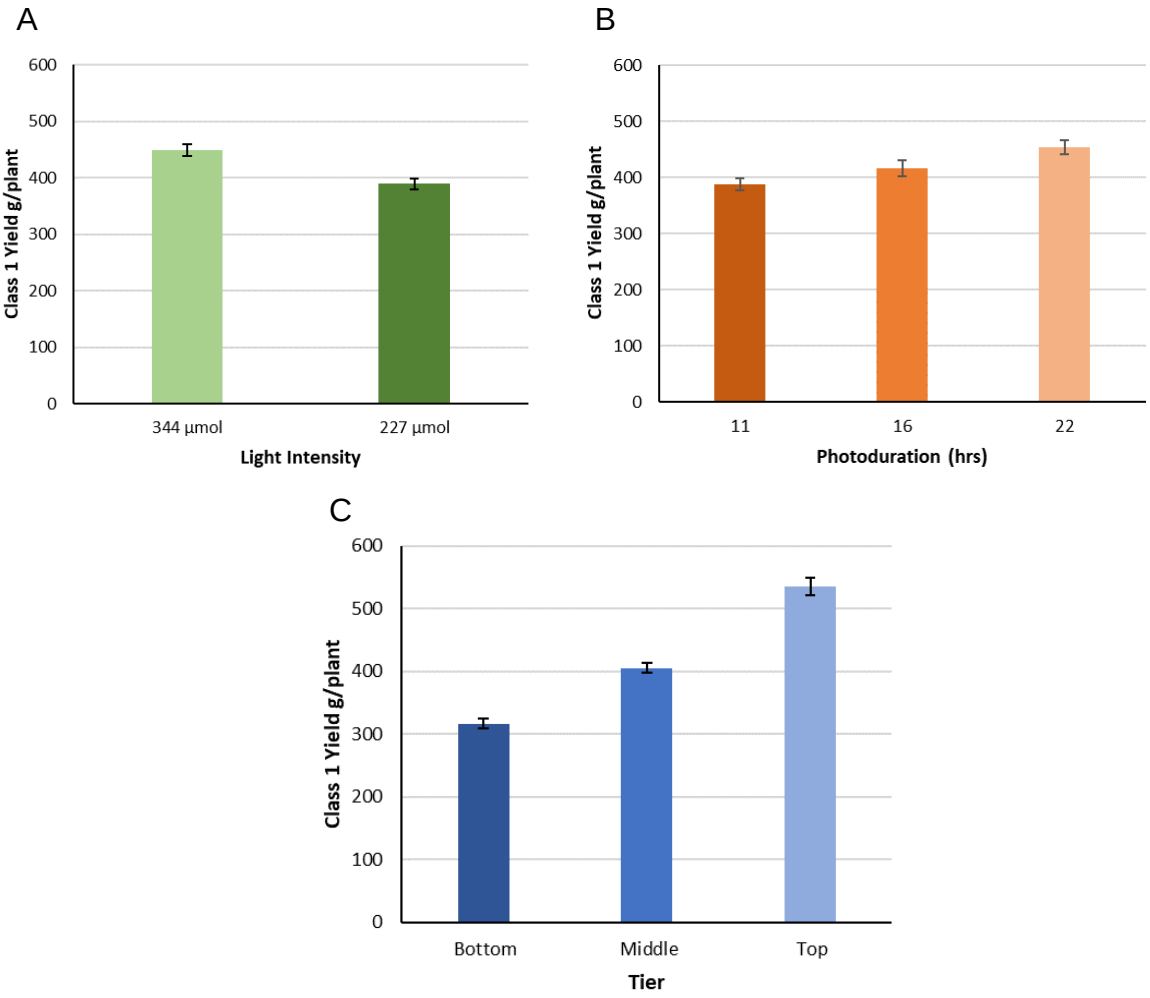


*Figure 2: The average Class 1 strawberry yield between A) 100% and 80% lighting, B) photoduration, C) tiers of the three-tiered system. Vertical lines on each bar represent ±SEM.*

The Everbearers flowered on average four days later than the Junebearer but the first flowers were removed to increase the fruit quality (as per commercial practice) which caused a further delay in fruiting. The Everbearer started fruiting two weeks later than the Junebearer (28th and 14th Feb respectively) (Figure 2). The Everbearer also yielded over 100g/plant higher than the Junebearer ($p<0.001$) and showed a stronger positive correlation with the increased photoduration (Figure 3).

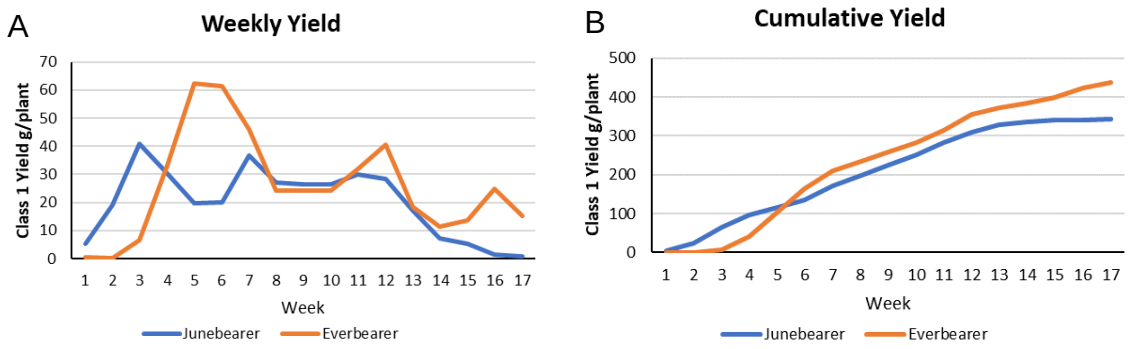


*Figure 2: The average Class 1 yield per plant A) weekly and B) cumulatively.*

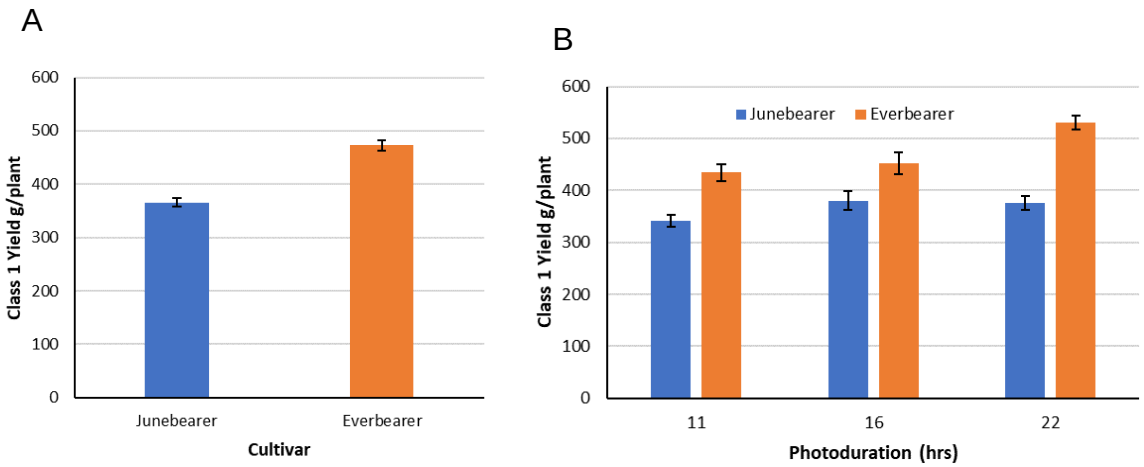


*Figure 3: The average class 1 yield between A) cultivar and B) cultivar and photoperiod. Vertical lines on each bar represent ±SEM.*

The increase in Everbearer yield was determined by the increased number of berries rather than the berry size. The Junebearer produced larger fruit than the Everbearer with the first picked fruit averaging 30g ($p<0.001$). The Everbearer produced significantly more fruit, averaging eight fruit per plant more than the Junebearer ($p<0.001$) (Figure 4). Berry weight increased slightly with increased light duration and intensity. The bottom tier had larger berries than the middle or top (data not shown).

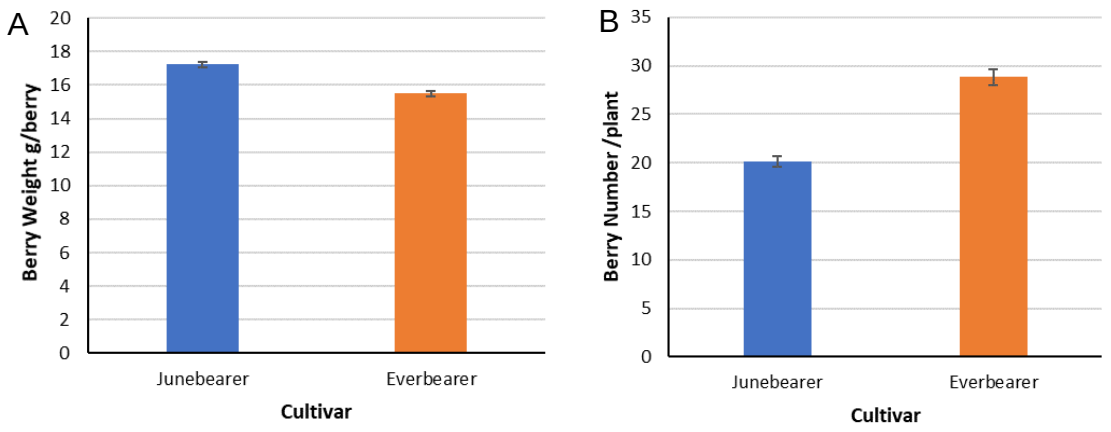


*Figure 4: The A) average berry weight and B) average berry number of class 1 fruit between cultivars. Vertical lines on each bar represent ±SEM.*

The supplementary daily light integral combines the effect of light duration and intensity. The yield of the Everbearer had a stronger correlation with the supplementary DLI, indicating that it had a higher capacity to utilise a more intensive lighting system (Figure 5).

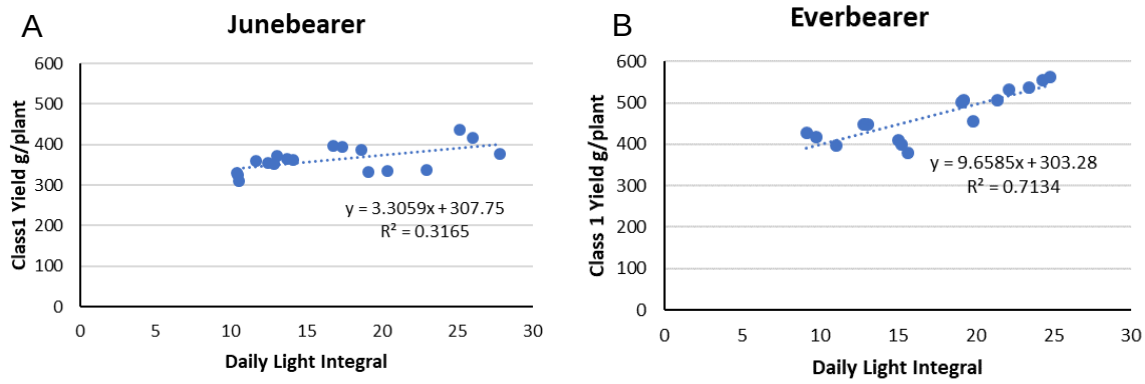


*Figure 5: The supplementary daily light integral of each linear meter on a three tiered system, averaging the effect of tier, compared to the yield for that meter in A) Junebearer and B) Everbearer.*

°Brix is the sugar content of the fruit, contributing to the flavour, 8 is the industry acceptable industry standard for strawberry (MFA, 2019). Longer light durations increased °Brix ($p<0.001$), however there was no significant effect of light intensity (Figure 6).

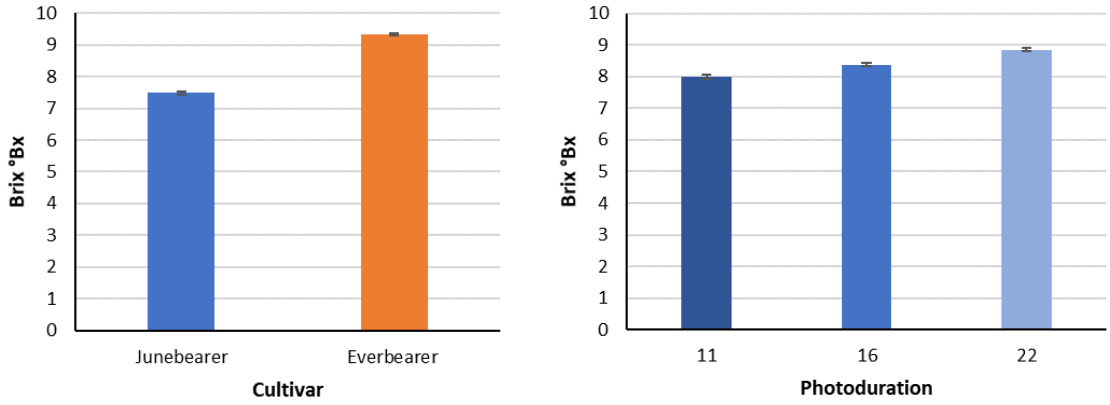


*Figure 6: The effect of A) cultivar and B) photoduration on the brix content of fruit from a three-tiered LED growing system. Vertical lines on each bar represent ±SEM.*

Based on the highest yielding treatment of the Everbearer fully lit at 22hrs over 100 tons per hectare could be produced (Table 1).

*Table 1: Extrapolate yield per hectare from the highest yielding treatment (22hr, fully lit, Everbearer) on an experimental three-tiered growing system.*

| Tier | g/plant | g/m | Kg/m | Kg/tier | Kg/60m² | Kg/1m² | Tonnes/hectare |
|---|---|---|---|---|---|---|---|
| Top | 694.8 | 5558.4 | 5.5584 | 277.92 | 684.84 | 11.41 | 114.14 |
| Middle | 536.8 | 4294.4 | 4.2944 | 214.72 | | | |
| Bottom | 480.5 | 3844 | 3.844 | 192.2 | | | |

## Discussion

The three-tier growing system described here was effective in producing large out of season strawberry yields of high-quality fruit. However, the lower tiers were less productive than the higher tiers, potentially due to reduced intensity of natural daylight (Tian, 2016). Furthermore, higher overall yields may have been achieved with a less compact tier structure increasing light dispersal and uniformity. Based on an average yield from the three tiers, electricity costs are likely be too great to make this intensive system profitable even based on out of season strawberry prices (DEFRA, 2020b). However, if space was the limiting factor, with a potential yield per hectare of over 100 tonnes, and significantly more with higher planting densities and the addition of $CO_2$, this high intensity method could be more cost-effective (Pérez De Camacaro *et al.*, 2004; Tariq *et al.*, 2013; Miyoshi *et al.*, 2017).

As shown in previous research, the Junebearer produced an early crop under long photodurations of intense artificial lighting but failed to produce subsequent flushes of fruit but instead produced increased vegetative growth (Dennis, Lipecki and Kiang, 1970; Sønsteby, 1997; Konsin, Voipio and Palonen, 2001; Yamasaki, 2013). Furthermore, Everbearers were

insensitive to the photoduration and could utilise higher DLIs to produce larger yields suggesting greater effectiveness in an intensive system (Okimura and Igarashi, 1997; Nishiyama and Kanahama, 2002; Savini *et al.*, 2005; Miyazawa *et al.*, 2009; Yoshida *et al.*, 2012). Fruit production in the Everbearer was two weeks later than the Junebearer. This slower flower development indicates why they are more commonly used to extend autumn production whilst Junebearers are used for spring production (Neri *et al.*, 2012). Further research needs to be conducted to increase earliness in Everbearers and to induce further flowering in Junebearers. The Everbearer was also sweeter, well above the requirement for summer strawberries which could be the result of the specific varieties chosen.

Shorter durations of high intensity lighting have been shown to be most efficient for strawberry production (Miura, Yoshida and Yamasaki, 1993; Hidaka *et al.*, 2014) However, here improvements in yields have been shown with longer daylengths and high intensity lighting with some cultivar variation. In contrast to the results of Smeets, (1980) and Miura, Yoshida and Yamasaki, (1993) higher light intensities were not shown to produce an earlier yield, however, in agreement with Okimura and Igarashi, (1997) increased lighting duration did. Increasing light intensity increased brix levels, however, in contrast to previous studies (Nestby and Trandem, 2013; Hidaka *et al.*, 2014) the effect of light intensity on °Brix was not significant. This experiment supports previous research indicating that long photoperiods and light intensities increased flowering in Everbearers and runnering in Junebearers (Dennis, Lipecki and Kiang, 1970; Smeets, 1980; Miura, Yoshida and Yamasaki, 1993). In contrast to Tang *et al.*, (2020) no benefits were seen of shading.

## Conclusions

High yielding out of season strawberry crops can be produced with a multitiered LED system. Both Everbearer and Junebearer cultivars are effective but require different lighting regimes. The Everbearer produced a higher yield. The Junebearer started cropping two weeks ahead of the Everbearer but did not yield as highly or achieved a second flush. There was a significant increase in yield up the three-tiered system with the top tier yielding significantly higher than the bottom tier. Increased light intensity and light duration increased the yield, with the Everbearer showing a stronger correlation between increased light and increased yield.

## Knowledge and Technology Transfer

These findings will be disseminated as an oral presentation and accompanying manuscript at the ISHS strawberry symposium 05-2021.

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## Appendices

The three-tiered system