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Plug size and density during greenhouse conditioning do not affect late summer and early fall production of June-planted 'Albion' strawberry (*Fragaria* X *ananassa* Duch.) in the plasticulture system

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ABSTRACT

The influences of plug size and plant density during conditioning of 'Albion' strawberry (*Fragaria* x *ananassa* Duch.) plants were evaluated for off-season field production in New Jersey, USA. Two plug densities (168 and 336 plants m^{-2}, 75 cm^3 cell volume) during conditioning in a greenhouse were evaluated. Conditioning consisted of 5 weeks under LD (natural daylength supplemented with 24 h incandescent radiation) with 100 ppm N the first week and 800 ppm N once each week during last 4 weeks. Controls were kept for 5 weeks under ND (natural daylength) with 100 ppm N once each week. Following conditioning, plants were evaluated in off-season plasticulture. Larger (134 cm^3) plugs were conditioned at 168 plants m^{-2} to compare with the smaller cells (75 cm^3) conditioned at the same density. Inflorescence, runner and branch crown production were monitored and fruit harvested from July through September. Conditioning accelerated flowering and fruiting. New inflorescence production in July was significantly enhanced with conditioning but treatment effects on flowering did not persist. Cumulative yield through early August was enhanced by conditioning however total yield was not affected by conditioning. Conditioning had no effect on branch crown production and significantly reduced runner production. Plug production at a higher density reduced flowering but the short day response was alleviated with conditioning. Smaller plugs flowered earlier, produced more inflorescences and produced fewer runners than plants from larger plugs. Plug size and density ultimately did not affect total yield regardless of treatment.

1. Introduction

Sustainable locally grown food is increasingly desirable in many parts of the world and consumers are willing to pay a premium for it even when less expensive alternatives are available. Interest in off-season strawberry production has increased in the temperate zone of the United States even with a nearly year round supply of relatively inexpensive fruit from California, Florida and Mexico (U. S. Dept. of Agriculture, 2018).

Local strawberries are available for a short time in late spring (early May through mid-June) in most of the US temperate zone from seasonal fruiting, short day (SD) cultivars. Off-season production involves forcing an early spring crop (late March through April) with either SD or long day (LD) cultivars or extending the season with LD cultivars with (September through February) (Demchack, 2009; Jett, 2014; Kadir et al., 2006; Ballington et al., 2008; Fernandez and Ballington, 2003; Rowley et al., 2011; Poling, 2011; Takeda and Newell, 2006; Durner, 1999, 2016a; Black et al., 2005; Takeda and Hokanson, 2002) or without (Durner, 2017b, 2017c) (July through October) high tunnels or greenhouses. Conditioning of plant material before planting may (Durner, 1999, 2017b, 2017c; Fernandez and Ballington, 2003) or may not (Black et al., 2005; Takeda and Hokanson, 2002) improve fruiting.

Success with off-season production has been inconsistent due to the lack of systematic evaluation of appropriate conditioning treatments for specific cultivars. While this type of work has been common in Japan (Hamano et al., 2015; Nishiyama et al., 2003, 2006) and Europe (Heide et al., 2013; Sonsteby and Heide, 2007a, 2007b; Sonsteby and Ness, 1998; Sonsteby et al., 2013), it is lacking in North America. Preparation of plant material prior to forcing is critical to production (Lieten, 1993; Yamasaki, 2013).

Durner (2016b, 2017a) recently evaluated photoperiod and N conditioning of LD cultivars demonstrating that flowering of 'Elan', 'Tarpan' and 'Gasana' could be enhanced by LD (weeks 1–5) and elevated (800 ppm) nitrogen (weeks 2–5). Durner also demonstrated that July-planted off-season, fall field plasticulture productivity of 'Albion' was enhanced with long day plus elevated N conditioning (Durner,

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2017b, 2017c). In addition, the reduced yield often observed using smaller plugs can be avoided with LD and N conditioning (Durner, 2017c).

Commercial availability of plug plants for use in annual or off-season plasticulture is limited to a few SD cultivars such as 'Sweet Charlie', 'Camarosa', 'Florida Festival' and 'Chandler' (Ballington et al., 2008). Personal production of plug plants is complicated by plant patent laws, thus contract commercial production or alternatives must be identified. The current recommendation for off-season LD cultivars is May or June planting of dormant, cold-stored crowns planted directly in the field or plugs produced from dormant, cold-stored crowns in the greenhouse in 32 cell trays (Lantz et al., 2010).

In this study two plug sizes (134 and 75 cm^3 cells at 168 plants m^{-2}) and two plug densities (75 cm^3 cells at 168 and 336 plants m^{-2}) during conditioning in a greenhouse were evaluated in off season plasticulture in New Jersey, USA.

2. Materials and methods

2.1. Pre-conditioning plant preparation

Dormant cold-stored crowns of the long day cultivar 'Albion' were obtained from a commercial nursery (Nourse Farms, Inc., South Deerfield, MA, USA). Roots were trimmed to 2.5 cm in length and crowns planted in 24-cell round plug flats (2.5 cm diameter x 2.4 cm deep, 134 cm^3 volume) or 50-cell round plug flats (2.0 cm diameter x 2.8 cm deep, 75 cm^3 volume) into Fafard Organic Mix (FOF-30) (Sun Gro Horticulture, Agawam, MA) on 10 April 2017 and allowed to grow under ambient greenhouse (natural daylength 24/18 °C day/night temperatures) conditions for 4 weeks.

2.2. Conditioning protocol

On 11 May 2017 plants in 50-cell trays were arranged as either full flats (50 plants in a 50-cell flat, 336 plants•m^2) or half flats (24 plants equally spaced in a 50-cell flat, 168 plants m^2) to provide two plant densities during conditioning. Half of the plants from each density were kept as controls (ND plus 100 ppm N for 5 weeks) and the other half were conditioned with 1 week of LD (natural daylength supplemented with 24 h incandescent radiation (Phillips Duramax Soft White A19 60 W) suspended 0.3 m above the plant canopy) and 100 ppm N followed by 4 weeks of LD with 800 ppm N. N was supplied as a solution of Scotts Miracle grow water soluble fertilizer (24% available N, 8% available P_2O_5, 16% available K_2O) (Marysville, Ohio) diluted with water to provide 100 or 800 ppm N. Each time plants received 100 ml of solution which was more than sufficient to saturate the soil. All plants in the 24-cell size trays were conditioned as described for plants in 50-cell size trays. These plants provided a larger conditioned plug (134 cm^3) for comparison to smaller (75 cm^3) conditioned plugs. There were no non-conditioned 134 cm^3 plugs.

2.3. Production field establishment and experimental design

One week after their fertility treatment was complete plants, were established in a plasticulture field planting at Rutgers Horticultural Research Farm 3 in New Brunswick, NJ. Plants were established on raised beds (20 cm high x 90 cm wide) covered with white on black (1 mil) plastic mulch with the white side exposed. The soil was a Sassafras sandy loam (siliceous, mesic, typical Hapludult). There were two staggered rows per bed with 30 cm between rows and 38 cm between plants in the row. Irrigation was provided twice weekly as needed to provide 25 mm per week via drip tape (10 Mil Medium Weight 5/8″ AquaTraxx Drip Tape, 12″ spacing, Flow rate 0.45, The Toro Company, Bloomington, MN) placed in the center of the bed underneath the plastic mulch. No fertilization program after conditioning was implemented for plants in the production field since they were vigorous and showed no signs of nutrient deficiencies. The experimental design was a randomized complete block with 5 treatments (134 cm^3 at 168 plants m^{-2} conditioned plugs, 75 cm^3 at 336 plants m^{-2} control plugs, 75 cm^3 at 168 plants m^{-2} control plugs, 75 cm^3 at 336 plants m^{-2} conditioned plugs, and 75 cm^3 at 168 plants m^{-2} conditioned plugs). There were 20 blocks and the experimental unit was a single plant plot.

2.4. Inflorescence counts

Inflorescences on each plant were counted on 28 June, and 06, 17 and 24 July 2017.

2.5. Fruit harvest

Ripe fruit were harvested, counted and weighed for individual plants on each of the following dates: 19, 24, 31 July; 2, 8, 14, 22, 28 August; 4, and 11 September 2017. Cumulative yield (weight and fruit number) was calculated on each harvest date and used in the analysis. Fruiting precocity was estimated as the date of first harvest for each plant.

2.6. Runner counts

Runners were counted and removed on 06, 17 and 24 July 2017.

2.7. Termination of experiment

Plants were harvested and the number of crowns and flowers per plant determined on 27 September 2017. Flowers and fruits per crown were estimated by dividing the numbers or flowers and fruit per plant by the number of crowns at the termination of the experiment. Total fruiting potential was calculated as the number of flowers and fruits at termination plus the number of harvested fruit. Total fruiting potentials were similarly adjusted to a per crown basis.

2.8. Experimental design and statistical analysis

All data were tested for normality using the Shapiro-Wilks test of the UNIVARATE procedure of SAS (SAS Institute, Cary, North Carolina, USA). Nearly all data were found to be from a non-normal distribution. Aligned rank transformations (ART) were performed as suggested by Wobbrock et al. (2011) using the ARTool program (http://depts.washington.edu/aimgroup/proj/art/). ART data were analyzed using an analysis of variance (ANOVA) using the GLM procedure of SAS (SAS Institute, Cary, NC).

Planned F-tests were performed to evaluate the main effects of plant density (during conditioning), conditioning, the interaction between the two as well as a plug size effect (Table 1). Since these four contrasts were not orthogonal to each other, the alpha level for determining significance was adjusted via the Bonferroni inequality to account for a greater chance of a Type I error with non-orthogonal contrasts and only contrasts with $P > F \leq 0.01$ were considered significant. This analysis accounts for the 2×2 factorial treatment structure combined with the additional treatment of 24-cell size conditioned plugs which were included in the experiment.

3. Results

3.1. Flowering precocity

Significant effects of plug density, conditioning and plug size were detected for flowering precocity (Table 2). Plugs grown at a higher density flowered later than those grown at a lower density (3 July vs 30 June, 336 vs 168 plants m^{-2}, respectively). Conditioned plugs flowered