Effects of Runner Tip Size and Plugging Date on Fall Flowering in Short-Day Strawberry (Fragaria × ananassa Duch.) Cultivars

Fumio Takeda
Michael Newell

ABSTRACT. Producing strawberry transplants from runner tips that were plugged ~1 month earlier (early July) than the standard time (early August) promoted fall flowering in some short-day strawberry cultivars. In 2002, 100% of ‘Chandler’ transplants produced in early July flowered in the fall, but none of the August-plugged ‘Chandler’ transplants flowered in the fall. In 2003, 73% of ‘Chandler’ transplants produced in mid-July from average-size runner tips and less than half of transplants from small-size runner tips flowered in the fall. Again, August-plugged plants did not flower in the fall. Flowering was absent in ‘Northeaster’ plants. Under protected cultivation, July-plugged ‘Sweet Charlie’ plants bloomed earlier and produced more fruit in November and December than those plugged in August. This study showed that fall flowering in ‘Chandler’ and ‘Sweet Charlie’ strawberry is possible if the transplants are prepared by plugging runner tips in early July. This novel technique for propagating strawberry transplants for annual plasticulture combined with production under high tunnels creates an opportunity for strawberry production in early winter and again in the spring (double cropping) in the mid-Atlantic coast region. doi:10.1300/J492v06n04_10 (Article copies available for a fee from The Haworth Document Delivery Service: 1-800-HAWORTH. E-mail address: <docdelivery@haworthpress.com> Website: <http://www.HaworthPress.com> © 2006 by The Haworth Press, Inc. All rights reserved.)

KEYWORDS. High tunnel, greenhouse, propagation, flower initiation, yield, season extension.

INTRODUCTION

The main strawberry harvest season in the mid-Atlantic coast region (39°N, 77°W) is from early May to late June. Out-of-season fruit production in the region is very limited. Fruit of the day-neutral ‘Seascape’ harvested in November and December have been direct-marketed at US$3.00–4.00 per pound or about four times higher than fruit harvested in spring to restaurants in the Metropolitan Washington-Baltimore area (Takeda, unpublished). As a result, interest in out-of-season strawberry production systems has increased in the mid-Atlantic coast region (Durner, 1999; Takeda, 1999; Takeda et al., 2004, 2006; and Takeda and Hokanson, 2002, 2003). Containerized nursery (plug) plants and the annual plasticulture system has allowed several cultivars developed elsewhere (e.g., ‘Chandler’, ‘Marmalada’, ‘Seascape’ and ‘Sweet Charlie’) to be grown in the region. Planting of these cultivars using the plasticulture system has provided opportunities to extend the harvest season in the spring and make fruit harvesting more efficient in areas with prevailing mild winter climates (e.g., eastern North Carolina and Virginia). Short-day strawberry plants that will flower in the fall or shortly after planting in late August or early September would be desirable for the region. Innovative production technologies such as plasticulture, floating rowcovers, and high tunnels for environmental modifications are already available for extending the harvest season well into late December in the mid-Atlantic coast region (Fernandez and Ballington, 2003). Short-term cropping systems improve opportunities for farm diversification and help growers to produce a variety of fruit and vegetable crops for niche markets. Income from fall and spring fruit production (double cropping) can raise farm profitability.
Flower buds initiation in short-day strawberry cultivars starts in the shorter days of late summer to early spring whenever the temperatures are high enough (Darrow, 1966). Darrow (1966) noted that although short-day strawberry plants developed in the mid-Atlantic coast region can differentiate flower buds in the fall, anthesis does not occur in them in the fall because of less than ideal temperatures for reproductive development. Recently, Bodson and Verheoven (2005) observed in the cv. ‘Elsanta’ that the first sign of inflorescence initiation started in October and carpel primordia initiated in November but they observed no further differentiation in the winter.

The physiological state of plug transplants and nursery conditions in which transplants are produced affect whether flower induction and inflorescence differentiation occur during the propagation phase or shortly after field establishment. Sonstebey and Hytonen (2005) and Verheul et al. (2006) reported that flower emergence and development in ‘Korona’ can be controlled by adjusting photoperiod, temperature, the duration of short-day treatment and plant age under greenhouse conditions. Fernandez and Bullington (2003) produced a moderate crop (175 g per plant) in the fall with conditioned ‘Sweet Charlie’ plants in the coastal region of North Carolina (USDA Hardiness Zone 7a). Their conditioning regime involved production of runner tips and transplants at a high elevation (~300 m above sea level) nursery in western North Carolina and 3 weeks of artificial short-day treatment. Durner (1999) reported that fruit production increased ~80 g per plant in January and February when ‘Sweet Charlie’ strawberry plug plants, 2-3 weeks old, were exposed in September to seven 9-h days without chilling (21°C day/21°C night, followed by seven 9-hour short days with chilling during the dark period (12°C night). In Japan, a technique described as an “extra early forcing method” is used to accelerate fall flowering (Oda, 1992). These treatments involve laborious daily movement of transplants in- and-out of cold rooms or dark rooms or the drawing of a black drop cloth over the plants for up to 3 weeks. The constraint to getting these preconditioning techniques widely accepted has been the high production cost coupled with low productivity (Sonstebey et al., 2006). In Maryland, Takeda and Newell (2006) reported that fall flowering occurred in plants of the short-day ‘Carmine’ strawberry by simply advancing the plugging date of runner tips to early July for producing transplants used in annual plasticulture.

The objectives of this study were to determine the effect of tip size and plugging date of ‘Chandler’ and ‘Northeaster’ strawberry transplants on fall flowering and spring yield in an outdoor plasticulture system and the effect of plugging date and planting date of ‘Sweet Charlie’ transplants on early winter and spring fruit production in a high tunnel.

**Materials and Methods**

**Strawberry Cultivars**

In 2002 and 2003, we used ‘Chandler’ strawberry, a 1983 University of California release (Voth and Brinthurst, 1984). ‘Chandler’ strawberry is the most widely used cultivar in the annual eastern production system outside Florida (Poling, 1993). In 2004, we evaluated ‘Sweet Charlie’ and ‘Norheaster’ strawberry. ‘Sweet Charlie’ strawberry is a short-day cultivar from the University of Florida (Chandler et al., 1997) that tends to produce fruit early (C.K. Chandler, University of Florida, personal communication). ‘Northeast’ strawberry, a 1994 USDA release (Galletta et al., 1995), is an early-season cultivar developed for the traditional matted row production system. The source of plants for runner production and runner tips for plug plants, planting dates and data collected in fall and spring are summarized in Table 1. Details of propagation methods and greenhouse growing conditions are provided elsewhere (Bish et al., 2001; Takeda and Hokanson, 2002, 2003; Takeda and Newell, 2006; Takeda et al., 2004, 2006).

In 2004, Davon Crest Farm, Hurlock, MD, provided runner tips of ‘Sweet Charlie’ strawberry on July 1, August 3 and 17. Tips were plugged into 50-cell packs containing Sunshine LC1 mix. The plug plants were mist sprinkled for 2 weeks in a greenhouse at the University of Maryland Wye Research and Education Center (WREC), Queenstown, MD, after which they were set outside the greenhouse until they were planted in raised beds prepared under a high tunnel in September (Table 1).

**Field Production System**

In all 3 years, strawberry transplants were established in the plasticulture system (Poling, 1993) at WREC. Information regarding the planting site and pre-plant preparation are given elsewhere (Takeda and Newell, 2006). Strawberry transplants were established in plasticulture system at WREC on September 10 in 2002, September 8 in 2003 and

<table>
<thead>
<tr>
<th>Source of plants</th>
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<th>Plugging and planting dates</th>
<th>Fall data</th>
<th>Spring data</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002-2003 study:</td>
<td>‘Chandler’</td>
<td>July 2 and September 10</td>
<td>Plant survival Branch crown Runner number Percentage of plants with flowers</td>
<td>Total yield Fruit size Branch crown number</td>
</tr>
<tr>
<td>Commercial nursery, Hurlock, MD</td>
<td>August 8 and September 10</td>
<td></td>
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<tr>
<td>2003-2004 study:</td>
<td>‘Chandler’</td>
<td>July 17 and September 8</td>
<td>Plant survival Branch crown Runner number Percentage of plants with flowers</td>
<td>Total yield Fruit size Branch crown number</td>
</tr>
<tr>
<td>University of Maryland: College Park, MD and Salisbury, MD</td>
<td>August 13 and September 8</td>
<td></td>
<td></td>
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<tr>
<td>2004-2005 study:</td>
<td>‘Northeaster’</td>
<td>July 3 and September 1</td>
<td>Crown number Runner number Percentage of plants with flowers Marketable yield</td>
<td>Marketable yield</td>
</tr>
<tr>
<td>USDA-ARS Kearneysville, WV</td>
<td>August 5-6 and September 1</td>
<td></td>
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<tr>
<td>Commercial nursery, Hurlock MD</td>
<td>‘Sweet Charlie’</td>
<td>July 1 and September 13</td>
<td>Marketable yield</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>August 3 and September 13</td>
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<td>August 17 and September 21</td>
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September 1 in 2004. Planting dates approximated the recommended transplanting for this region. The plants were arranged in offset double row spaced 30 cm between and in rows with 10-plant plots. Plots were randomized in a complete block design with four replications for each cultivar/treatment. Plots were irrigated by overhead micro-sprinklers for 2 days during establishment.

Field Performance Data Collection

In 2002, the following data were collected on November 14 in each plot: number of surviving plants, number of plants with flowers and fruit, and runner and branch crown number (only for three plants per plot). Runners, flowers and fruit were discarded. In fall 2003, runner, crown, and flower/fruit development was determined on December 10 as previously detailed for year 2002, except runner and branch crown numbers were recorded for all 10 plants in the plot. In fall 2004, data on runner and branch crown number for each plant and number of plants with flowers and fruit in each plot were recorded on November 3 after which all runners were detached by hand. On November 18, we detached and counted flower buds, flowers, and green and red fruit, and weighed large fruit.

‘Sweet Charlie’ strawberry plants grown in a high tunnel were harvested on November 12 and 24, and December 7 and 21, 2004. At each harvest, data were collected for plot yield and number of fruit harvested.

In spring 2003, 2004 and 2005, we harvested ripe strawberries twice weekly from mid-May to mid-June in field plots. In spring 2005, plots of ‘Sweet Charlie’ strawberry inside the tunnel were harvested twice weekly from late March to June. Each fruit was graded as marketable or cull, and weighed. Individual plant yield for the season was calculated.

soil by shallow tillage at the rate of 450 kg ha⁻¹. Crowned beds (10 cm high and 43 cm wide) were formed with a bed shaper at 1.25 m spacing between row middles, a drip irrigation tube with discharge rate of 1.7 l min⁻¹ (30.5 m)⁻¹ was placed off-center on each bed. Beds were covered with black polyethylene mulch. Strawberry transplants were hand-planted in the middle of each raised bed at 30 cm intervals. On September 13, 2004, ‘Sweet Charlie’ transplants that were started on July 1 and August 3 were set in the ground. On September 21, transplants started on August 17 were set in the ground. Twenty transplants were set in each plot. Plots were irrigated with micro-sprinklers for 2 days. Transplants received a post-transplant application of starter fertilizer (20-20-20) at 1 kg (380 l)⁻¹ water. Fungicides, insecticide and drip irrigation were applied as needed. There were four replications consisting of a combination of plugging and planting dates.

High Tunnel Production

For high tunnel production studies in 2004, we used a 29.5-m long x 9.1-m wide high tunnel (Ledgewood Farm Greenhouse Frames, Moultonboro, NH), constructed in 2003 at WREC. Plants and plastic mulch from the 2003-2004 production cycle were pulled out on July 16, 2004, and the ground was roto-tilled deeply. Fertilizer (16-8-8) was incorporated into
Statistical Analysis

Analysis of variance (ANOVA) for treatment and cultivar was carried out using PROC GLM of SAS (2001). Calculated percentage values were arcsin transformed prior to imposing statistical analysis. Means separations were determined using the DIFF option for all contrast (P ≤ 0.05).

RESULTS

2002-2003 and 2003-2004 Studies

Post-establishment plant loss was minimal in 2002 and 2003 (Table 2). All the July-plugged 'Chandler' transplants had produced flowers by mid-November while none of the August-plugged transplants had (Table 2). Branch crown development was greater in the early July-plugged transplants than in the early August-plugged transplants, 2.3 versus 1.2 per plant, respectively. Runner production was rather low in all treatments. In the 2003 study, 73% of the July-plugged transplants had flowered by November, but fall bloom was not observed in the August-plugged transplants (Table 2). None of the transplants obtained from a commercial nursery flowered in the fall (data not presented). Since the plants were in the open culture system, fruit were injured by frost and none reached the stage for harvesting in fall of 2002 and 2003. The plugging date of July 17 for 2003 season was 2 weeks later than in the previous year. The delay in plugging may have been a factor in that only 73% of the July-plugged 'Chandler' plants producing flowers in the fall.

In spring 2003, fruit was harvested for 4 weeks. Yield per plant was 704 g for the July-plugged transplants and ~560 g for the August-plugged transplants (P = 0.082). These yields are equivalent to ~29.6 and 23.5 metric t ha⁻¹ based on the ~42,000 transplants ha⁻¹ planting density and are far better than those reported for annual plasticulture studies conducted in New Jersey (Fiola et al., 1995), and slightly higher than those obtained in commercial fields in North Carolina (Poling, 1993). Total marketable yields obtained in our 2003-2004 study were ~25 metric t ha⁻¹ across treatments. The tonnage approached those yields obtained from 'Chandler' plants in a field study conducted near Raleigh, NC (USDA Plant Hardiness Zone 7b) during 1986-1987 season (Poling, 1993). Average fruit size for the season was similar with 23 and 24 g per fruit for the July- and August-plugged treatments, respectively. By the end of the harvest period in June, July-plugged plants possessed one
more branch crown than those plugged in August ($P = 0.008$). In 2004, fruit was harvested for 2 weeks from May 10 to May 25. Yield per plant was between 600 and 650 g, average fruit weight was ~18 g and branch crown numbers averaged about five on each plant across the treatments (not significantly different at $P = 0.05$; Table 2).

**2004-2005 Study**

None of the 'Northeaster' plants flowered in the fall (Table 3). In the field, runner production was less than two per plant in 'Northeaster' plants (Table 3). These runner numbers were lower than in a previous study in which five runners were produced on the July-plugged 'Northeaster' transplants that were established in plasticulture on August 12 at Beltsville, MD (Hokanson et al., 2004). These results agree with findings of Poling (1993) that containerized strawberry plants established in the annual plasticulture system in mid-to-late summer (August) tend to produce more runners in fall than those established in early fall (September). In spring 2005, 'Northeaster' was harvested from May 12 to June 7 totaling eight pickings. There was no effect of runner tip size on spring marketable yield or fruit size (average fruit weight of 17 g across all treatments). The lowest marketable yield (646 g per plant) was noted in plants propagated in August from small tips (Table 3).

In the high tunnel study, we harvested fruit from 'Sweet Charlie' strawberry in November and December again starting in late March

There is an optimal planting date for each cultivar recommended for the plasticulture in the region (Fiola et al., 1995; O'Dell and Williams, 2000). Transplants that are field planted late produce less fruit in spring (Fiola et al., 1995; O'Dell and Williams, 2000; Takeda and Hokanson, 2002). Takeda and Newell (2006) suggested that spring yield was related to branch crown development in the fall. Earlier planting dates provide more days in the fall for plant growth. However, if plantings occur too early then plants may grow excessively and more runners may appear in the fall (Poling, 1993). In our study, the growing conditions under the high tunnel in December appeared to be satisfactory for plant growth since 'Sweet Charlie' plants were still producing flowers in late December.

Other researchers have described 'conditioning' treatments for plug plants such as exposure to specific high and low temperatures (Bish et al.,

<table>
<thead>
<tr>
<th>Plugging date</th>
<th>Tip size</th>
<th>Fall branch crown development (no./plant)</th>
<th>Fall runners production (no./plant)</th>
<th>Plants with inflorescences in fall (%)</th>
<th>Spring crop yield (g/plant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early July</td>
<td>Average</td>
<td>3.5a</td>
<td>1.2b</td>
<td>0a</td>
<td>873a</td>
</tr>
<tr>
<td></td>
<td>Small</td>
<td>3.3b</td>
<td>1.3b</td>
<td>0b</td>
<td>781a</td>
</tr>
<tr>
<td>Early August</td>
<td>Average</td>
<td>2.5c</td>
<td>2.2a</td>
<td>0a</td>
<td>699a</td>
</tr>
<tr>
<td></td>
<td>Small</td>
<td>1.8d</td>
<td>1.3b</td>
<td>0a</td>
<td>646a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment planting time</th>
<th>Planting date</th>
<th>Early winter marketable yield (g/plant)</th>
<th>Spring crop yield (g/plant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early (July 1)</td>
<td>September 13</td>
<td>21a</td>
<td>482a</td>
</tr>
<tr>
<td>Standard (August 3)</td>
<td>September 13</td>
<td>21</td>
<td>307b</td>
</tr>
<tr>
<td>Late (August 17)</td>
<td>September 21</td>
<td>0b</td>
<td>218b</td>
</tr>
</tbody>
</table>

*All transplants were established on September 2, 2004 in outdoor plasticulture at the Wye Research and Extension Center, Queenstown, MD (fall growth measurements were collected on November 3, 2004). Values in columns followed by the same letters are not significantly different ($P = 0.05$). Mean separation performed by DIFF option of SAS Proc.
plug transplanting technology, for example, transplanting plug plants, cold winters (Darrow, 1966). For example, in winter fruit production of-season bloom in northern cultivars or those developed for areas with a short autumn environment in the mid-Atlantic coast region are not adequate for promoting flower bud formation or out-of-season bloom in northern cultivars or those developed for areas with severe winter climates to double-crop short-day cultivars in late fall and in spring. Transplants of short-day cultivars 'Chandler' (Table 2), 'Sweet Charlie' (Table 4) and 'Carmine' (Takeda and Newell, 2006) strawberries that were propagated in early July and established in the field in early September respond to natural photoperiodic induction (long nights) for reproductive development. At the test site in Queenstown, MD (latitude 39°N), daily dark period increases to >10 hours around September 1. Temperatures in September and October are generally sufficient for July-propagated plants to complete floral bud differentiation shortly after field establishment and subsequently flower around October 1 and produce harvestable fruit by early November.

CONCLUSIONS

Our studies demonstrated that fall flowering in 'Chandler' and 'Sweet Charlie' strawberry is inducible by advancing the plugging date to early July. As Bish et al. (2004), Fernandez and Ballington (2003) and Verheul et al. (2006) showed, short-day cultivars can be induced to flower early by growing transplants in artificial, short-day and cool temperature conditions in late summer. However, the cost of the equipment and the energy needed to condition transplants by these methods for floral induction are high. Our method for promoting fall flowering in some short-day cultivars appears to be more practical and does not require artificial lighting or cooling. Transplants produced by this method are ~8-weeks-old by the time they are established in the field. Commercial plug-plant propagators prefer to deliver ~4-week-old transplants to growers (D. Lankford, Hurlock, MD, personal communication). An earlier tip harvesting time and additional time in the nursery would cer-
tainly increase cost of producing transplants, but this new planting material allows growers in the mid-Atlantic coast region to double-crop short-day strawberries in high tunnels.

The potential strawberry yield in the fall and early winter under protected cultivation can increase income. There are several methods to obtain fall fruit production in the mid-Atlantic coast region. Dormant day-neutral ‘Seascape’ strawberries planted in late spring and de-flowered for 2 months produce some fruit as early as September (T. Nourse, South Deerfield, MA, personal communication). Cold-stored waiting bed plants and module or tray plants are used in Europe for autumn cropping on substrate culture (Lieten et al., 2005). In our study, the transplants plunged early in July grew in the greenhouse until the first week in September under environmental conditions generally considered not favorable for floral induction (e.g., long days and temperatures > 21°C during day and night). However, they began flowering in ~40 days after planting in the field under natural short-days and chilling temperatures at night. It is possible to grow tray transplants after they are rooted outside the greenhouse until field establishment as we have shown with ‘Sweet Charlie’ transplants in the 2004-2005 study and still have transplants that will flower in October and November. Our studies also confirmed as others (e.g., Fernandez and Ballington, 2003) have shown that high tunnels are useful for extending the production season. ‘Sweet Charlie’ strawberry under a tunnel produced a small crop in November and December and the main spring crop starting in late March for ~12 weeks. In contrast, ‘Sweet Charlie’ plants in outdoor plasticulture did not have harvestable fruit until early May and harvest ran for only several weeks. We will determine whether transplants of other short-day cultivars (e.g., cvs. ‘Camarosa’, ‘Darselect’, ‘Raritan’ and ‘Ventana’) can be induced to flower in fall by advancing the time of propagation to early July. The goal is to increase our understanding of the physiological control of flowering and create environmental conditions for improving the cropping potential of short-day strawberry cultivars in fall and out-of-season.

LITERATURE CITED


doi:10.1300/J492v06n04_10