Performance of Strawberry Varieties Developed for Perennial Matted-Row Production in Annual Plasticulture in a Cold Climate Region

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Abstract: Annual plasticulture production of strawberries promises superior weed control, fruit quality and yields. However, strawberry varieties adapted for perennial, matted-row production and local markets in cold climate regions have not been widely tested for adaptation to an annual production cycle. Productivity of seven short-day varieties developed for matted-row and/or annual production was examined in an annual plasticulture system in two consecutive trials in central NY (lat. 42.87° N, long. 76.99° W) harvested in 2013 and 2014. ‘Flavorfest’ demonstrated good performance in Trial 1 with high yield (390 g/plant) and large fruit size (13.9 g mean berry weight). ‘Jewel’ was shown to be well adapted to the annual plasticulture system with consistently high yields (330 and 390 g/plant) that equaled or surpassed other varieties and had moderate fruit size. ‘Chandler’ performed similarly to previous trials conducted in warmer regions with yield (340 g/plant) and fruit size (9.8 g mean berry weight) similar to ‘Jewel’. ‘Clancy’ yielded less but was consistent from year to year. The late season varieties Seneca and Ovation showed marked variability between years, possibly due to drastically different temperatures during flowering and fruit development in Trial 1 compared to Trial 2. High temperatures in Trial 1 likely caused higher early fruit yield, a compressed season and a precipitous decline in fruit size in the later season, thus reducing yield in the late season. Survival after a second dormant period was poor resulting in a small second harvest and reduced fruit size. Overall, the system demonstrated many of the expected benefits but may be more sensitive to weather conditions in the region. While many varieties developed for matted-row production may work well in an annual plasticulture system, not all varieties are equally adapted. Performance of each variety should be determined independently before large scale adoption by growers.

Keywords: annual hill production; perennial production; variety trial

1. Introduction

Strawberry production in cold climate regions has traditionally utilized a perennial matted-row production system. This system utilizes short-day varieties with a concentrated harvest season in late spring and early summer, peaking in June in much of the upper Midwest, Northeast and New England regions of the U.S. [1], hence the colloquial “June-bearing” label for short-day strawberry varieties grown in these regions. This system relies on perennial production, typically for three to five seasons, to spread out the establishment costs over multiple years while increasing the cumulative productivity of each planting. Varieties adapted to this production system rely on daughter plants to produce most of the crop rather than the crown that was originally planted. This has been a reliable system, especially for retailing into local markets where shelf-life is of lesser concern to consumers but has weed management challenges because few herbicides with limited residual effect are available to growers in this region [2]. The matted-row system also produces relatively low annual yield compared to annual plasticulture production in warmer regions [3,4].
In warmer production areas from which more fruit is sold into the larger wholesale market, the annual hill or plasticulture growing system [5] is the predominant production system utilized to achieve high yield, combining high plant density with precision production practices to optimize production [6]. This system is also used in warmer areas by growers who predominantly use direct-to-consumer marketing with varieties not typically grown in northern production areas that may have limited wholesale market appeal (e.g., ‘Chandler’). Adaptation of this production system to temperate climate regions using short-day varieties has demonstrated superior weed control, higher yields and improved fruit quality [5–7]. However, this system comes with the added risk of poor establishment under less-than-ideal planting conditions and may not justify the increased installation and disposal costs if the yield potential of the varieties or higher prices are not realized.

Challenges in weed control combined with labor shortages has made the annual hill system more attractive to matted-row producers [8] with the promise of improved yields and fruit quality. However, there is relatively little information on the performance of short-day (June-bearing) varieties popular in traditional matted-row production regions when grown in the plasticulture system. Numerous extension bulletins and industry guides describe the system for cool climate regions, but these generally target the mid-Atlantic states (PA, NJ, MD) to the mid-south (NC, KY) [1,9,10]; www.noursefarms.com/resources/pdfs/plasticulture/plasticulture.pdf; www.hort.cornell.edu/expo/proceedings/2012/Berries/Berry%20Strawberry%20Plasticulture%20Poling.pdf (July 2021). Relatively little information is available for regions where winter protection is required for acceptable plant survival. According to the latest U.S. Department of Agriculture statistics available for NY, WI, MI, OH, PA and New England, northern production areas, where matted-row production is common, account for thousands of hectares of strawberry production [3,4]. These growers struggle with effective weed control while dealing with labor shortages and a changing climate [11] as well as attempting to improve yield and fruit quality.

Guidelines for annual plasticulture production in colder regions utilizing short-day plants include variable recommendations on planting stock, planting date, irrigation practices, renovation practices, winter protection and variety choice. However, little replicated testing has been done with uniform production practices. Typical planting for matted-row production in these areas occurs from early May through June utilizing cold stored, dormant bare-root crowns. However, later plantings are often recommended to reduce the need for alley weed management and to push the labor demand past the spring/summer strawberry harvest [1]; newenglandvfc.org/sites/newenglandvfc.org/files/content/proceedings2003/strawberry/production_basics_strawberry_plasticulture.pdf (accessed on 13 July 2021). Storing bare root plants longer to plant later in the summer has been shown to be problematic as crowns often lose vigor or die in long term storage [12]. Additionally, planting bare-root plants in mid-summer when temperatures are highest can lead to excessive transplant stress and poor establishment [12]. Given the many possible variations suggested in different production manuals, a systematic approach to determining the optimal conditions for utilizing this system in cold climate regions is needed. As a first step, this project examines the performance of seven short-day varieties, including several standard varieties for the region, over approximately three years in two separate plasticulture trials mimicking the production practices most familiar to matted-row producers in order to bring clarity to some of the recommendations. Total yield, potential marketable yield, and fruit size were recorded and compared among varieties and across years. Potential yield across different plant densities is also discussed as most growers will utilize existing equipment that varies from farm to farm in order to begin utilizing this system.

2. Materials and Methods

2.1. Site Description and Preparation

The trials were performed in consecutive years (planted in 2012 and 2013 and harvested in 2013 and 2014, respectively) in adjacent plots in the same field at Cornell AgriTech at the New York State Agricultural Experiment station in Geneva, NY (lat. 42.87° N, long.
was evaluated for the potential to hold over for a second harvest season. Trial 2 included six varieties (Chandler, Clancy, Jewel, Ovation, Seneca and Ventana). Trial 2 was evaluated for the potential to hold over for a second harvest season.

In the fall prior to Trial 1 (2011), a winter rye cover crop was planted. This crop was sprayed with herbicide on 1 May 2012 and plowed into the field two weeks after spraying to prepare the field for planting. For Trial 2, a summer cover crop of sorghum–sudangrass (*Sorghum x drummondii* (Nees ex. Steud.) Millsp. & Chase) was planted in early summer 2012, then mowed and tilled into the site in August, approximately eight weeks prior to fall bed formation in October. For both trials, the unfumigated site was rotovated prior to bed formation, and 15 cm high × 61 cm wide raised beds with 1.7 m center to center spacing were formed and covered with 1.5 mil black plastic (Filmtech Corp., Allentown, PA, USA) in mid-May 2012 for Trial 1 and in October 2012 for Trial 2. Irrigation was supplied with a single 10 mil T-tape drip line with 30 cm emitter spacing (Rivulis Irrigation, San Diego, CA, USA) down the row center. For Trial 2, the beds rested through the winter prior to planting in the spring of 2013. The timeline for site preparation and field activities for the trials is outlined in Figure 1.

![Timeline](image)

**Figure 1.** Timeline for field operations for short-day strawberry production trials utilizing the annual plasticulture system in the cold climate region of western New York state from 2011–2015. Trial 1 included five varieties (Flavorfest, Clancy, Jewel, Ovation, and Seneca) and Trial 2 included six varieties (Chandler, Clancy, Jewel, Ovation, Seneca, and Ventana). Trial 2 was evaluated for the potential to hold over for a second harvest season.

### 2.2. Experimental Design

A completely randomized design was used in both trials with five varieties (Flavorfest, Clancy, Jewel, Ovation, and Seneca, NY, USA) in Trial 1 and six varieties (Chandler, Clancy, Jewel, Ovation, Seneca, and Ventana, CA, USA) in Trial 2. ‘Jewel’, ‘Clancy’, ‘Ovation’ and ‘Seneca’ were developed for matted-row production in the region [15–18]. ‘Flavorfest’ was introduced as suitable for both matted-row and annual plasticulture systems [19] while ‘Chandler’ and ‘Ventana’ were developed for annual plasticulture production in California [20,21]. Planting was done on 25 May 2012 and 23 May 2013 in Trial 1 and
2, respectively, with four replications of 25 plants per plot. Border rows and plots were planted on the sides and ends of the plantings to avoid edge effects.

2.3. Plant Establishment and Management

Dormant crowns were purchased from commercial nurseries and stored at 2 °C prior to planting. On each day of planting, the crown bundles were soaked in tap water for 2 h prior planting to ensure adequate hydration in the root systems. Double offset rows were planted in the bed at 30 cm spacing between plants and between rows within the bed. This spacing was chosen based on soil conditions and available equipment and results in a plant density equivalent to 39,124 plants per ha. Crowns were set by hand through the plastic using an L-shaped special tool (20 cm × 10 cm) made by bending a 30 cm piece of 3.8 cm wide metal at a 90 angle. This tool is used to push the roots through the plastic and into the soil. This is the technique recommended by a local commercial nursery and sets the plants while minimizing the size of the hole in the plastic to help reduce weed encroachment around the plants [www.noursefarms.com/resources/pdfs/plasticulture/plasticulture.pdf]. Locally sourced wheat straw (Triticum aestivum L.) was spread between the row to suppress weeds with supplemental manual weed removal as needed through the season.

The flush of flowers that emerged from the dormant crowns was removed from the plants as they emerged after planting to facilitate establishment and vegetative growth. Plots were fertigated starting after planting with 20-20-20 (N-P-K) general purpose soluble fertilizer (Jack’s Fertilizer, JR Peters, Inc., Allentown, PA, USA) on a weekly basis to supply approximately 5 lb. N/acre equivalent per week during the growing season. Irrigation was supplied three times weekly to total 2.5 cm of water per week during the vegetative phase. The beds/plants were covered with wheat straw in mid-December of each planting year to a depth of 7.5 to 15 cm for winter protection as recommended for the region [1]. In the following spring, the straw was removed on or about March 15 in each harvest year to allow the plants to emerge from dormancy. During the following development and harvest periods, fertilizer was supplied in as in the previous year and irrigation was supplied to total 5 cm per week.

Due to the mixed variety composition of the trials, pest management could not be optimized by variety and was targeted at peak phenological dates across all varieties. This necessarily reduced the effectiveness of control of common diseases occurring in the planting. An application of fenhexamid fungicide (Elevate 50 WDG, Arysta Life Science, Cary, NC, USA) was applied at early bloom for the trial each year for control of gray mold caused by Botrytis cinerea Pers., and azoxystrobin fungicide (Abound 2.08F, Syngenta Crop Protection, Inc., Greensboro, NC, USA) was applied after fruit set to target anthracnose (Colletotrichum acutatum Simmonds) and leather rot (Phytophthora cactorum (Lebert & Cohn) Schröt.) following the manufacturers’ label. No further applications were made. Scouting through the harvest season detected no significant insect/mite pressure resulting in no insecticide applications in these trials.

2.4. Harvest and Data Analysis

Ten plant sections were harvested from the four replicate plots of each variety starting on 28 May 2013 in Trial 1 and 4 June 2014 in Trial 2. Fruit was harvested three days a week and weighed and counted for yield and fruit weight means. The maximum individual fruit weight from each plot was also recorded at each harvest date. Individual plot harvests were graded as marketable or non-marketable based on mean berry weight. Total harvest included all berries harvested in each season. Harvests where the mean berry weight was equal to or exceeded 8.0 g were included in the marketable yield calculation; this is considered an acceptable minimum weight in local markets of the region. Other factors that affect marketability, such as disease, pest feeding and fruit shape, are highly variable due to environmental conditions and production practices that are more controllable by producers and can be optimized by variety. Because pest management could not be optimized by
variety, these factors were beyond the scope of this project and were not considered when determining potential marketable yield.

In Trial 2, the survival and second harvest potential after a second dormant period was also investigated. Plants were renovated in July after harvest was complete by removing the vegetation with a powered hedge trimmer. This encouraged regrowth and reduced the production of runners through the summer. Runners that did form were removed every two weeks starting in late August through September. The plants were covered with clean wheat straw for winter protection in mid-December in the same manner as in the planting year and remained covered until approximately 15 March after the second winter dormant period. After straw removal, plants were fertigated and irrigated as in the previous season. The number of healthy plants were counted in each plot to estimate production potential in a second season. Plots with at least 75% healthy plants (19 of the original 25 plants) were harvested in the second year. This harvest began on 10 June 2015.

An analysis of variance (ANOVA) of total yield per plant, marketable yield per plant and mean fruit weight data was carried out using the procedures outlined in Gomez and Gomez [22] for a CRD design on each year’s yield and fruit weight data with the formulas set up in the spreadsheet program Excel (Microsoft Corp., Redmond, WA, USA) for the calculations. Means were separated utilizing Duncan’s multiple range test ($p<0.05$) following the finding of significant treatment effects and also following the procedures outlined in Gomez and Gomez [22]. Year to year comparisons of the four varieties duplicated in the trials were analyzed in a similar manner following the procedure outlined in Gomez and Gomez [22].

### 3. Results and Discussion

Trial 1 harvest began on 28 May 2013 (Figure 2), even though there were no early season varieties. This is relatively early for the region without the use of row covers or tunnels to advance bloom and fruit development. Harvest in region typically begins in the first week of June with early season varieties, such as AC Wendy and Earliglow (personal observation). Spring temperatures were relatively high early in the season (Figure 3), reaching nearly 25 °C in mid-March and 30 °C in mid-April, resulting in a heavy flush of early fruit in four of the five varieties (Figure 2). ‘Jewel’, ‘Flavorfest’, ‘Clancy’ and ‘Seneca’ all began harvest simultaneously in what is considered the early season in the region. These varieties would typically produce in the mid to late mid-season, and ‘Ovation’ was advanced to the mid-season (Figure 2, Table 1). This compressed the overall season and reduced the overall harvest period across the five varieties to 28 days (Figure 2) with ‘Jewel’ having the longest overall harvest period of 25 days (Table 1). Maximum fruit size also declined quickly during the season in Trial 1 (Figure 4), possibly due to sustained high temperatures in May and June (Figure 3) and difficulties in supplying adequate irrigation.
Figure 2. Mean total yield per plant through the harvest season for five short-day varieties in Trial 1 harvested in 2013 in an annual plasticulture production system in a cold climate region (central NY). High temperatures early in the season during flower and fruit development shifted production to the early part of the season.

Figure 3. Minimum and maximum daily temperatures in Trial 1 from the removal of straw winter protection (16 March 2013) through the end of harvest (9 July 2014) harvest in Trial 1 of five short-day strawberry varieties in a cold climate region (central NY).
A precipitous decline in fruit size towards the middle of the season. High temperatures during fruit development and into the harvest season coincides with a precipitous decline in fruit size towards the middle of the season.

Table 1.

In Trial 2, both ‘Chandler’ and ‘Ventana’ produced earlier than ‘Jewel’ (Table 1) with ‘Seneca’, ‘Clancy’ and ‘Ovation’ following (Figure 5; Table 1). Temperatures were more typical for the spring season in the region (Figure 6) resulting in separation in the yield pattern between the varieties (Figure 5) and a more uniform maximum fruit weight that was maintained through the entire season (Figure 7). The overall harvest period across all varieties in Trial 2 was 36 days. ‘Chandler’ and ‘Ventana’ had the longest overall harvest period in Trial 2 at 28 days (Table 1). These trials demonstrate the relatively short harvest period in cold climate areas when growing short-day varieties and the potential to expand the overall period by utilizing varieties with differing maturity dates. The higher temperatures during Trial 1 accentuated the early part of harvest and concentrated the productivity into the largest fruit. In Trial 2, the harvest was extended into the later season and more fruit developed with smaller overall mean size. ‘Jewel’ was consistently high yielding in both trials and ‘Clancy’, while lower yielding, was consistent. ‘Seneca’ and ‘Ovation’, both later season varieties that typically produce larger fruit longer into the season, were less productive when high temperature occurred early in the season as occurred in Trial 1 (Table 2). Analysis of the total yield data also showed significant year, variety and year by variety interactions across the common varieties in the two trials ($p \leq 0.01$) (Table 3). This effect is likely a result of variable temperatures and demonstrates the risk of a shortened harvest period due to early high temperatures. Mean total yield per plant across all varieties was higher in Trial 2 but the % marketable yield was higher in Trial 1.

Growers can extend the season with the addition of early and very late season varieties to their variety mix. The total summer harvest of short-day varieties in the region could be expanded by 10 days in the beginning and end of the season using standard production practices and by as much as an additional 10 days in the beginning of an ideal season by using row covers or tunnels in the spring to advance flowering and fruit development. However, utilizing additional varieties and season advancement techniques increases the risk of crop loss due to frost in the early season and excessive temperatures in the very late season, and increases the demands of irrigation management and harvest labor. Market conditions and economic factors should be examined to determine if these approaches make sense at an individual farm level.
Table 1. First, peak and last harvest date and length of harvest for seven short-day strawberry varieties grown in annual plasticulture in a cold climate region (central NY) in consecutive trials harvested in 2013 and 2014. Peak harvest date is the date when the greatest fruit weight was harvested in a single daily harvest. ‘Flavorfest’ was only included in Trial 1, and ‘Chandler’ and ‘Ventana’ were only included in Trial 2.

| Variety  | First Harvest Date | Peak Harvest Date | Last Harvest Date | Harvest Period (Days) |
|----------|--------------------|-------------------|-------------------|----------------------|
| Chandler | Trial 1            | N/A               | N/A               | N/A                  |
|          | Trial 2            | 4 June            | 13 June           | 1 July               | 28                   |
| Clancy   | Trial 1            | 31 May            | 7 June            | 21 June              | 22                   |
|          | Trial 2            | 11 June           | 17 June           | 1 July               | 21                   |
| Flavorfest | Trial 1       | 31 May            | 3 June            | 21 June              | 22                   |
|          | Trial 2            | N/A               | N/A               | N/A                  | 22                   |
| Jewel    | Trial 1            | 28 May            | 7 June            | 21 June              | 25                   |
|          | Trial 2            | 8 June            | 17 June           | 1 July               | 24                   |
| Ovation  | Trial 1            | 10 June           | 10 June           | 24 June              | 15                   |
|          | Trial 2            | 24 June           | 1 July            | 9 July               | 16                   |
| Seneca   | Trial 1            | 31 May            | 5 June            | 21 June              | 22                   |
|          | Trial 2            | 8 June            | 17 June           | 1 July               | 24                   |
| Ventana  | Trial 1            | N/A               | N/A               | N/A                  | N/A                  |
|          | Trial 2            | 4 June            | 13 June           | 1 July               | 28                   |

Figure 5. Mean total per plant yield through the harvest season for six short-day varieties in Trial 2 harvested in 2014 in an annual plasticulture production system in a cold climate region (central NY). More typical spring temperatures pushed peak production later into June.
Figure 6. Minimum and maximum daily temperatures in Trial 2 from the date of straw removal (16 March 2014) through the end of harvest (9 July 2014) harvest in a trial of six short-day strawberry varieties grown in plasticulture in a cold climate region (central NY).

Figure 7. Maximum fruit weight for six short-day strawberry varieties grown in plasticulture in a cold climate region (central NY) in Trial 2 harvested in 2014. High maximum fruit weights were maintained throughout the harvest. Mean fruit weight is reduced as fewer large fruit are harvested.

An ANOVA of the total yield, marketable yield and mean fruit weight data showed significant difference among the varieties (Tables 2 and 3). Total yield in Trial 1 ranged from 389 g/plant for ‘Flavorfest’ to a low of 133 g/plant for ‘Ovation’ and in Trial 2 ranged from 441 g/plant for ‘Jewel’ to a low of 240 g/plant for ‘Clancy’ (Table 2). Marketable yield was equally variable ranging from 84% of total yield in ‘Seneca’ to over 98% in ‘Flavorfest’
in Trial 1, and from 100% in ‘Seneca’ to 48% in ‘Ventana’ in Trial 2 (Table 2). However, due to limitations in pest management caused by variable flowering and fruiting in a mixed variety trial, marketable yield in these trials was only based on mean fruit weights and would likely vary with pest management optimization.

Table 2. Total yield per plant, % marketable yield and mean fruit weight for seven strawberry varieties grown in plasticulture in two trials in consecutive years. Percent marketable yield included fruit from dates when the mean fruit weight for the plots was 8 g or greater. ‘Flavorfest’ was only included in Trial 1 and ‘Chandler’ and ‘Ventana’ were only included in Trial 2.

| Variety       | Total Yield 1 (g/plant ± SEM) | % Marketable | Mean Fruit Weight 1 (g ± SEM) |
|---------------|-------------------------------|--------------|-------------------------------|
|               | Trial 1                       | Trial 2      | Trial 1                       | Trial 2               |
| Chandler      | N/A                           | 343 ± 10.1 ab| N/A                           | 9.8 ± 0.4 c           |
| Clancy        | 263 ± 9.7 ab                  | 240 ± 24.7 c | 91.7                          | 12.0 ± 0.3 a          |
| Flavorfest    | 389 ± 69.0 a                  | N/A          | 98.3                          | N/A Approximation     |
| Jewel         | 332 ± 75.4 a                  | 442 ± 50.6 a | 90.2                          | 9.6 ± 1.1 b           |
| Ovation       | 133 ± 18.0 b                  | 280 ± 26.9 bc| 88.2                          | 11.3 ± 0.9 ab         |
| Seneca        | 272 ± 39.0 ab                 | 343 ± 21.2a  | 84.0                          | 9.4 ± 0.2 b           |
| Ventana       | N/A                           | 280 ± 31.7bc | N/A                           | 8.8 ± 0.3 c           |

1 Values in each column followed by the same letter are not significantly different based on comparisons by Duncan’s multiple range test means analysis ($p \leq 0.05$).

Table 3. Values from an analysis of variance (ANOVA) on total yield per plant, marketable yield per plant and mean fruit weight for two short-day strawberry trials comparing five and six varieties in Trial 1 and Trial 2 in consecutive years in a completely randomized design with four replicates per variety. An ANOVA was performed separately for each parameter. The ANOVA for year by year interactions was performed on mean total yield per plant from the four varieties in common between the two trials (Clancy, Jewel, Ovation and Seneca).

Source of Variation | Degrees of Freedom | Calculated F Value 1 (p ≤ 0.05; 0.01) | Threshold F Values (p ≤ 0.05; 0.01) |
|---------------------|--------------------|--------------------------------------|--------------------------------------|
| Trial 1              |                    |                                      |                                      |
| Variety             | 4                  |                                      |                                      |
| Total yield         | 4                  | 3.69                                 | 3.06                                 |
| Marketable yield    | 4                  | 5.08                                 | 4.89                                 |
| Mean fruit weight   | 4                  | 4.56                                 |                                      |
| Error               | 15                 |                                      |                                      |
| Trial 2              |                    |                                      |                                      |
| Variety             | 5                  |                                      |                                      |
| Total yield         | 5                  | 6.54                                 | 4.25                                 |
| Marketable yield    | 5                  | 13.95                                |                                      |
| Mean fruit weight   | 5                  | 6.03                                 |                                      |
| Error               | 18                 |                                      |                                      |
| Year x Year         |                    |                                      |                                      |
| Year                | 1                  | 9.87                                 | 4.41                                 |
| Replication (plot)  | 6                  | 1.1                                  | 3.66                                 |
| Variety             | 3                  | 8.91                                 | 3.16                                 |
| Year x Variety      | 3                  | 14.55                                | 3.16                                 |
| Error               | 18                 |                                      |                                      |

1 F values in bold are significant at the $p < 0.05$ or 0.01 level.

Yield in these trials was in a similar range to the trials in New Jersey [6] and Maryland [7] in which ‘Chandler’ was also included. In those trials, which were fall planted with
plug plants produced from runner tips, total yield for ‘Chandler’ averaged 203 g/plant in NJ over two years and 424 g/plant in MD over five years. Similar total yield was recorded in MD for ‘Allstar’ and ‘Northeaster’, which are short-day varieties adapted to matted-row production in cold climate regions [7]. In Trial 2 presented here, the total yield for ‘Chandler’ was 343 g/plant (Table 2) and the range across varieties is in line with those observed in the MD and NJ trials.

Mean fruit size in these trials was also similar to that observed in other trials [6,7] with significant differences observed among the varieties in both trials ($p < 0.01$) (Table 3). In Trial 1 ‘Flavorfest’, ‘Clancy’ and ‘Ovation’ had the largest fruit and ‘Seneca’ the smallest mean size. In Trial 2, ‘Clancy’ and ‘Seneca’ had the largest mean weight (Table 2). In most cases, the varieties with higher yields had smaller mean fruit size, with the notable exception of ‘Flavorfest’ in Trial 1 with the highest yield and the largest mean fruit weight. Typically mean fruit weight is reduced as the season progresses in varieties developed for matted-row production as secondary and tertiary fruit is harvested but ‘Flavorfest’ in Trial 1, and ‘Seneca’ in Trial 2, maintained fruit size better that other varieties (Figures 3 and 6). ‘Ventana’ fruit size dropped off precipitously in Trial 2 (Figure 6) contributing to the low (48%) marketable fruit. Varieties developed for matted-row production develop fruiting trusses with multiple fruit that develop sequentially over time. With high fruit numbers, possible increased irrigation is needed for later fruit to develop adequate size. Unfortunately, with a mixed variety block, optimizing irrigation by variety was not possible with the irrigation system available.

 Marketable yield can be difficult to quantify, especially in local markets, as standards can vary over the season based on supply and demand. In pick-your-own operations and local markets, smaller fruit size is often acceptable to consumers, and growers need to set their own limits on when harvested fruit is no longer marketable. While mean fruit size often falls below a set standard near the end of the season, larger fruit that are acceptable in the market are often still being produced (Figures 4 and 7). By tracking the maximum fruit size, growers can monitor when the largest fruit has been exhausted and make a determination regarding future harvest based on their own market conditions. Depending on the supply of fruit in the market and demand by consumers, harvest may still be economical and larger fruit can be sorted for sale.

 Projecting total yield per area can be equally difficult on smaller farms with equipment that is used for multiple crops. Recommendations for plant density per area for strawberry plasticulture production in the region range from 37,000 to 44,500 plants per ha, depending on the source [1]; www.hort.cornell.edu/expo/proceedings/2012/Berries/Berry%20Strawberry%20Plasticulture%20Poling.pdf; www.noursefarms.com/resources/pdfs/plasticulture/plasticulture.pdf. Even higher plant densities are often planted in California where four row beds are common, as well as two and three row beds [23], thus reducing the empty alley space between rows. At the equivalent of 39,124 plants per ha utilized in the trials described here, total yield ranged from 5200 (‘Ovation’; Trial 1) to 17,270 kg·ha$^{-1}$ (‘Jewel’; Trial 2), which was similar to or much greater than yields from matted row production [15,16] and in other plasticulture trials [6,7], and generally exceeds average yields reported for the region [4]. Since yield per area is a function of plant density and individual plant yield, per hectare yields could be increased through different approaches. In trials in NJ, Fiola et al. [6] found that closer in row plant spacing increased overall yield by area but reduced the yield per plant and was not as profitable due to increased establishment costs. Plant density per area can also be increased by reducing the alley width between rows, which is more feasible in production areas with sandy soils that flow better in bed makers. This would have the effect of increasing plant densities per area and subsequent yield. Sandier soils may also allow for larger, four row beds but producers need to assess what is possible at their site based on soil type and available equipment for bed making, pest management, harvest and other relevant operations. Larger beds also require additional lines of drip tape, and therefore precise bed laying, which may be a challenge for small growers.
The potential for holding plantings over for a second season as recommended in some production guides [www.noursefarms.com/resources/pdfs/plasticulture/plasticulture.pdf] was also investigated. Trial 2 was held over for a second harvest season to gauge the yield potential in each variety. Plant survival for each plot was evaluated on approximately 1 May (six weeks after the straw was removed) to determine if a viable harvest could be made. ‘Ovation’ was the only variety for which all four plots had at least 75% survival through the second winter. ‘Seneca’ had three plots and ‘Chandler’ had two. For ‘Jewel’, ‘Clancy’ and ‘Ventana’, none of the four plots had survival above the 75% threshold. Fruit was harvested in the surviving plots with total yield, marketable yield and mean fruit weight calculated. ‘Ovation’ produced a similar yield to the first harvest season (251 g per plant vs. 281 g per plant) but with a reduced mean fruit weight (8.5 g per fruit vs. 10.3 g per fruit). Total yield in ‘Seneca’ and ‘Chandler’ was significantly reduced on both a per plant basis as well as per area as not all plots survived (data not shown). Based on these results, only the most vigorous varieties, such as ‘Ovation’, would have reasonable potential to overwinter through a second winter for a subsequent harvest under this management schedule. This second harvest is unlikely to be satisfactory for most producers using the annual plasticulture system with the reduced mean fruit weight.

4. Conclusions

Overall, the annual plasticulture system holds great potential for growers in cold climates. ‘Flavorfest’, ‘Jewel’ and ‘Chandler’ showed good potential for the system in the region and produce fruit that is acceptable in local markets. Increased inputs for plants, plastics and irrigation supplies are partially offset by reduced inputs for weed control (herbicides and tillage) and further by superior yield. High yield potential for some varieties is very attractive to growers but may not be the solution for every situation. Matted-row production has a place in many areas, especially for small acreage producers utilizing the pick-your-own model where reducing production costs is most important because much fruit may be left unharvested in the field. Furthermore, for those marketing into small local markets or on farms, the traditional production practices evoke a positive image of the farm and be appealing to consumers, which may increase market traffic.

There are many potential modifications to the annual plasticulture system that may make it more suitable for cold climate production. Later planting using green plug plants and the use of row covers and/or low tunnels to advance the season or provide additional protection from weather events could make the system more reliable and productive. Utilizing day-neutral varieties is also of great interest and is being trialed and tested with researchers and growers in cold climate production areas [24,25] to extend the production season and give greater flexibility and market opportunities to growers in the region. Greater adoption of the annual plasticulture production system for strawberries in the cold climate regions is likely to happen over time as specific production details are optimized.

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