Strawberry Plant Growth Parameters and Yield among Transplants of Different Types and from Different Geographic Sources, Grown in a Plasticulture System

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SUMMARY. Strawberry (*Fragaria ×ananassa*) 'Chandler' plants from three sources were grown in the annual hill plasticulture system during two growing seasons (1996–97 and 1997–98). These trials evaluated the yield and vegetative performance of bareroot plants from Prince Edward Island and Ontario, Canada, and plug plant tips that were rooted in North Carolina but obtained from Ontario Canada. At the end of the season, total and marketable yields and fruit weight were not different among the plant sources. In addition, plants from all three plant sources produced equivalent yields on a weekly basis. Monthly whole plant harvests revealed that plant source did not affect leaf area, root, crown, leaf, flower or fruit dry weight during most of the growing season. In addition, plant growth parameters (specific leaf area, leaf area ratio, leaf weight ratio, and root to shoot ratio) in general did not differ among plant source in any 1 month. Plant growth did show shifts in dry weight allocation and leaf area as the season progressed that were uniform among plant sources, with the majority of the growth occurring in the spring in the two months prior to harvest. This uniformity among plant sources will allow future research to emphasize plant production practices that may reduce the risk of pest and disease problems or optimize production practices favored by growers.

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The strawberry plasticulture system employed by growers in the southeastern United States typically begins with methyl bromide fumigation of soil in the late summer to early fall, and a layer of black plastic mulch over raised beds. Transplants are obtained in the fall and planted into the fumigated beds. Transplants are set in double rows at high densities [17,400 plants/acre (43,000/ha)] (Poling, 1993). Although plasticulture systems are expensive to implement, the increased productivity and reduced labor costs allow for higher returns (Garwood, 1998). Average gross income for plasticulture systems in North Carolina of greater than $15,000/acre ($36,300/ha) can be obtained, whereas matted row production grosses approximately $7,200/acre ($17,424/ha) (Garwood, 1998). In 1999, the cost of bareroot plants was $1427/acre ($3453/ha), unrooted tips were $1253/acre ($3032/ha) and rooted plug plants were $2610/acre ($6316/ha). Freshly dug, or bare-root, transplants are the traditional plant type used; however, they require a significant amount of water during the first 2 weeks for establishment. In addition, they need to be planted at a specific depth, which requires trained labor. Rooted runner plants from tips, commonly called plugs, require less irrigation during establishment in the fruiting field, and are easier to set at the correct depth, allowing for better crop uniformity. Therefore, plugs are becoming more widely used and now compose a large proportion of transplants in North Carolina.

Strawberry transplants for use in the plasticulture system in North Carolina traditionally have been obtained from nurseries in the eastern provinces of Canada, from Ontario to Prince Edward Island; where certified plants are grown for vegetative propagation, and shipped bare-root or as tips to fruit production sites in the United States. In any particular year, the weather can vary substantially among nursery sites. Temperature differences and slight differences in daylength patterns between the nursery sites could have an effect on transplant performance in the fruit production field. Researchers in Florida found that transplants from northern or midlatitude sources typically produced fruit earlier, yielded higher and had larger fruit than those from Florida nurseries (Stapleton et al., 2001). They also found that Florida plug plants had smaller initial crown diameters, and in 1 of 2 years, had lower yields than Canadian-grown bareroot transplants. We have previously documented the seasonal progression of plant growth and development of bareroot plants of three cultivars (Fernandez et al., 2001). All cultivars had similar patterns of growth and development, in that while both vegetative and reproductive tissue developed throughout fall and spring, the majority of the biomass accumulated in the spring, and harvest occurred over 6 to 8 weeks (April to May). However, variations in plant growth and development due to plant source and type have not been examined in depth.

A component of our long-term mission is to develop or foster plant production systems that minimize pest risk and maximize crop productivity. Most serious strawberry diseases are introduced in production fields via infected planting stock. Diseases of concern include angular leaf spot (*Xanthomonas fragariae*), anthracnose (particularly that caused by *Colletotrichum acutatum*), and more recently phytophthora crown rot (*P. cactorum*) (F. Louws, unpublished). Likewise, two-spotted mite (*Tetranychus urticae*) pressure can often be associated with populations introduced on imported plants (K. Sorensen, personal communication). The method of producing strawberry transplants can impact insect or disease pressure and strategies may be developed to limit risk of losses due to pests. For example, it may be easier to augment strawberry plug plants with biological control agents to limit the incidence of Phytophthora crown rot as

Table 1. Total yield, marketable yield, and fruit weight of 'Chandler' strawberry transplants from three plant sources [plug, bareroot 1 (BR1), and bareroot 2 (BR2)] in 1996–97 (year 1) and 1997–98 (year 2); 28.35 g = 1.0 oz.

	Total yield/plant (g)		Marketable yield/plant (g)		Fruit wt (g)	
Source	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Plug	355.6[z]	446.3	291.1	307.4	17.5	21.4
BR 1	314.2	481.4	253.9	408.4	15	32.7
BR2	239.2	410.5	184.9	321.4	14.1	17.3
LSD	NS	NS	NS	NS	2.6	NS

[z]Mean separation in columns by Fishers LSD, $P \leq 0.05$; [NS]Nonsignificant.

compared to augmentation of field-grown transplants. However, limiting pest pressure at the expense of compromising optimum productivity would be counterproductive. Likewise, we envision developing integrated pest management (IPM) recommendations that are linked to plant phenology as opposed to being calendar-based. Therefore, an understanding of plant growth and phenology as impacted by plant source or plant type is fundamental to our long-term mission.

We hypothesized that plant type (plug versus bareroot) or plant source (Canada versus North Carolina) would have an impact on plant growth and productivity. This hypothesis, if correct, would require the development of production and IPM recommendations that take into account the source and type of transplants. Therefore, the objectives of the present study were to compare plant growth parameters and yield, and to document plant phenology among transplant types and their geographic sources.

Materials and methods

Field experiment sites and plot design. Field experiments were conducted in North Carolina during the 1996-97 and 1997-98 field seasons. The site was located on a commercial farm in Johnston County, N.C., (USDA Hardiness Zone 7b, lat. 35°31'N, long. 78°20'W). The soil was a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Kandiudults). The three sources of 'Chandler' plants were 1) bare root (BR1) transplants obtained from a nursery in Ontario, Canada, 2) bare root transplants from Prince Edward Island, Canada (BR2), and 3) plug transplants (plugs), with Canadian tips rooted in a North Carolina greenhouse.

Experiments were set up in a randomized complete block design, with four replications and three plant sources. Plants were set in 2.5 ft (0.76 m) wide fumigated beds, with 5 ft (1.52 m) between the centers of each bed. Soil was fumigated with methyl bromide (98% bromomethane: 2% trichloronitromethane). Plots consisted of 144 plants in three adjacent rows. Each row was 12 ft (3.7 m) long with plants staggered 14 inches (35.6 cm) apart. Yield was taken from 44 plants in the middle row, while whole plants were randomly sampled from the outer rows. Average fruit was determined by compiling a season average of 25 marketable fruit from each harvest date. Plants were set on 5 Oct. 1996 and 7 Oct. 1997. No fungicides were applied in either year. All other standard cultural programs were followed according to North Carolina recommended practices (Poling and Monks, 1994).

Growth parameters and yield. Whole plants were harvested every 4-5 weeks starting in October and concluding in May, with the exception of December, which was skipped each year and February that was skipped in year 2. At each whole plant harvest date, four whole plants from each treatment were harvested, with the exception of May of year 2 when plants were harvested from only one replicate. Roots were washed over fine mesh sieve to separate soil from root tissue. Plants were then divided into roots, crowns, leaves, flowers and fruit. Leaf area of fresh leaves was determined using a leaf area meter (LI-3200l; LI-COR Inc., Lincoln, Nebr.). All plant parts were bagged separately, then placed in a drying oven (Fisher Scientific, Pittsburgh, Pa.) at 158 °F (70 °C) for 10 d. Individual plant yield was calculated on each harvest date by dividing total yield (grams) per plot by the number of plants in each plot (44).

Specific leaf area (SLA), leaf area ratio (LAR), leaf weight ratio (LWR), and root to shoot ratio (RSR) were calculated from leaf area and dry weights of harvested plants. These factors of plant growth were defined by the following equations (adapted from Chiarello et al., 1989): $LAR = A/W = W_L/W\,(A/W_L)$; $SLA = A/W_L$; $LWR = W_L/W$; $RSR = (W_R + W_C)/(W_L+W_F+W_{FL})$, where W is individual whole plant dry weight in grams, A is leaf area in square centimeters, and W_L, W_R, W_C, W_F and W_{FL} are plant leaf, root, crown, fruit and flower dry weight biomass in grams, respectively. The growth parameters LAR, SLA, and LWR characterize plant biomass in ways that can be used to detect changes in carbohydrate assimilation throughout the season. Specific leaf area represents the leafiness (leaf area) of a plant on a dry weight basis. Leaf area ratio measures the potential for a plant to accumulate above ground biomass. Leaf weight ratio defines the partitioning of dry weight to leaves, a parameter that determines the plant's capacity to increase dry weight through photosynthesis. Root to shoot ratio represents the balance between the above and below ground plant parts. Growth parameters were analyzed separately each year due to variation in number and dates of whole plant harvests.

Harvested fruit from each treatment was separated into marketable and nonmarketable berries. Marketable berries weighed more than 10 g (0.35 oz) and did not have any blemishes. Differences in yield and growth parameters among treatments were detected using analysis of variance. The ANOVA indicated there was a year effect; therefore yields are presented separately for each year.

Results

The mean total yield of plugs was 48% higher than the mean total yield of BR2 in year 1 (Table 1) but these means were not statistically different ($P \leq 0.05$), due to high variability in data in all treatments and replications. In year 1, fruit weight was higher in plug plants than BR2, but no differences in fruit weight were detected in year 2 (Table 1). In year 1, analysis of weekly yields revealed there were significant differences between sources ($P \leq 0.001$), week ($P \leq 0.0001$) and source × week (P

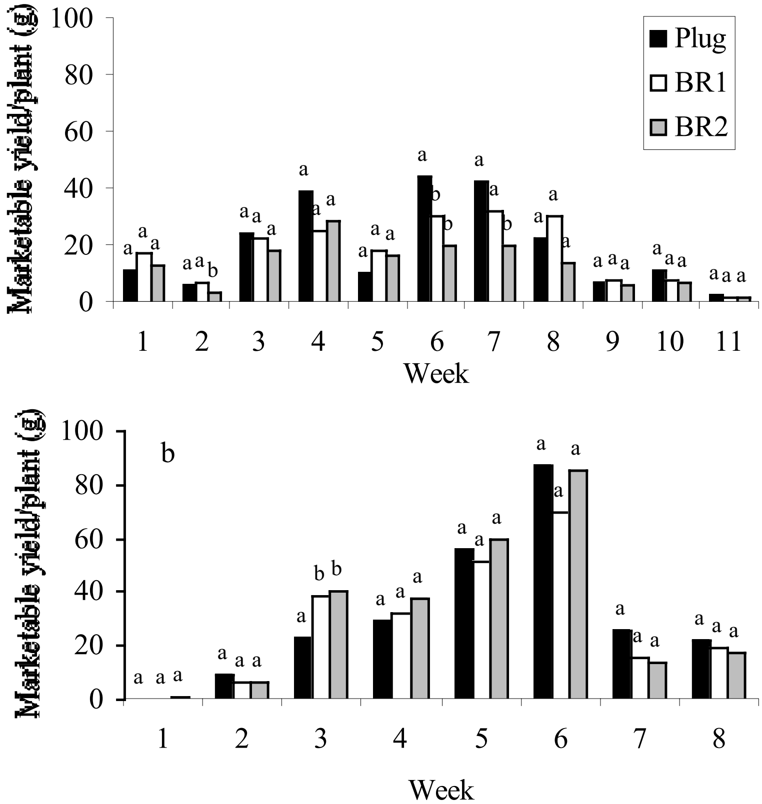

Fig. 1. Weekly marketable yield from 'Chandler' strawberry plants obtained from three sources [plug, bareroot 1 (BR1), and bareroot 2 (BR2)] in (A) 1996–97 and (B) 1997–98. Means separated by different letters are significantly different, $P \leq 0.05$, Fisher's protected LSD test; 28.35 g = 1.0 oz.

≤ 0.0179). In year 2, week ($P \leq 0.001$) was the only significant effect. Although final total and marketable yields were equivalent, separate analysis of weekly yields revealed that there were differences in marketable yield between sources in weeks 5 and 6 in year 1 (Fig. 1). However, these differences did not occur every year and no one source was early or delayed.

Leaf area of plug plants was significantly lower than bareroot plants in October at planting and in January in year 2 (Table 2). However, leaf area was equivalent for all three treatments by November in both years. Leaf area almost doubled during the period from March to April . In year 2, both bareroot sources had higher leaf areas than plug plants in January. Dry weight accumulation in roots, crowns and leaves were similar throughout the two seasons among plants of different sources. Root dry weight was slightly higher in year 1 in plug plants in February and crown dry weight was lower in plug plants in year 2 in January. Dry weight of flowers and fruit were equivalent throughout the season for all sources (data not shown). Dry weights of all plant parts were greater in March than in January.

Leaf area ratio, SLA, LWR, and RSR were similar among sources for most harvest dates both years (Table 3). An exception occurred in year 1 when the LAR of plug plants increased greatly from March to 1 Apr., and was significantly higher than the LAR of bareroot plants in May. Leaf area ratio was highest at the end of the season both years for all treatments. In year 1, SLA was highest (leaves were thinnest) for all treatments at the end of the season; however, they did not show this pattern in year 2. Leaf weight ratio was generally lowest in November then increased in January through March (Table 3).

Discussion

We hypothesized that plant source or plant type would have a measurable effect on growth and yield. Though the strawberry transplants originated from diverse geographic regions (Ontario versus Prince Edward Island) and different methods of production (bareroot versus plug), plant growth and productivity were highly similar in both years of this study.

The consistent results among treatments were similar to those in a previous report (Fernandez et al., 2001), which documented the growth and development of three cultivars grown from bareroot transplants in North Carolina. The establishment phase was characterized by an active period of root, crown and leaf growth in the fall for all three plant sources. Throughout the winter, the plants underwent a period of slow growth, ending in a transition period in late winter and early spring, when resources were allocated to both vegetative and reproductive growth. In the spring, all plant parts received significantly increased allocation of, or redistribution of, resources. Stapleton et al. (2001) found that 'Sweet Charlie' plants from northern (Canada, Massachusetts, Oregon), and mid (North Carolina) latitude origin had equivalent total yields. Although the cultivar we evaluated differed, our data are similar to their findings. The performance of 'Chandler' was not influenced by either the geographic source (which in our case was equivalent to their northern and mid latitude sources), or the type of transplants used in this study. The uniformity among bareroot and plug plant dry weights, leaf area, SLA, LAR, LWR and RSR indicate that overall biomass accumulation and allocation were the same, regardless of plant type.

Plants costs vary depending on transplant type. In 1999 bareroots cost \$81/1000 plants and plugs were \$150/1000 plants. Therefore, growers must consider the cost of plug plants in their production planning. There are, however, attributes to plug production, which may ultimately make them more economical. Plug plants expedite plant establishment, i.e., there is a reduced need for overhead irrigation and less care needs to be taken to set the plants at the correct depth so mechanized planting can be and often is used. These latter attributes save labor and money and may outweigh plant costs in some production systems.

Changing strawberry production practices in the southeastern U.S. necessitated a comparison of plant growth and development of plug and bareroot plants from different geographic sources throughout the growing season. There were no apparent advantages or disadvantages for growing bareroot or plug plants from any of the sources in terms of yield or growth parameters we examined. The consistent nature of the data

Table 2. Leaf area, root, crown, and leaf dry weight of 'Chandler' strawberry plants from three sources [bareroot 1 (BR1), bareroot 2 (BR2), and plug] in 1996–97 (year 1) and 1997–98 (year 2).

	Leaf area (cm^2)[z]				Root dry wt (g)				Crown dry wt (g)				Leaf dry wt (g)			
Month	**BR1**	**BR2**	**Plug**	**P (LSD)**	**BR1**	**BR2**	**Plug**	**P (LSD)**	**BR1**	**BR2**	**Plug**	**P (LSD)**	**BR1**	**BR2**	**Plug**	**P**
Year 1																
October	449.8[y]	333.02	121.47	0.0208 (204.9)	2.8	5.1	8.3	0.5405	3.5	3.5	3.2	0.9797	17.1	12.5	23.6	0.2192
November	245.69	205.11	130.60	0.2940	1.9	1.9	1.8	0.9932	0.7	1.0	0.9	0.6408	2.3	1.8	1.6	0.5440
January	244.84	183.62	181.34	0.3270	2.6	2.8	2.6	0.9880	1.1	1.2	0.8	0.6416	3.1	2.0	2.1	0.4038
February	334.25	222.63	229.08	0.3180	2.6	2.0	5.1	0.0060 (2.39)	2.9	2.8	4.3	0.0821	7.9	5.7	9.4	0.3256
March	516.33	390.97	684.76	0.0955	3.4	6.8	5.9	0.3638	4.1	3.6	3.4	0.7242	14.8	15.7	34.3	0.1474
April	1326.86	523.85	1552.34	0.1760	1.5	1.5	1.5	0.9989	0.8	0.8	0.5	0.3057	2.8	1.8	1.2	0.1653
May	1781.97	927.55	2286.62	0.0606	2.7	0.5	0.2	0.0867	1.7	0.5	0.3	0.1214	8.3	2.3	0.7	0.2466
Year 2																
October	310.46	165.79	112.73	0.007 (95.5)	1.7	0.9	1.7	0.3819	0.4	0.3	0.1	0.4160	2.3	1.5	0.9	0.0590
November	76.10	133.36	100.24	0.1419	2.3	3.3	1.8	0.4825	0.7	0.9	0.6	0.3852	1.2	1.6	1.0	0.2830
January	200.23	181.13	133.19	0.0342 (47.8)	1.8	3.5	2.7	0.3493	1.9	1.5	0.6	0.0208 (0.8)	1.9	1.9	2.5	0.8345
March	947.73	541.32	782.94	0.1302	3.9	2.8	4.2	0.4864	4.1	2.6	2.6	0.2366	10.2	5.5	6.5	0.0690
April	2392.97	1971.10	2622.25	0.2015	6.1	3.2	6.9	0.1748	4.1	3.6	3.5	0.7242	20.3	16.9	21.4	0.2995
May[x]	2140.03	2337.99	1845.88	6.8	14.2	7.0	10.4	15.9	8.2	20.4	25.6	17.1				

[z] $6.45 cm^2 = 1.0 inch^2$, 28.35 g = 1.0 oz.
[y] Mean separation in rows by Fisher protected LSD, $P \leq 0.05$, LSD provided when significant.
[x] One plant harvested/treatment in this month only.

Table 3. Plant growth parameters of 'Chandler' strawberry plants from three sources [bareroot 1 (BR1), bareroot 2 (BR2), and plug] in 1996-97 (year 1) and 1997-98 (year 2).

	Leaf area ratio ($cm^2 \cdot g^{-1}$)z				Specific leaf area ($cm^2 \cdot g^{-1}$)				Leal wt ratio ($g \cdot g^{-1}$)				Root to shoot ratio (g.g-1)			
Month	**BR1**	**BR2**	**Plug**	**P (LSD)**	**BR1**	**BR2**	**Plug**	**P (LSD)**	**BR1**	**BR2**	**Plug**	**P**	**BR1**	**BR2**	**Plug**	**P**
Year 1																
October	35.00[y]	13.87	3.86	0.3062	52.74	42.34	6.07	0.4453	0.70	0.50	0.62	0.2879	0.40	0.42	0.38	0.9170
November	53.87	45.16	31.85	0.4113	124.94	114.78	92.25	0.8111	0.46	0.41	0.39	0.7078	1.20	1.57	1.97	0.6497
December	40.65	35.31	34.18	0.8556	98.88	97.84	90.62	0.9670	0.44	0.37	0.40	0.6927	1.30	1.98	1.75	0.6550
January	25.71	23.00	12.56	0.2295	49.63	45.49	25.13	0.5328	0.57	0.52	0.52	0.5379	0.81	0.94	1.15	0.5240
March	28.01	14.82	13.35	0.1151	85.19	30.29	22.36	0.1578	0.50	0.55	0.63	0.5759	1.20	0.68	0.33	0.2623
April	329.81	143.99	626.57	0.2177	600.20	327.85	1513.29	0.0793	0.52	0.40	0.39	0.2477	0.76	1.90	1.62	0.2275
May	242.28	373.50	2047.29	0.0011 (684.06)	433.48	559.89	3128.11	0.0001 (700.12)	0.54	0.69	0.64	0.0976	0.79	0.46	0.62	0.4551
Year 2																
October	86.24	66.20	42.90	0.5421	170.22	118.37	124.90	0.6213	0.55	0.55	0.34	0.1030	0.95	0.89	2.01	0.0686
November	17.82	24.39	29.51	0.3781	70.95	86.16	105.30	0.4460	0.29	0.28	0.29	0.9855	4.66	2.71	2.63	0.5494
January	39.22	29.02	27.78	0.4769	106.39	99.58	77.31	0.4721	0.36	0.29	0.41	0.2257	1.87	2.55	1.82	0.2246
March	43.83	44.15	50.33	0.5586	93.19	97.94	120.81	0.0981	0.48	0.45	0.42	0.7108	0.61	0.78	0.77	0.3748
April	43.81	49.39	53.34	0.4173	118.78	115.31	122.45	0.2880	0.37	0.43	0.44	0.4806	0.23	0.21	0.26	0.6782
May[x]	49.05	39.17	46.90	105.03	91.24	108.13	0.47	0.42	0.43	0.65	1.01	0.63				

[z] $1.00 cm^2 \cdot g^{-1} = 4.39 inch^2/oz$, $1.00 g \cdot g^{-1}$ = 100%.
[y] Mean separation in columns by Fisher's protected LSD $P \leq 0.05$, LSD provided when significant.
[x] One plant harvested/treatment in this month only.

highlights that standardized crop production and IPM recommendations can be implemented for strawberry plasticulture production systems and emphasis can be placed on plant production systems that minimize pest risk or allow for grower preference.

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