Reducing Mechanical Damage during Transplant Digging Increases Early Season Fruit Yield of Strawberry

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SUMMARY. Transplant quality can have a major effect on the productivity of many crops. Bare-root, green-top transplants for Florida winter strawberry (*Fragaria* ×*ananassa*) production are produced mainly in high-latitude (>42° N) nurseries. Mechanical digging machines are used to remove plants from the soil at these nurseries before transport to production fields in Florida. In the course of this operation, crowns, petioles, and leaves may be crushed and broken. Machine and hand-dug bare-root transplants of 'Camarosa' and 'Sweet Charlie' were obtained from a Nova Scotia, Canada nursery, planted at the Gulf Coast Research and Education Center, Dover, Fla. field facility on 2 Nov. 1999 and 10 Oct. 2000, and grown using standard annual-hill production practices. Plots were harvested twice weekly beginning 5 Jan. 2000 and 15 Dec. 2000. Hand-dug transplants produced significantly higher monetary returns both seasons. Therefore, fruit producers may consider paying the higher cost associated with changes in harvesting and packing operations needed to reduce damage to transplants.

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Commercial strawberries are propagated asexually by producing daughter plants on stolons originating from a mother plant. Bare-root transplants are produced in open fields where daughter plants remain attached to the mother plant and are allowed to root into the soil. According to Latimer (1998), the goal of transplant production is to produce plants that 1) withstand the stress of handling, transportation and transplanting, 2) adapt rapidly to the field environment, 3) establish and resume active growth soon after transplanting, and 4) produce acceptable yields without reduction or delay compared to other establishment methods. Water management (Leskovar, 1998), pretransplant nutrition (Dufault, 1998), transplant size (Latimer 1998; NeSmith and Duval, 1998), transplant age (Vavrina, 1998) and transplant root structure (Nicola, 1998) may all be contributing factors to a transplant's success in the fruiting field.

To supply the demand for strawberry plants in Florida, most bare-rooted green-top transplants for winter production are mechanically harvested, using modified potato-digging equipment, in highlatitude (>42°) or highaltitude nurseries in Canada or the Pacific northwest U.S. A typical harvest operation involves the following procedures; plants are 1) remove from the soil using digging equipment, 2) place in large bins using pitchforks, 3) transferred to a packing facility, 4) separate from each other by hand, 5) count and place in plastic lined boxes (400 to 600 plants per box) and 6) precool and ship to Florida in refrigerated trucks. During harvesting and packing operations, transplant petioles, leaves and crowns may be crushed and/or broken. Damaged plants are likely to take longer to resume normal growth after establishment in the fruiting field.

Demand for fruit in late fall and early winter creates a lucrative market for Florida strawberry producers. A plant that resumes growth quickly and produces more fruit early in the season is highly desirable for Florida strawberry growers. Earlier plantings are not feasible due to the transplants need to be exposed short day lengths in the nursery to initiate flowering in the fruiting field. Crown size at planting and the effect of chilling temperatures in nursery production fields have shown to influence early season yields of strawberry in Florida (Albregts, 1968; Chandler et al., 1989; Kirschbaum et al., 1998). However, the influence of transplant digging and packing operations on subsequent strawberry yields has not been determined. The purpose of this study was to determine the influence on performance of traditionally harvested transplants (machine-dug) in comparison to transplants that do not undergo the rigors of traditional harvesting (hand-dug).

Material and methods

Transplants of 'Sweet Charlie' and 'Camarosa' were randomly selected from among plants that were dug and packed using standard mechanized harvesting and packing practices in a commercial transplant producer's field in Nova Scotia, Canada. On the same day additional plants from the same field, were randomly selected and carefully dug and packed entirely by hand minimizing all potential damage during transplant harvest and packing operations. Soil was removed from the roots of all transplants, by the mechanical digger for machine-dug plants and gentle hand shaking for hand-dug plants. Transplants of both types were placed in the same waxed boxes with plastic liners for cooling and shipment, via truck, to the Gulf Coast research and Education Center, Dover, Fla. (GCREC-Dover). Transplants were planted 2 Nov. 1999 and 10 Oct. 2000 on black plastic mulch using annual hill culture system. Cultivar and digging method were arranged in a 2 × 2 factorial design replicated four times with 16 plants/treatment. Overhead irrigation was used for 10 $h \cdot d^{-1}$ for 10 d to establish transplants. All other irrigation was through drip tape placed underneath the polyethylene mulch. Frost protection, by overhead impact sprinkler irrigation, was applied six times during the 2000–01 season. Plant fertilization and pest control were maintained in accordance with University of Florida recommendations (Maynard and Olson, 2000). Fruit were harvested twice weekly beginning on 5 Jan. 2000, and 15 Dec. 2000 for the 1999–2000 and 2000–01 seasons, respectively. All harvested fruit were graded for marketable weight, marketable number and cull fruit [number of small [<10 g (0.4 oz)], misshapen, and diseased fruit]. Data

were organized monthly and seasonally (Chandler et al., 2000; Albregts and Chandler, 1995) and analyzed by analysis of variance using SAS statistical software (SAS Institute, 1999). Economic analysis was conducted by averaging monthly prices using data obtained from the USDA Agricultural Marketing Service, Fruit and Vegetable Market News (Orlando Fla.).

Results and discussion

Monthly and seasonal marketable yields for strawberry production in the 1999–2000 season revealed significant treatment differences for digging technique and cultivar, and a significant interaction of the two in January and March of 2000 (Table 1). During January 2000 'Sweet Charlie' and 'Camarosa', which were hand-dug produced 2.96 and 3.22 tons/acre (6.63 and 7.21 $Mg \cdot ha^{-1}$) respectively compared to machine-dug, which produced 1.30 and 2.47 tons/acre (2.91 and 5.53 $Mg \cdot ha^{-1}$) respectively. March 2000 marketable yields of 'Sweet Charlie' and 'Camarosa', which were hand-dug produced 4.30 and 6.51 tons/acre (9.64 and 14.58 $Mg \cdot ha^{-1}$), respectively, compared to machine-dug, which produced 4.39 and 4.60 tons/acre (9.83 and 10.30 $Mg \cdot ha^{-1}$) respectively. 'Camarosa' produced higher yields than 'Sweet Charlie' over the course of the season.

Digging technique showed significant differences only in the month of December for the 2000–01 season with hand-dug transplants out performing machine-dug transplants by 125%. No significant treatment interactions were found between digging technique and cultivar during the 2000–01 season (Table 1). The unusually low air temperatures during January (Fig 1) may have been a contributing factor in the lack of treatment differences. Above ground development of all plants appeared to be minimal during this period. Cultivar had a significant effect on marketable yields each month, with the exception of February, and for the whole season (Table 2). As typically observed, 'Camarosa' produced less fruit than 'Sweet Charlie' during the month of December but significantly higher amounts every other month.

Total number of marketable fruit harvested were significantly affected by digging technique during 1999–2000 with hand-dug plants producing a greater number of fruit (Table 2). 'Camarosa' produced a greater number of marketable fruit than 'Sweet Charlie' during the 2000–01 season. More marketable fruit were produced during the 1999–2000 season than the 2000–01, possibly a result of cold weather in west central Florida during January 2001 (Fig. 1). January is a time when flowers are initiated for the main crop harvested in February and March. Average fruit weight was affected by cultivar both seasons with 'Camarosa' having heavier mean fruit weight (Table 2). Number of culled fruit was significantly higher for 'Sweet Charlie' than 'Camarosa' for the 1999–2000 season.

Economic analysis based on average monthly price for a 10.25 lbs (4.65 kg) flat packed with medium-large fruit

Table 1. Average fruit yields for machine-dug and hand-dug 'Sweet Charlie' and 'Camarosa' strawberry transplants grown in the annual hill production system at Dover, Fla.

Parameter	Marketable wt (tons/acre)[z]				
	December	January	February	March	Total
			1999–2000		
Digging technique (DT)					
Hand-dug			5.21		13.71
Machine-dug			3.69		10.07
Cultivar (C)					
Sweet Charlie			3.70		10.17
Camarosa			5.20		13.60
DT × C					
Hand-dug Sweet Charlie		2.96		4.30	
Machine-dug Sweet Charlie		1.30		4.39	
Hand-dug Camarosa		3.22		6.51	
Machine-dug Camarosa		2.47		4.60	
Statistical analysis (P)					
DT		0.0001	0.0018	0.0226	0.0001
C		0.0002	0.0019	0.0046	0.0001
DT × C		0.0050	0.6206	0.0140	0.4717
			2000–2001		
Digging technique (DT)					
Hand-dug	0.70	1.98	3.23	3.02	8.93
Machine-dug	0.31	1.76	3.30	2.65	8.03
Cultivar (C)					
Sweet Charlie	0.64	1.21	3.15	1.38	6.38
Camarosa	0.37	2.53	3.38	4.30	10.58
Statistical analysis (P)					
DT	0.0007	0.1883	0.7463	0.3393	0.0991
C	0.0089	0.0001	0.2806	0.0001	0.0001
DT × C	0.2320	0.0906	0.8547	0.2788	0.2932

[z]Numbers represent means of four treatment replications of 16 plants each; 1 ton/acre = 2.24 $Mg \cdot ha^{-1}$.

Table 2. Seasonal data for number of marketable fruit, average fruit weight and total number of cull fruit of machine-dug and hand-dug 'Sweet Charlie' and 'Camarosa' strawberry transplants grown in the annual hill production system at Dover, Fla.

Parameter	Marketable[z] fruit (1000/acre)	Avg wt (g)	Total culls (1000/acre)
		1999–2000	
Digging technique (DT)			
Hand-dug	581	21.7	181
Machine-dug	420	21.7	153
Cultivar (C)			
Sweet Charlie	510	18.2	255
Camarosa	491	25.2	79
Statistical analysis (P)			
DT	0.0001	0.9876	0.2303
C	0.4485	0.0001	0.0001
C × DT	0.5809	0.3664	0.5243
		2000–01	
Digging technique (DT)			
Hand-dug	414	19.3	97
Machine-dug	366	19.7	75
Cultivar (C)			
Sweet Charlie	327	17.7	90
Camarosa	453	21.3	82
Statistical analysis (P)			
DT	0.0604	0.2864	0.0171
C	0.0001	0.0001	0.3129
C × DT	0.1937	0.2043	0.4700

[z]Numbers represent means of four treatment replications of 16 plants. 1000/acre = 2471/ha; 28.4 g = 1.0 oz.

was the same for all months as harvest data (Table 3). However, when seasonal totals were analyzed significant difference were detected for cultivar and digging technique each year. Monetary returns for hand-dug plants over the course of the whole growing period were $5,440 and $900 per acre ($13,437 and $2,223 per ha) higher than machine-dug plants for the 1999–2000 and 2000–01 seasons respectively. Returns for 'Camarosa' were $4,940 and $4,200 per acre ($12,202 and $10,374 per ha) higher than 'Sweet Charlie' during the 1999–2000 and 2000–01 seasons respectively. This economic analysis show that small differences in yield during the earlier portion of the strawberry season can have dramatic effects on profits growers receive.

Currently, growers in the major production area of Florida are considering transplants grown in standard transplant production trays (plug plants) to increase their early yields. Research to date on plug plants has shown an increase in early marketable yields when compared to typical bare-root transplants (Hochmuth et al., 2000). Their greater early yield may be at least partially the result of less mechanical damage that plug transplants receive during harvesting, packing and shipping operations. Plug plants do not undergo mechanical harvesting operations, which limits the amount of damage prior to planting. These transplants are left in trays and packed 50 to 200 plants to a box, whereas a similar size box can

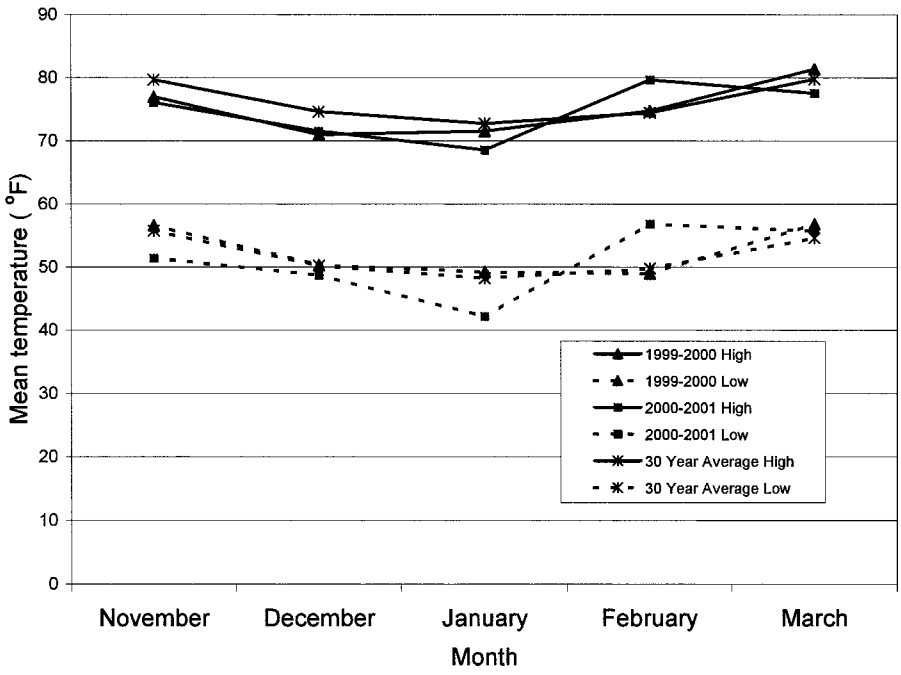

Fig. 1. Monthly average high and low temperature (°F) average for Plant City, Fla., for the 1999–2000 and 2000–01 seasons, and the 30-year historical average. Data from the National Weather Service, Ruskin, Fla; °C = 5/9 (°F – 32).

Table 3. Fruit value for machine-dug and hand-dug 'Sweet Charlie' and 'Camarosa' strawberry transplants grown in the annual hill production system at Dover, Fla.

Parameter	Marketable value ($1000/acre)[z,y]				
	December	January	February	March	Total
			1999–2000		
Digging technique (DT)					
Hand-dug			8.46		19.43
Machine-dug			5.99		13.99
Cultivar (C)					
Sweet Charlie			6.00		14.24
Camarosa			8.45		19.18
DT × C					
Hand-dug Sweet Charlie		4.85		4.69	
Machine-dug Sweet Charlie		2.13		4.79	
Hand-dug Camarosa		5.28		7.11	
Machine-dug Camarosa		4.05		5.02	
Statistical analysis (P)					
DT		0.0001	0.0018	0.0226	0.0001
C		0.0002	0.0019	0.0046	0.0001
DT × C		0.0050	0.6206	0.0140	0.9660
			2000–01		
Digging technique (DT)					
Hand-dug	2.13	4.77	5.49	3.50	8.93
Machine-dug	0.95	4.25	5.60	3.08	8.03
Cultivar (C)					
Sweet Charlie	1.95	2.91	5.35	1.59	6.38
Camarosa	1.13	6.11	5.74	4.98	10.58
Statistical analysis (P)					
DT	0.0007	0.1883	0.7463	0.3393	0.0001
C	0.0089	0.0001	0.2806	0.0001	0.0385
DT × C	0.2320	0.0906	0.8547	0.2788	0.3846

[z]Numbers represent means of four treatment replications of 16 plants each. $1000/acre = $2471/ha.
[y]Economic data from USDA Agricultural Marketing Services, Fruit and Vegetable Market News, Orlando Fla.

contain up to 600 bare-root transplants. These less compacted conditions may limit damage during shipping. Although containerized transplants are roughly double the cost of machine-dug bare-root plants, the increased production of high value early fruit may offset this cost.

While significant gains due to digging techniques were evident during each evaluation period the first season, only December yields showed improvement during the second season. Economic analysis of seasonal yields indicates that there is an economic advantage to using hand-dug transplants for field establishment in Florida. This may justify the conclusion that the mechanical damage a green-top bare-rooted transplant receives during digging, packing and transport from the nursery to the fruiting field affects its performance in Florida fruiting fields. Although effects of digging technique on yield vary from year to year, a reduction in performance, especially early in the season, can have a dramatic effect in terms of monetary returns to growers. Further research examining where and when damage during harvest, packing and shipping occurs and how to minimize it needs to be conducted.

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