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Influence of Leaf Removal, Root Pruning, and Soil Addition on the Growth of Greenhouse-grown Strawberry Plants

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Abstract. Experiments were conducted to examine strawberry (*Fragaria × ananassa* Duchesne) plant renovation practices, singly and in combination, for effects on vegetative growth of greenhouse-grown, potted strawberry plants. The major results of these experiments were as follows: a) most of the plants that were both defoliated and root-pruned after fruit harvest died; b) there was a negative linear relationship between the number of leaves removed and the number of new leaves and runners produced; c) root, leaf, and total plant dry weights were negatively correlated with the severity of root pruning; and d) soil addition after fruit harvest decreased the shoot : root ratio of multiple-crown plants, but had no effect on single-crown plants.

Renovation practices for strawberry plantings commonly include removing foliage following fruiting and narrowing rows by tilling (10). These practices evolved from a need to control leaf diseases and row widths (7, 13).

The effects of defoliation on fruit yield seem to vary with location and cultivar. In Scotland, Guttridge et al. (5) reported up to 4-fold yield increases in the season after defoliation. Later studies (6) showed the yield increase was due to an increased proportion of crowns forming fruit trusses and increased number of trusses per crown. Others (3, 4, 12) concluded that defoliation removed a flowering inhibitor produced by old leaves. Moore (9), in Arkansas, found either a reduction or no increase in yield from various defoliation treatments. Results with defoliation have varied widely among cultivars, and a full canopy of leaves appears necessary for successful flower initiation (8).

The effects of defoliation on vegetative growth have not been studied in detail. Defoliation late in the growing season increased crown death and decreased formation of new branch crowns (6). In California, severe defoliation of summer-planted strawberries at the end of the first growing season reduced vegetative vigor and subsequent yield (15). Plantings must be of

good vigor for defoliation to be a stimulus to increased truss formation (5, 7); old, weak, or unhealthy plantings will not be rejuvenated (7). Waldo (13), working with the cultivar Corvallis, reported that defoliated plants produced far fewer runners than plants whose leaves had been left intact.

Tilling or plowing to narrow rows potentially prunes roots and mounds soil around plant crowns. Dana (1) states that the application of ≈2.5 mm of soil over the plant bed after harvest enhances the rate and extent of new root production.

In a group of four experiments, we examined the influence of leaf removal, root pruning, and soil addition, singly and in combinations, on the vegetative growth of containerized strawberry plants in the greenhouse.

Materials and Methods

Dormant, single-crown plants of 'Allstar' were potted in 190-mm plastic pots immediately upon reception from a commercial nursery in late January. The soil mix consisted of 25 silt loam soil : 40 sand : 35 calcined clay, by volume. Each pot received 15 g of slow-release fertilizer (18N-2.6P-10K).

The potted plants were placed under supplemental light (high-pressure sodium lamps from 0700 to 1900 HR) in a heated greenhouse (24°C day; 16° night). All flowers were hand-pollinated at anthesis to ensure fruit set.

After the fruit was harvested, the plants were used in one of three experiments.

Experiment 1. In this 2 × 2 × 2 factorial experiment, all leaves (including petioles) were removed or left intact; roots were pruned or left intact; and 500 ml of soil mix was added or not added around the crown. The experimental layout consisted of 12 replications (pots) of each treatment in a randomized complete block design.

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Roots were pruned using a 74-mm o.d. steel pipe sharpened at one end, with a handle welded to the other end. The pipe was placed over the plant (being careful not to damage any leaves), pushed into the soil vertically, and twisted until the bottom of the pot was reached. Using some extra plants, it was determined that the pipe severed $\approx 70\%$ of the roots from the plants.

The second node of the first four runners produced by each plant was pegged onto the soil mixture described above in a 100-mm plastic pot. Additional runners were removed.

Experiment 2. Leaves were removed acropetally until five fully expanded leaves remained on each plant. Then, one of the following treatments was applied: 1) the youngest (fully expanded) leaf was removed; 2) the two youngest leaves were removed; 3) the three youngest leaves were removed; 4) the four youngest leaves were removed; 5) all five leaves were removed; or 6) all five leaves were left intact.

Experiments 1 and 2 were terminated 11 weeks after treatments were applied.

Experiment 3. All leaves were removed from each plant. Then, one of the following treatments was applied: roots were pruned with a steel pipe of 99, 74, or 54 mm diameter, or they were left unpruned. Using extra plants, it was determined that the three pipes severed $\approx 50\%$, 70% , and 78% of the roots from the plant.

The experimental layout for Expts. 2 and 3 consisted of 10 replications (pots) of each treatment in a randomized complete block design. New leaves and runners produced were counted, and runners removed at weekly intervals. Experiment 3 was terminated 7 weeks after treatments were applied.

Experiment 4. Dormant, multiple-crown plants of 'Allstar' were potted in 190-mm plastic pots and placed in a greenhouse in early April. All flowers were hand-pollinated at anthesis to ensure fruit set. After all fruit was harvested and weighed, the plants were grouped into 24 pairs (blocks) based on fruit yield. Then, 500 ml of soil mix was added around crowns of one-half of the plants; the others received no soil. The experiment was terminated 5 months after treatments were applied.

At the end of each experiment, the dry weight of leaves, crowns, and roots was determined.

Results

Experiment 1. Addition of extra soil mix did not significantly affect total plant dry weight or the components of total plant dry weight (Table 1). The combination of leaf removal and root

Table 1. Analysis of variance for root, crown, leaf, and total dry weight of greenhouse-grown 'Allstar' strawberry plants.

Source of variation	Dependent variable			
	Dry wt			
	Root	Crown	Leaf	Total plant
Added soil mix	NS	NS	NS	NS
Root pruning	**	*	**	**
Root pruning \times added soil mix	NS	NS	NS	NS
Leaf removal	**	**	**	**
Leaf removal \times added soil mix	NS	NS	NS	NS
Leaf removal \times root pruning	**	**	*	*
Leaf removal \times root pruning \times added soil mix	NS	NS	NS	NS

NS, **, ***Nonsignificant or significant at the 5% or 1% levels, respectively.

pruning had a devastating effect: 19 of 24 plants died. Only two of 24 plants died that had their roots pruned and their leaves left intact, even though they wilted for several days. The mean dry weight of plants that had been defoliated was $\approx 50\%$ less than plants that had not been defoliated. The mean dry weight of plants that had been root-pruned was $\approx 10\%$ less than plants that had not been root-pruned.

Root-pruning and defoliation of the mother plants significantly affected runner production (Table 2). Root pruning delayed average pin date by 6 days, and leaf removal delayed average pin date by 12 days. There was a significant root pruning \times leaf removal interaction for total dry weight of runner plants (Table 2). Defoliation had an effect on runner plant dry weight only when defoliation was applied to non-root-pruned mother plants (Fig. 1). Likewise, root pruning had an effect on runner plant dry weight only when root pruning was applied to non-defoliated mother plants.

Experiment 2. There was a significant linear relationship between the number of leaves removed and the number of new leaves and runners produced and total plant dry weight at the end of the experiment (Table 3). Defoliation delayed runner formation, and this delay may have been due to a temporary increase in leaf formation (Fig. 2).

Experiment 3. Root, leaf, and total plant dry weight was negatively correlated with the proportion of roots removed. The simple correlation coefficients (r) between level of roots removed and root, leaf, and total plant dry weight were -0.55 (significant at the 5% level), -0.69 (significant at the 1% level), and -0.74 (significant at the 1% level), respectively.

Experiment 4. Although a significant difference between root,

Table 2. Analysis of variance for average pin date and total dry weight of runner plants from greenhouse-grown 'Allstar' strawberry plants.

Source of variation	Dependent variable	
	Pin date	Total plant dry wt
Added soil mix	NS	NS
Root pruning	**	**
Leaf removal	**	*
Added potting mix \times root pruning	NS	NS
Added potting mix \times leaf removal	NS	NS
Root pruning \times leaf removal	NS	*

NS, **, ***Nonsignificant or significant at the 5% or 1% levels, respectively.

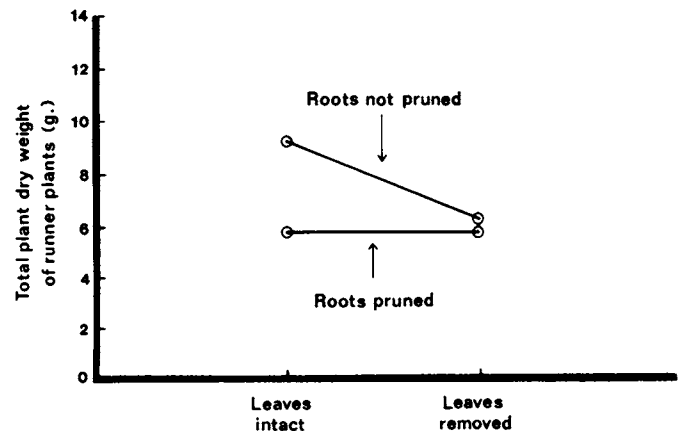


Fig. 1. Interaction ($P = 0.02$) of leaf removal and root pruning of mother 'Allstar' plants on the total dry weight of runner plants.

Table 3. Mean number of new strawberry leaves and runners, and mean plant dry weight at the end of the experiment, as influenced by leaf removal treatments.

Remaining	No. leaves		No. runners	Plant dry wt (g)
		New		
5		4.7	8.8	65
4		4.4	8.4	61
3		4.8	8.1	58
2		4.2	8.4	50
1		4.0	7.4	47
0		3.2	4.0	27
Linear trend		*	**	**
Quadratic trend		NS	**	*

NS,*,** Nonsignificant or significant at the 5% and 1% levels, respectively.

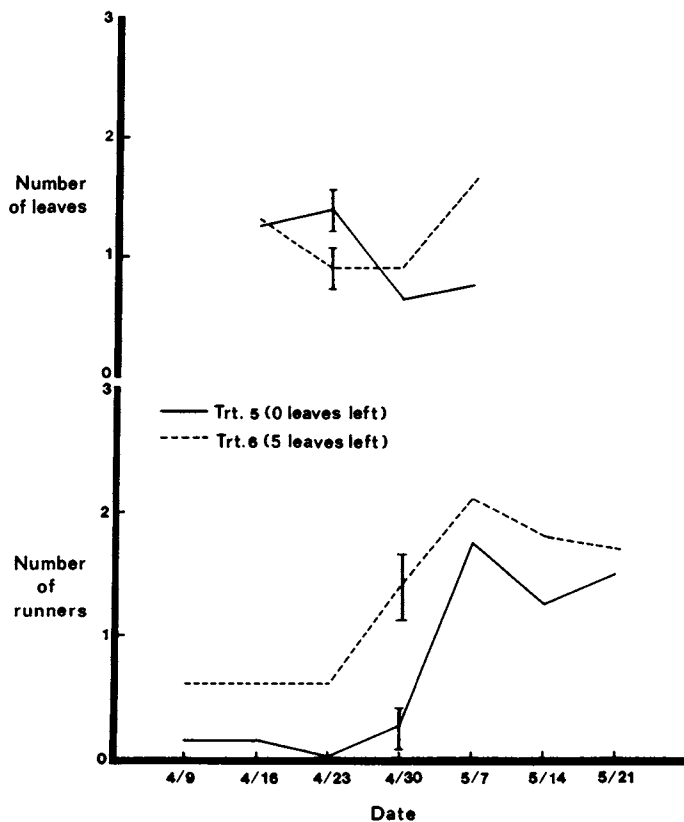


Fig. 2. Number of leaves (top) and runners (bottom) produced as a function of defoliation of strawberry plants (no leaves or five leaves left on plant) in Expt. 1.

Table 4. Effect of soil addition on the growth of potted, multiple-crown 'Allstar' strawberry plants.

Treatment	Dry wt (g)			Leaf : root ratio
	Root	Crown	Leaf	
No soil added	28.4 a ²	29.3 a	52.4 a	2.0 a
Soil added	32.5 a	30.9 a	51.2 a	1.7 b

²Mean comparison using Duncan's multiple range test, 5% level.

crown, and leaf dry weights was not detected for soil added vs. no soil added, the leaf to root ratio of soil added plants was significantly lower than the leaf to root ratio of no soil added plants (Table 4).

Discussion

The failure of extra soil mix to affect the plants in Expt. 1 was not totally unexpected. These plants were young, single-crown plants that normally would not be initiating new primary roots. The older, multiple-crown plants in Expt. 4 were more likely to initiate new primary roots, and were, therefore, more likely to benefit from the addition of extra soil mix.

The death of plants that were both defoliated and root-pruned may be a result of a lack of sufficient food reserves to rebuild their leaf and root systems. This extreme treatment is not likely to occur to plants in a matted-row cultural system, except possibly at the edge of a row, where cultivation is intended to kill plants.

In our experiments, defoliation clearly had a greater effect on plant growth than did root pruning. Studies directly comparing removal of equivalent amounts of root and leaf/shoot tissue are not available in the literature. However, in separate studies of summer-pruning and root-pruning young apple trees, removal of 50% of the shoot resulted in a 44% reduction in total dry weight (11), while removal of 59% of the root system resulted in only a 25% reduction in total dry weight (2). These findings support our observation with strawberry that defoliation causes a greater reduction in growth than root pruning. Had soil moisture been limiting, the relative effects of defoliation and root pruning might have been different.

The delay in pin date (i.e., formation of a second node) caused by root pruning and defoliation of the mother plant could be a disadvantage in the field because fruit yield has been correlated to rooting date (14). On the other hand, delayed or reduced runner formation could be an advantage in the field if plant density is already optimum. In a well-established matted row, vigorous runner production could increase plant density to a point where interplant competition becomes a limiting factor. Postharvest mowing significantly reduced the number of runners produced in a 1986 field trial involving 'Allstar', 'Earliglow', and 'Delite' (unpublished data). Whether this reduced runner formation affects yield will, we believe, depend on the influence of runner production on plant density.

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Relationships of Plant Density and Harvest Index to Seed Yield and Quality in Carrot

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Abstract. Carrot (*Daucus carota* L. cv. *Danvers*) seed were produced at plant spacings of 0.05, 0.10, 0.20, and 0.30 m in 0.80-m rows to give populations of 25, 13, 6, and 4 plants/m². Samples from the adjacent commercial carrot seed field provided an additional density of 36 plants/m². Seed yield, harvest index, and seed quality were evaluated with respect to umbel order and plant density. Phenological development was unaffected by plant density, but plant height increased significantly as density increased. The number of umbels per plant and the number of seeds per umbel decreased with increasing plant density, while seed weight was unaffected. The proportion of the seed contributed by primary umbels increased from 20% at the lowest to 60% at the highest density. Seed yield per plant declined continuously as population increased, but seed yield per unit area increased to a maximum at 12 plants/m², then declined. Total biological yield (above-ground biomass) rose to a plateau level with increasing plant population. Ceiling biological yield coincided with maximum seed yield. Seed quality within each umbel order, assessed by germination percentage and rate, seedling growth, embryo length, and abnormal or embryoless seeds, was unaffected by plant density, but consistently decreased from primary to tertiary umbel orders. Harvest index (seed yield/biological yield) was highly correlated with seed quality. The relationship between harvest index and plant density in carrot seed production may be useful in optimizing plant populations for maximum seed yield and quality.

The primary aim in vegetable seed production is to obtain high yields while maintaining maximum seed quality. This has proven to be difficult in carrots due to the flowering pattern and morphology of the reproductive structures. Carrot inflorescences form a terminal primary umbel, followed by lateral branching to produce secondary, tertiary, and higher orders of umbels. This indeterminate habit and prolonged flowering period results in varying seed maturities on different umbel orders when the entire crop is harvested at once (2, 5, 11). Consequently, the quality of seeds decreases as the umbel order increases (2, 5, 11, 13). However, the majority of the seed yield is produced on the numerous secondary umbels (4, 13). The degree of branching of the carrot inflorescence is sensitive to plant density. As plant density is increased, the number of secondary and tertiary umbels per plant is reduced, resulting in a greater contribution of primary umbels to the total seed yield. The percentage of seed from primary umbels can increase from

<20% at low plant densities (three to 10 plants/m²), to >50% at high plant densities (70 to 80 plants/m²) (4, 9, 13). In addition, in most studies, total seed yield increased almost linearly with increasing plant density (4, 9, 10, 13). High plant densities, therefore, should satisfy both objectives in carrot seed production: improving seed quality by increasing the proportion of seed from the primary umbels, while also giving higher total seed yields.

Some studies have reported a positive relationship between carrot seed yield and plant density up to very high plant populations (256 to 320 plants/m²) (4). In cereals, where the relationship between plant density and grain yield has been extensively studied, the reproductive components of yield generally rise to a maximum, then decline at higher plant densities. The total dry matter produced per unit area (biological yield), on the other hand, approaches a maximum plateau at moderate to high densities (3, 17). In general, the ceiling biological yield and the maximum grain yield are achieved at about the same plant density (3). The harvest index (grain yield/total biological yield) consistently declines at densities above that giving the maximum grain yield. The competition for light in dense populations results in greater resource allocation to vegetative growth and a reduction in reproductive output. This relationship between harvest index and grain yield has proved to be a simple and valuable criterion to plant breeders in developing high-yielding cultivars (3). However, to the best of our knowledge, this relationship has not been documented for carrot seed crops. Harvest index could prove useful in determining the optimum population for maximum yield in carrot seed production. In addition, the influence of plant density on seed quality, generally not consid-

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