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A Comparison of Annual and Perennial Production Systems in 'Redcrest' June-bearing Strawberry for a Processing Market[1]

BERNADINE STRIK,[2] PAULA STONEROD,[3] NEIL BELL,[4] and HELEN CAHN[3]

Department of Horticulture, Oregon State University,
4017 ALS, Corvallis, OR 97331-7304

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Abstract. Annual production systems, where 'Redcrest' strawberries were planted after strawberries without pre-plant fumigation, were compared to perennial production systems at various densities. The spacing systems studied were a 38cm single matted row and a 20cm double- and 20cm triple-hill system. Plants in the perennial system were fruited from 1994-96, the first through third fruiting seasons. Plants in the annual production system were harvested in 1994, then were removed and plots replanted with cold-stored crowns on July 14th, two weeks after last fruit harvest. In 1995, the annual plots were harvested, then removed and plots replanted with cold-stored crowns on July 6 (one week after fruit harvest). Annual plots were compared to second- and third-year perennial plots. The 20cm triple-hill had a greater yield than the 38cm double matted row in the first production season and took longer to harvest. Planting density did not affect fruit mass or yield in 1995 or 1996. In 1995, there was no significant difference in yield between the annual plots (planted 14 July, 1994) and the second year perennial plots. The annual plants produced 39 to 97% larger fruit than the perennials. Also, the annual plots had 8% rot compared to 28% in the perennial plantings. Picking time later in the season in the annual treatments was less than half that of the perennial plots which cost $103.04 more per tonne to harvest (averaged over two harvests). In 1996, annual treatments produced an almost eightfold greater yield than perennial plots in their third fruiting season. Fruit mass in annual plots was almost three times greater than in perennial plots. The cost to harvest a tonne of fruit averaged over two harvests in the perennial plots was $604.57 more than in the annual plots. There were significantly fewer root weevil larvae per plant in annual plots than in perennial plots in 1996.

Introduction

Growers in the Pacific Northwest (Ore. and Wash., USA and B.C., Canada) use various production systems to produce June-bearing strawberries for the processing market, including a single or double matted row on raised beds or flat ground. Plantings are usually established in April or May and are typically kept for two to four fruiting seasons after the non-productive planting year. However, perennial production systems are difficult to manage when pests, particularly phytophthora root rot and root weevils (*Otiorhynchus* sp.), become prevalent in the planting. These types of pests may be more easily managed in annual systems.

Mechanical destruction of leaves shortly after harvest, as is done when tilling in plants in preparation for continuous annual planting, has reduced the severity of gray mold fruit rot in the following season (Sutton *et al.*, 1988). This practice has also been suggested to reduce root weevil damage, because the adults are deprived of a food source during a period when they are ovipositing (Collins and Fisher, 1993). In addition, mortality of root weevil eggs, which are deposited on the soil surface, was highest when the soil surface was exposed to direct solar radiation (Shanks and Finnigan, 1973).

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[2] Professor

[3] Research Assistant, Berry Crop Production, NWREC

[4] Research Assistant, presently in Ornamentals, NWREC

Raised beds have been shown to improve drainage and decrease soil compaction (Goulart and Funt, 1985) and have been associated with decreased incidence of red stele (*Phytophthora fragariae* Hickman) and other diseases caused by phytophthora (Strand, 1993). Annual planting of certified plants has also been implicated in a reduction of phytophthora (Strand, 1993).

Annual planting is commonly used in strawberry production in California. New plantings can be established in summer or winter after fumigation for pest control (Welch, 1989). To our knowledge no work has been done to study the feasibility of re-planting strawberries, after fruit harvest, without pre-plant fumigation in a more temperate climate. Fumigation is often not an economic alternative for a processing market.

Dozier *et al.* (1993), in Alabama, found that yield and fruit mass decreased with planting dormant nursery plants from July 18 to Nov 21. Previous work has demonstrated that increasing plant density can increase yields (Dozier *et al.*, 1993; Hesketh *et al.*, 1990; Martin, 1976; Norton *et al.*, 1973; Unger and Strik, 1988). Thus higher planting densities could perhaps be used in late planting dates to increase yield.

The objectives of our study were to compare traditional, perennial production systems to annual systems where strawberries are planted after fruit harvest, without preplant fumigation.

Materials and Methods

The June-bearing strawberry 'Redcrest' (Stahler *et al.*, 1995), a processing cultivar that is susceptible to root rot and virus but has exceptionally good fruit traits for processing, was studied. A 0.08 ha (0.2 acre) planting was established at the North Willamette Research and Extension Center, Aurora, Ore. in spring, 1993. The soil was fumigated with a mixture of methyl bromide and chloropicrin (67-33 at 396 kg/ha) prior to establishing the planting on raised beds. Three spacing/runner management treatments were assigned to plots consisting of two adjacent 9.1m (30′) rows spaced at 1m (40″): a double matted row where plants were staggered with 38 cm (15″) between plants and rows (49,400 plants/ha [20,000/acre]); a triple hill system with 20cm (8″) between plants and staggered rows (69,470/ha [28,125/acre]); and a double hill system with 20cm (8″) between plants and staggered rows (90,750/ha [36,735/acre]). The matted row treatment was maintained to a 45cm (18″) width. Runners were removed from the hill system treatments three times during each growing season. Treatments were arranged in a split plot with annual or perennial culture as main effects and spacing/runner management as subplots, with four replications.

Blossoms were removed in all treatments in the planting year. In the perennial production system, plants were harvested from 1994 to 1996 (first through third production years). Plants in the annual production system were harvested in 1994, then were mowed and the beds rototilled. Raised beds were subsequently reformed and planted with cold-stored crowns on 14 July, 1994, two weeks after last fruit harvest. These plants were harvested in 1995 with yield and yield component data compared to the second year perennial system. The methods for re-establishing the annual treatments were repeated in 1995 and 1996 with new cold-stored plants established in the same plots on 6 July, 1995 (one week after harvest) with their yield compared to the third year perennial plots in 1996.

Annual systems were fertilized with 33.6 kg N/ha (30 lb/a) at the end of July. Perennial plots were fertilized with 56 kg N/ha (50 lb/a) at renovation. Renovation was two weeks after the last fruit harvest (Zhang *et al.*, 1992) and involved mowing, narrowing the row in matted row treatments to 45cm (18″), fertilizing and irrigating. A pre-emergent herbicide was applied to all treatments in spring and fall of 1993-96. From 1994 through 1996, plots were treated with two to three fungicide applications to control botrytis fruit rot (at 5-10% bloom; 50% bloom; and/or green fruit). No straw mulch was applied in the winter, as it is not necessary for cold protection in the Pacific Northwest.

From 1994 through 1996, yield data were collected from a 3m (10′) section of row for each treatment plot. Plots were harvested three to four times at one-week intervals during the season and the time required to harvest each plot was recorded for the first two harvests. At each harvest a 25-fruit sample was used to obtain an average fruit mass per harvest. A weighted average fruit mass for the entire season was calculated. All rotted fruit were harvested and weighed separately. Harvest rate (weight of fruit picked by one person in an hour) and harvest cost (cost to harvest one tonne of fruit based on a wage rate of $5.50/hour) were calculated for the first and second pick.

The number of plants and crowns per meter of row and average crown diameter (5 crowns per plot) were measured after the last fruit harvest in 1995 and 1996. The number of root weevil larvae per plant was determined per plot (three plants sampled per plot) in spring, 1996, because of evidence of pest pressure. Data were analyzed by analysis of variance for split plot designs (SAS, 1988). Means were compared using a protected LSD.

Results and Discussion

Production year significantly affected all variables measured. There were no production system (annual/perennial) by spacing interactions in any year. Thus, main effects are presented here.

Spacing/runner management system did not affect fruit mass or percent rotted fruit in 1994 (Table 1). The 20cm triple-hill had a greater yield than the 38cm double matted row in the first production season (1994; Table 1).

The hill systems tended to have a greater yield than the matted row system in the second production year (1995) whereas, the matted row systems tended to have the greatest yield in 1996 (Table 1). Spacing did not affect fruit mass or percent rot (Table 1). Our data support the findings of Baumann *et al.* (1993) who found no effect of planting density on yield of Pacific Northwest, June-bearing cultivars the year after planting. In our study, planting density had relatively little effect on fruit mass, as has been found by others (Caldwell and Grimes, 1987; Dozier *et al.*, 1993). However, Poling and Durner (1986) found that fruit mass decreased with higher planting densities in hill systems in North Carolina. In our study, fruit mass did decrease significantly from the first to third production season (Table 1).

In 1994, the 20cm triple-hill system took the longest time to harvest, although only on the first picking. This was probably due to the higher yield in this system (Table 1). Pickers were able to harvest significantly more (kg) fruit per hour in the triple hill system than the other treatments on the second harvest date (Table 2). This reduced the cost of harvest ($/tonne) by 18% as compared to the matted row system (Table 2). There were no differences in harvest rate or cost among spacing systems in the second fruiting season. However, in 1996, the harvest rate for the 20cm double-hill system was lowest increasing cost per tonne for the second harvest by more than twofold compared to the matted row (Table 2).

Yield declined considerably from 1994 to 1995 probably due to the later planting date in the annual plots in 1994 as compared to 1993 and as is typical in second year perennial plots as compared to the first fruiting season (Table 1). There was no significant difference in yield between annual and perennial production systems in 1994—this was expected, as both systems were planted in April, 1993. However, in 1995 there was also no difference in yield between the annual plots (planted 14 July, 1994) and the second year perennial plots (Table 1). However, the annual plots produced fruit of better quality and offered some economic and pest control advantages over the perennial system.

The annual plants produced 39 to 97% larger fruit than the perennial plots in their second fruiting season. This may be considered to offer quality and economic advantages in the field (picking time) and in the processing plant (reduced sorting time on the production line). Picking time later in the season in the annual treatments was less than half that of the perennial plots in 1995 (Table 1). Pickers tended to harvest more fruit (68% kg/hr second picking; $P = 0.08$) in annual than in perennial plots (Table 2). This affected costs of production, as perennial plots cost significantly more to pick ($103.04/tonne averaged over the two harvests; Table 2) than annual plots.

As there was no interaction between spacing and production system, planting at the higher densities in this study offered no advantage even at the late planting date imposed by the annual system. In 1995, annual hill systems had fewer plants per meter of row and a larger crown diameter than those in perennial plots (data not shown). The greater fruit mass (Table 1) may have been the result of less crowding (trend, data not shown) and larger crowns in the annual system.

Annual plots, in 1996 (planted 6 July, 1995), produced a greater yield (almost eightfold higher) than the perennial plots in their third fruiting season (Table 1). This was predominantly due to an almost threefold increase in average fruit mass, but may have also been related to significantly less root weevil larval feeding on plants in annual plots. There were an average of 0.7 and 6.00 larvae sampled per plant in annual and perennial plots, respectively ($P = 0.004$). Thus, the procedure of mowing, tilling and re-shaping beds immediately after fruit harvest in the annual plots either led to high mortality in the root weevil adults and eggs (Shanks and Finnigan, 1973) and/or deprived the surviving adults of a food source during their ovipositing season (Collins and Fisher, 1993). The surviving adults may have moved to the perennial plots which, although renovated, developed a new leaf canopy relatively quickly compared to the replanted annual plots. The adults apparently did not return to the annual plots which had significantly lower larval counts the following spring. Yield was particularly low in the third year perennial plots (Table 1) due to the presence of root weevils and perhaps damage from cold injury the previous winter (data not shown).

Percent fruit rot was significantly affected by production system in 1995 when the annual plots had 8% rot compared to 28% in the perennial plantings. Leaf mowing post-harvest, as was done in the perennial plots, has been shown to reduce the severity of gray mold fruit rot in the following season (Sutton *et al.*, 1988). Fruit rot may have been significantly less in the annual plots due to the destruction or incorporation of leaves when tilling (in the perennial plots leaves were left between rows) or due to the more open leaf canopy and thus better air circulation. Percent fruit rot did not differ among annual and perennial plots in 1996 when spring weather increased fruit rot in all plots relative to 1995 (Table 1).

Although cumulative yield did not differ significantly among the annual and perennial production systems over the three harvest years (73.5 and 69.0 tonnes per hectare for annual and perennial, respectively), growers would probably not have harvested the third year perennial plots due to low yield (1.3 t/ha) and small fruit size (3.3 grams). In 1996, pickers harvested the first two pickings of the perennial plots at about half the rate and at a $604.57 higher cost per tonne (on average) as compared to the annual plots (Table 2). The annual plots also did not yield at their full potential due to winter injury; this was evidenced by the fewer number of plants and crowns per meter of row in 1996 as compared to 1995 (data not shown).

Conclusions

Late annual planting where strawberries follow strawberries without pre-plant fumigation looks promising when compared to perennial plantings of 'Redcrest'. Planting density had little effect on yield in this study. Yields of annual plantings were similar or higher than second and third year perennial plantings, respectively. Fruit mass was 39% to almost 300% larger in annual plantings. Harvest rate was greater due to larger fruit size and perhaps a more open canopy as compared to perennial plots. Thus, harvest costs per tonne of fruit were reduced in annual plots. A cost study to determine whether the reduced harvest costs and anticipated reduced pesticide requirements would offset the higher establishment cősts, has not yet been completed.

The benefits of annual production on pests, even without pre-plant fumigation, looked promising with a reduction in fruit rot in one of two years and a reduced incidence of root weevil larvae in annual plots.

Annual production for a processing market may be particularly suited for 'Redcrest', that is susceptible to pests and tends to produce only one good fruiting season.

The effect of planting date in systems with or without fumigation needs to be further studied in temperate climates.

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Table 1. Effect of annual and perennial production systems on 'Redcrest' strawberry grown in Aurora, Ore., 1994-1996.

Production system	Yield (t/ha)	Fruit mass (g) Early	Mid	Late	Average	Rot %	Picking time/plot (min.) 1st Harvest	2nd Harvest
1994								
38cm double matted row	45.1 b[y]	19.3	16.7	14.3	16.9	14.6	5.3 ab	9.8
20cm triple-hill	52.8 a	20.8	17.6	15.5	18.1	14.4	5.9 a	9.7
20cm double-hill	49.2 ab	21.3	16.9	14.9	17.8	19.2	4.7 b	10.6
Sig.[z]	*	NS	NS	NS	NS	NS	**	NS
Annual[x]	48.1	20.1	16.7	15.2	17.4	15.9	5.1	10.1
Perennial (first year)	50.1	20.8	17.5	14.6	17.8	16.3	5.6	9.9
Sig.	NS	NS	NS	NS	NS	NS	NS	NS
1995								
38cm double matted row	15.0	11.3	11.2	8.4 b	10.7 b	16.9	11.6	7.7
20cm triple-hill	17.3	11.9	11.7	9.8 a	11.4 a	18.6	12.5	8.9
20cm double-hill	17.5	11.8	10.9	9.1 ab	10.9 ab	17.8	11.9	11.6
Sig.	NS	NS	NS	**	*	NS	NS	NS
Annual	15.5	13.9 a	13.1 a	12.0 a	13.2 a	7.8 a	9.9	5.9 a
Perennial (second year)	17.7	9.4 b	9.4 b	6.1 b	8.8 b	27.7 b	13.5	12.8 b
Sig.	NS	**	**	**	***	**	NS	**
1996								
38cm double matted row	6.9	7.7	6.6	4.6	6.2	14.5	0.8	0.9
20cm triple-hill	5.8	7.7	7.6	5.1	6.7	14.9	0.9	1.2
20cm double-hill	4.5	7.4	6.9	4.8	6.3	15.3	1.1	1.7
Sig.	NS	NS	NS	NS	NS	NS	NS	NS
Annual	10.3 a	11.1 a	10.6 a	7.1 a	9.5 a	14.6	1.2 a	1.5 a
Perennial (third year)	1.3 b	4.1 b	3.4 b	2.6 b	3.3 b	15.2	0.7 b	0.9 b
Sig.	*	***	***	**	***	NS	*	**

[z] NS, *, **, *** = nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively, as determined by analysis of variance.
[y] Means followed by the same letter are not significantly different (protected LSD, $P = 0.05$).
[x] Annual plots established April, 1993, 14 July, 1994, and 6 July, 1995 for harvest in 1994, 1995, and 1996, respectively.

Table 2. Effect of production systems on harvest parameters of 'Redcrest' strawberry, 1994-1996.

Treatment	Harvest rate[z]		Harvest costs[y]	
	$kg \cdot hr^{-1}$ 1	$kg \cdot hr^{-1}$ 2	$/tonne 1	$/tonne 2
1994				
38cm double matted row	53.2	24.6 b[w]	104.76	229.31 a
20cm triple-hill	51.5	30.1 a	107.76	199.83 b
20cm double-hill	59.4	25.6 b	100.29	215.32 a
Sig.[x]	NS	**	NS	*
1995				
38cm double matted row	10.7	13.6	522.68	424.75
20cm triple-hill	10.4	16.6	543.72	431.30
20cm double-hill	10.4	12.2	537.16	515.80
Sig.	NS	NS	NS	NS
Annual[v]	9.8	17.7	564.91 a	327.66 b
Perennial (second year)	11.0	10.5	511.73 b	586.92 a
Sig.	NS	NS	*	*
1996				
38cm double matted row	8.6	11.3 a	802.45	535.37 b
20cm triple-hill	9.6	13.1 a	561.33	641.19 b
20cm double-hill	9.3	8.8 b	760.21	1306.25 a
Sig.	NS	**	NS	**
Annual	12.2 a	14.2 a	530.51 b	415.25 b
Perennial (third year)	6.2 b	7.9 b	914.97 a	1239.92 a
Sig.	**	*	*	*

[z] Yield of fruit (kg) picked in an hour by one person on first and second harvests.

[y] Cost to harvest a metric tonne of fruit for first and second harvest. Based on a wage of $5.50/hour.

[x] NS, *, **, *** = nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively, as determined by analysis of variance.

[w] Means followed by the same letter are not significantly different (protected LSD, $P = 0.05$).

[v] Annual plots established 14 July, 1994, and 6 July, 1995 for harvest in 1995 and 1996, respectively.

Table 3. Effect of production systems on yield components of annual and perennial 'Redcrest' strawberry, 1995 and 1996.

Production system	Plants/meter	Crowns/meter	Crown/diameter (mm)
1995			
38cm double matted row	30.1 a[y]	68.0	10.4
20cm triple-hill	12.0 b	66.3	11.1
20cm double-hill	19.6 b	71.6	10.0
Sig.[z]	0.0011	NS	NS
Annual	16.6	38.6 b	11.4
Perennial (second year)	24.6	98.7 a	9.5
Sig.	NS	0.0008	NS
1996			
38cm double matted row	5.0	15.9	10.3
20cm triple-hill	3.9	13.3	10.8
20cm double-hill	5.0	21.9	9.4
Sig.	NS	NS	NS
Annual	4.7	18.9	11.1
Perennial (third year)	4.6	15.1	9.3
Sig.	NS	NS	NS

[z] P value or indication of nonsignificance (NS) as determined by analysis of variance.

[y] Means followed by the same letter are not significantly different (protected LSD, $P \geq 0.05$).