Table 3. Variation Among Years in Growth Characteristics of Red Raspberry Plants Trained in Woven System

Year	Canes ft²	Cane diameter[z] (in)	Inter-node length[y] (in)	Percent-age of bud break[x]	Buds/2 ft cane mid section	Fruits/ lateral
standard (10 ft between-row) spacing						
1982	.44	.34	2.04	55	11.6	8.3
1983	.24	.27	2.46	65	9.6	12.3
1984	.40	.36	3.19	75	7.4	13.8
1985	.42	.36	3.75	87	6.3	15.4
avg.	.38	.33	2.86	70	8.7	12.5
modified (alternate 10 ft and 5 ft between-row) spacing						
1982	.60	.33	2.15	68	11.0	7.3
1983	.28	.24	2.27	56	10.4	11.0
1984	.51	.33	3.11	62	7.6	15.8
1985	.56	.37	3.87	84	6.1	15.6
avg.	.49	.32	2.86	68	8.8	12.4

[z]Measured at 3 ft above soil surface.
[y]Between 18 and 42 in above soil surface.
[x]Buds between 18 and 42 in above soil surface that grew and developed fruiting laterals.

56 percent were oriented toward the wide (10-foot) between row space. The laterals that were oriented toward the narrow row space averaged fewer fruits (9.5) than the laterals that were oriented toward the wide row space (11.5).

Failure of buds to break and produce fruiting laterals in woven plots in both the standard and modified plantings averaged 69 percent over a 4-year period, indicating a loss of nearly one-third the crop potential (Table 3). Budbreak was recorded in all training systems in 1984 and 1985, but was not affected by training method (data not shown). Cane population density and budbreak were not correlated.

Annual plant measurements illustrate interaction and compensation among yield components. As internodes (the distance between buds) increased over the life of the planting, 1982 to 1985, percentage budbreak and fruits/lateral increased also (Table 3), but yield generally decreased (Table 1).

Training method did not affect the amount of fruit lost between harvests (Table 4). Losses averaged 22 percent of the total yield in the standard planting and 21 percent of the total yield in the modified planting in 1984. The losses approximate the loss of 25 percent reported by Cormack and Waister in Scotland, but are probably greater than those of Pacific Northwest growers who are not hampered by the inefficiencies of operating the mechanical harvester in small plots.

Again in 1985, harvest losses were unaffected by the training system (Table 4), but total percentage loss was greater in both plantings: 29 percent in the standard planting and 23 percent in the modified planting. In the standard planting, 43 percent of the loss occurred between harvests rather than in harvesting. In the modified planting, 34 percent of the loss occurred between harvests rather than in harvesting. The need to accommodate harvest to available labor (Monday through Friday, 8 a.m. to 5 p.m.) accounts for much of the loss between harvests.

The trials demonstrated that the Littau harvester can operate effectively in a high-density planting, but yield increases were neither consistent nor proportionate to the increased number of plants. High-density planting requires additional initial investments in plants, posts, and wires and additional recurring costs for labor. Even considering fluctuations in berry price and unit production costs, it appears unlikely that the modest gains in yield that are possible can offset the one-third greater cost of materials and labor.

Table 4. Red Raspberry Fruit Gleaned[z] from Ground Before and After Mechanical Harvesting

Training system	1984 postharvest lb	1984 postharvest %[y]	1985 preharvest lb	1985 preharvest %[y]	1985 postharvest lb	1985 postharvest %[y]
standard (10 ft between-row) spacing						
Upright	.40	23.6	.17	13.7	.23	18.2
Woven	.31	22.2	.15	12.0	.20	16.0
Looped	.34	20.4	.13	12.2	.18	16.5
significance[x]	NS	NS	NS	NS	NS	NS
modified (alternate 10 ft and 5 ft between-row) spacing						
Upright	.40	22.2	.86	7.8	.18	16.1
Woven	.31	20.7	.90	8.3	.16	15.2
Looped	.35	19.2	.81	7.0	.16	13.4
significance[x]	NS	NS	NS	NS	NS	NS

[z]Berries were picked from the ground immediately before harvesting and immediately after harvesting.
[y]Percentage of sum of mechanically harvested and gleaned fruit.
[x]Nonsignificant (NS) at 5% level.

The Effect of Cane Population Density and Training System in Mechanically Harvested Red Raspberry

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ABSTRACT

Red raspberry *(Rubus idaeus L.)* cv Meeker was grown with either 10-foot or alternate 10-foot and 5-foot between-row spacing. Canes were trained as 1) pruned upright bundles, 2) pruned and individually woven canes, or 3) unpruned looped bundles, all secured to wires 5 feet high. Training did not consistently affect yield as obtained with a Littau mechanical harvester. Fruit size was smallest in the unpruned bundles. Fruit that dropped to the ground in the interval between harvests and fruit that dropped during harvests were gleaned and weighed, but the amount of fruit drop had no relationship to row spacing or training system.

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The 2 to 2.5 T/A average annual yield of red raspberries in Oregon is below the actual crop potential. Researchers and growers have experimented with training systems, pruning techniques, and soil fertility and studied the effects of such treatments on cane population density and cane characteristics and their relationship to yield. Many factors contribute to variations in yield, often compensating for each other. The characteristics which consistently and predictably relate to yield have not been identified. Most work with yield components (individual characteristics that contribute to yield) has been done in hand-harvested raspberries.

This study was undertaken to determine the effects of three training systems on raspberry plant characteristics and yield in mechanically harvested plantings with traditional row spacing and modified row spacing. High-density planting has been suggested as an approach to increasing raspberry yields in mechanically harvested fields, but has not been tested. The modified planting, with rows alternately spaced 5 feet and 10 feet apart, contained 33 percent more plants and allowed testing of high-density planting.

Materials and Methods

The red raspberry (*Rubus idaeus* L.) cv Meeker was established in two adjacent plantings at North Willamette Experiment Station, Aurora, OR, in 1980. One planting had 10-foot spacing between rows (standard); the second had alternate spacing of 5 feet and 10 feet between rows (modified). Each plot within each planting consisted of a hedge row 100 feet long. The modified planting required 33 percent more rows than the standard planting. A Littau mechanical harvester was operated in the 10-foot between-row spaces.

Within each planting, three training systems were compared: 1) upright bundles pruned to 6 feet, 2) individually woven canes pruned to 6 feet, and 3) looped bundles of canes 6 to 8 feet. All canes, individual or bundled, were secured to a wire 5 feet from the ground. Plots were replicated 4 times in 1982 and 1983 and 3 times in 1984 and 1985 in each planting, standard and modified.

In addition to yield and berry size recorded for all treatment combinations, cane number/plot and diameter (10 canes/plot), bud number/2-foot cane midsection (10 canes/per plot), fruiting laterals/2-foot midsection (10 canes/plot), and berries/lateral (1 midsection lateral/each of 10 canes/plot) were recorded in 1982 and 1983 for the woven training system. In 1984 and 1985, data were taken on all three training systems. In 1984, 16-foot sections of each plot were gleaned for dropped fruit after each harvest. In 1985, dropped fruit was gleaned immediately before harvest and immediately after harvest to identify loss occurring in the interval between harvests and loss during harvest.

Harvest data and cane measurements were subjected to two-way analysis of variance in comparisons of training methods. Duncan's multiple-range test was applied for LSD's. Correlation coefficients (r values) were calculated for identifying relationships between harvest data and cane characteristics.

Because the two row spacings actually constituted independent experiments, the yields and cane numbers from the standard and modified plantings were compared using a paired t-test each year. Comparisons of yield and cane number in standard and modified plantings were confounded by root rot in one replicate in 1982 and 1983. In 1984 and 1985, the infested replicate was not used.

Results and Discussion

Training method did not affect mechanically harvested yield in the modified planting (Table 1). In the standard planting, no differences in yield were attributable to training method in 1982, 1983, or 1985; however, in 1984, significant yield differences occurred. In 1984, upright bundles produced the highest yields and individually woven canes the lowest yields. Berry size differences in both the standard and modified plantings were usually attributed to small berries from looped bundles (Table 1). The small berries in terminal clusters of unpruned canes in the looped bundle system apparently reduced the average berry size in this treatment. Small berry size is of practical importance in hand-harvested fields, but of little importance in mechanically harvested fields.

When cane population density proved significant in either planting, woven plots had fewest canes and upright bundles had most canes (Table 1). Cane population of trained canes was the factor most consistently associated with yield (Table 2). The unexpectedly poor production of woven plots with evenly spaced canes with buds well-exposed is attributed to the plots' having fewer trainable canes for a given area than other plots (Table 1). All canes too short to reach the training wire or too delicate to support an adjacent cane were removed at training. The upright bundle training system allowed for the retention of marginally acceptable canes since even the smallest canes not long enough for looping could be secured in a bundle with other canes.

The onset of root rot in 1982 and continuation in 1983 contributed to the nonsignificance of yield differences in the two plantings when yields were subjected to a t-test (Table 2). When the infested area was discontinued in 1984, yield was significantly higher in the modified row planting. The greater yield in the modified planting in 1985 was not significant.

The reduction in available light and plant competition for water and nutrients, in part, may explain the failure of the modified row spacing to increase yield in proportion to the increase in plant population. At a cane height of 2.5 feet, 43 percent of the laterals were oriented toward the narrow (5-foot) between row space and

Table 2. Effect of Row Spacing on Cane Population Density[z] and Yield[z] of 'Meeker' Red Raspberry

Row spacing	*Canes/ft²*				*Yield (lb/ft²)*			
	1982	*1983*	*1984*	*1985*	*1982*	*1983*	*1984*	*1985*
Standard[y]	.51	.32	.49	.43	.162	.094	.110	.079
Modified[x]	.74	.33	.58	.54	.174	.174	.124	.082
	**	NS	*	**	NS	NS	**	NS

[z]Values are combined average of all training systems.
[y]10 ft between rows.
[x]Alternate 10 ft and 5 ft between rows.
NS, *, ** Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels in paired t-test.

Table 1. Relationship of Training and Row Spacing of Red Raspberries to Mechanically Harvested Fruit Yield and Cane Population

Training System	*Yield (lb/ft²)*				*Berry size (g/berry)*				*Canes/ft²*			
	1982	*1983*	*1984*	*1985*	*1982*	*1983*	*1984*	*1985*	*1982*	*1983*	*1984*	*1985*
standard (10 ft between-row) spacing												
Upright	.166	.098	.119	.082	2.8	3.0	3.0	2.6	.56	.38	.58	.46
Woven	.156	.093	.100	.082	2.8	3.0	2.9	2.5	.44	.24	.40	.42
Looped	.158	.091	.111	.073	2.6	2.9	2.8	2.4	.54	.32	.51	.39
significance[z]	NS	NS	*	NS	*	NS	*	**	NS	**	**	NS
LSD	......	......	.008	......	0.11	......	0.07	0.12	......	.05	.06	......
modified (alternate 10 ft and 5 ft between-row) spacing												
Upright	.182	.100	.130	.078	2.6	2.8	2.9	2.6	.82	.42	.67	.57
Woven	.164	.077	.110	.082	2.7	2.8	2.9	2.4	.60	.28	.51	.56
Looped	.176	.084	.132	.084	2.5	2.7	2.8	2.4	.81	.31	.58	.49
significance[z]	NS	NS	NS	NS	**	NS	NS	*	*	*	*	NS
LSD	......	......	......	......	0.09	......	......	0.08	.11	.06	.06	......

[z]Nonsignificant (NS) or significant at 5% (*) or 1% (**) levels.