Effects of Cane Number on Yield Components in 'Chester Thornless' Blackberry on the Rotatable Cross-Arm Trellis

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Abstract. Mature 'Chester Thornless' blackberry plants were trained to the rotatable cross-arm (RCA) trellis to determine the effect of retaining two, four, or six primocanes on plant productivity. Retention of only the two oldest primocanes and generally the most vigorous primocanes per plant yielded 14.1 kg of fruit compared to 17.1 kg per plant in which as many as six primocanes were retained. Increasing the number of canes did not result in significant yield increase ($P = 0.09$) because the primocanes trained in late-June and July produced only a few, and, in some cases, no lateral branches. Thus, retaining only those canes that become trainable early in the season decreased labor inputs and allowed primocane training to be completed prior to the onset of harvest. As a result, the effort to train and retain only those primocanes that reach the trainable height before mid-June may be advantageous to minimize labor costs, but will not effect plant productivity.

Several eastern thornless blackberry (*Rubus* subgenus *Rubus* Watson) cultivars have been evaluated at the Appalachian Fruit Research Station on a number of trellis systems with wide static configurations of "V"-, "T"-, and "Y"-shaped canopies for machine harvesting (Peterson et al., 1992; Takeda and Peterson, 1999). Mechanically harvested yields of fresh market quality fruit from the eastern thornless blackberries trained to these static trellises were less than 50% (Peterson et al., 1992).

We developed a modified "Y"-shaped trellis with a rotatable cross-arm (RCA) and primocane training techniques to maximize yield and improve mechanical harvestability while minimizing labor in the production of eastern thornless blackberries (Peterson and Takeda, 2003). A detailed description is provided elsewhere for trellis components and primocane training practices for the RCA trellis system (Takeda and Peterson, 1999; Takeda et al., 2003). Our technique of training primocanes onto the RCA trellis system forces them to grow horizontally in the direction the mechanical harvester travels once they reach a height of ≈1.2 m. Orienting primocanes to grow horizontally promotes the development of lateral branches from the portions tied to the training wires. The bending of the main canes also facilitates the rotation of the cross-arm without causing main cane breakage. Improved knowledge of the relationship between node number distribution and yield will help determine the best pruning method.

The blackberry has a clearly defined growth cycle (Carew et al., 2000; Moore and Skirvin, 1990). In biennial-fruiting cultivars such as the one investigated here, vegetative cane (primocane) growth occurs in the first year. Primocanes grow in length and buds develop in the leaf axils. A number of these axillary buds develop into lateral branches. The primocane typically exhibits strong apical dominance. Lateral branching is promoted either by removal of distal portions (topping) (Strik, 1992) or bending of primocanes (Takeda and Peterson, 1999). In temperate regions, shoot extension growth diminishes in late summer or fall and an irreversible process termed "flower induction" occurs in the axillary buds, whereby some parts of the meristem are programmed to form flowers (Bernier et al., 1981). As a result, the apical meristem become reproductive and inflorescence axis and flower buds develop (Takeda and Wisniewski, 1989; Takeda et al., 2003). Canes lose their capacity for further extension growth at this point and they overwinter as dormant canes. When growth resumes in the spring, the canes produce flowers and become floricanes. Flower shoots emerge from axillary buds on main and lateral branches of floricanes. The flowering shoots elongate, first with leaves and eventually terminate in a racemose inflorescence, that is comprised of one primary flower/fruit and as many as 7–15 secondary, 5–15 tertiary, and similar numbers of quaternary flowers/fruit (Takeda, 1987).

The studies described herein determined the effect of primocane number trained to the RCA trellis system on the vegetative and reproductive capacity of 'Chester Thornless' blackberry.

Materials and Methods

Plot description. 'Chester Thornless' eastern thornless blackberry plants were established in a replicated block (0.4 ha) of eastern thornless blackberries established at the Appalachian Fruit Research Station, Kearneysville, W.Va. (39°N lat., elev. 158 m), in 1991 using tissue-cultured, nursery matured transplants on a Hagerstown silt loam soil (fine, mixed, Typic Hapludalf). The ground had a ≈3% grade. Plants were set in rows oriented in a north–south direction more or less following the slope at a 1.3 × 4-m spacing. Plants were trained to a rotatable cross-arm (RCA) trellis (Takeda and Peterson, 1999). Plot maintenance and pest control followed the published bramble production guidelines for the region (Demchak, 2000). Plants received annual fertilizer applications (kg·ha⁻¹) of 45N–19.6P–37.4K in April and supplemental drip irrigation when required in June, July, and August.

Effect of primocane number on yield: In 1998, 24 four-plant plots were randomly selected for a cane management study. Treatments consisted of retaining two, four, or six primocanes per plant for training onto the RCA trellis, resulting in 8 four-plant replications per treatment. In 1999, the same cane management treatments were repeated again on the 24 four-plant plots. Vegetative growth measurements were recorded in summer and fall of both 1998 and 1999 as previously described (Takeda et al., 2003) and included counts of actual numbers of primocanes that developed on each plant.

Reproductive parameters were measured in the year following training (1999 and 2000). In 1999, the plots were machine harvested with a U.S. Dept. of Agriculture (USDA) bramble harvester twice weekly after the primary fruit were mature (Peterson and Takeda, 2003). In the spring of 2000, a range of winter injury and cane dieback was observed among plants in the block, ranging from little or no injury in plots located at the highest point of the block to more severe injury at the low end of the plot. For this reason, reproductive measurements in 2000 were obtained from two healthy replicates of each treatment located where winter injury was minimal. Flower data were collected in spring of 1999 and 2000. Three inflorescences from each of these floricanes within the basal 0.9 m of lateral branches trained to the trellis wires were selected and the primary (1°), secondary (2°), tertiary (3°), and quaternary (4°) flowers in each inflorescence were counted (Takeda, 1987). All mature, black-colored 1°, 2°, 3°, and 4° fruit were hand-harvested twice weekly from 13 July to 5 Sept. 2000, counted, and weighed to determine the total and mean fruit weight for each week throughout the season.

Statistical design and analysis. The experiments were conducted using a randomized complete-block experimental design

with 8 four-plant replications in 1999 and 2 four-plant replications in 2000. Percentage data were transformed to square root-arcsin prior to statistical analysis. Reproductive data were subjected to PROC GLM and vegetative data were subjected to PROC MIXED (SAS Institute, Cary, N.C.). Statistical significance was evaluated at $P \leq 0.05$.

Results and Discussion

In both years, primocanes began to emerge from the ground in mid-April. Cane tying and training onto the RCA trellis system began in mid-May and continued until late July. Once primocane extension growth was oriented in a horizontal direction, lateral branch emergence occurred first near the bend.

The effects of restricting the number of primocanes trained onto the RCA trellis in 1998 to two, four, or six per plant on vegetative growth are presented in Table 1. Two primocanes were trained in 100% of plants in plots designated for two-cane retention. However, not all plants in plots assigned for four- and six-primocane retention treatments developed the designated number of primocanes. In 1998, the actual numbers of primocanes trained in four- and six-primocane plots averaged 3.7 and 4.6 primocanes per plant, respectively, or only 70% and 35% of plants developed the designated numbers (4 or 6) of primocanes. Although the numbers of lateral branches per plant increased as more primocanes were retained, the number of long and medium length lateral branches per plant was similar regardless of the number of primocanes retained (data not presented). The primocanes on two-primocane plants were trained early in the season and they developed as many as 10 long- and medium-length lateral branches (57% of the primocane nodes above the bend had laterals) and each lateral branch averaged 25 to 40-plus nodes, while the younger primocanes (e.g., fourth to sixth primocanes trained later in the summer) retained in four- and six-primocane plants developed only a few or no long- and medium-length lateral branches (<40% of the primocane node above the bend had laterals). The oldest primocane produced a total lateral branch node number of about 288, while the sixth primocane developed only 108 (Takeda et al., 2003).

The following spring in 1999, parameters related to reproductive potential were collected for plants pruned to two, four, or six floricanes (Table 2). The inflorescence numbers per plant ranged from 229 for plants in two-cane reten-

tion plots to 294 for plants in six-cane retention plots. Attempts to triple the number of primocanes retained to six per plant increased flowering shoot (raceme) number per plant by only 28%. The size of inflorescences on plants with 2, 4, and 6 floricanes varied. The inflorescences on plants with two floricanes were longer and possessed more secondary, tertiary, and quaternary flowers (Table 2). The total flower numbers per inflorescence averaged 23 on plants with two floricanes, but only 16 flowers (26% less) per inflorescence on plants pruned to six primocanes cane retention. Inflorescences on plants with six primocanes tended to have fewer tertiary flowers. This suggests that the potential increase in productivity in 'Chester Thornless' plants by retaining more primocanes on the RCA trellis would be small, because late-emerging primocanes develop fewer lateral branches on the main canes and their inflorescences possess fewer flowers.

When the plants were machine harvested twice a week with the USDA bramble harvester, plant yields, which took into account the dropped fruit between harvests and yield loss due to the detachment of immature fruit, ranged from 8.7 kg per plant with two floricanes to 10.3 kg per plant with four to six floricanes (data not presented). Mean fruit weight of samples comprised of primary, secondary, tertiary, and quaternary fruit was 6.6 g across the three cane retention treatments. In summary, plants with two floricanes had fewer nodes and inflorescences, more flowers per inflorescence, and similar fruit weight compared to plants with four or six floricanes. Based on the results from the 1998–99 season, only those primocanes that become trainable early in the season should be retained for 'Chester Thornless' plants on the RCA trellis system. Canes that emerge early and become trainable in May and early June have greater capacity for higher axillary bud breaks, greater lateral branch extension growth, and larger inflorescences than primocanes that become trainable much later in the season.

In 2000, the actual numbers of floricanes trained were 1.8, 3.6, and 5.6 per plant designated for retention of 2-, 4-, and 6-primocanes, respectively. The range of cane diameters and

number of lateral branches on these plants was quite similar to that recorded in 1998 (data not presented). Lateral branch numbers per plant increased by about 50% from 21 to 32 when the numbers of primocanes retained were tripled from 1.8 to 5.6 per plant. However, plants at all levels of cane retention developed about 17 lateral branches in the long- and medium-length categories. Based on the number of axillary buds (≈18 nodes for each primocane) on the horizontal portion of primocanes, the percentage of buds that developed a lateral branch was 58%, 33%, and 30% for three levels of cane retention. We estimated that plants designated for retention of 2, 4, and 6 floricanes possessed ≈525, 600, and 800 axillary buds on their lateral branches, respectively.

In 2000, reproductive data were collected from only two replicates of each treatment. As a result, the statistical analysis of the data collected in the 2000 season was not performed with a high degree of precision due to low replication numbers. The plants with 2.0, 3.9, and 5.6 floricanes developed 150, 186, and 217 flowering shoots on lateral branches, respectively (Table 3). Based on the estimated total number of axillary buds on lateral branches, flowering shoots developed from about 29% of axillary buds. These values were somewhat less than the range of percent budbreak reported in 1999. Flower numbers averaged 21, 16, and 18 per inflorescence on 2.0, 3.9, and 5.6-floricane plots, respectively. Larger inflorescences on 2.0-floricane plants resulted from increased numbers of tertiary flowers. The number of secondary flowers was constant at ten flowers per raceme across the pruning treatments.

In summer 2000, plants were hand harvested twice a week from 13 July to 5 Sept. (Fig. 1A). No significant differences in plant yields due to cane retention treatment were detected ($P = 0.09$). About 14 kg of mature fruit were harvested from plants with 2.0 or 3.9 floricanes during an 8-week harvest season. Plants with 5.6 floricanes produced 17 kg of fruit. The primary fruit ripened during the initial 5 weeks of harvest (Fig. 1A) and combined to produce 1 to 1.3 kg per plant or 8% of total yield. The secondary fruit was harvested over

Table 1. Effect of primocane retention treatments on vegetative growth and development of 'Chester Thornless' blackberry, 1998.

No. primocanes[z]	No. lateral branches per plant
2.0	17 a[y]
3.7	20 ab
4.6	28 b

[z]Actual number of primocanes trained on each plant.
[y]Mean separation within columns by Duncan's multiple range test, $P < 0.05$.

Table 2. Effect of 1998 primocane cane retention treatments on reproductive development of 'Chester Thornless' blackberry in 1999.

No. primocanes	No. nodes	No. racemes	Budbreak (%)	No. flowers/inflorescence 1°	2°	3°	4°	Total
2.0	677 a[z]	229 a	33	1.0	10.1 a	9.6 a	2.5 a	23.2 a
3.7	697 a	244 a	35	1.0	9.1 b	6.5 b	0.9 b	17.5 b
4.6	913 b	294 b	32	1.0	8.8 b	5.5 b	0.7 b	16.0 b

[z]Mean separation within columns by Duncan's multiple range test, $P < 0.05$.

Table 3. The results of primocane retention treatments in 1999 on number of racemes per plant and raceme size in 2000.

No. primocanes	No. racemes	No. flowers/raceme[z] 1°	2°	3°	4°	Total
2.0	150 c[y]	1 a	10 a	9 a	<1 a	21 a
3.9	186 b	1 a	10 a	5 b	<1 a	16 b
5.6	217 a	1 a	10 a	6 b	<1 a	18 b

[z]Determined by counting primary, secondary, tertiary, and quaternary flowers from six to 18 inflorescences per plant.
[y]Mean separation within columns by Duncan's multiple range test, $P \leq 0.05$.
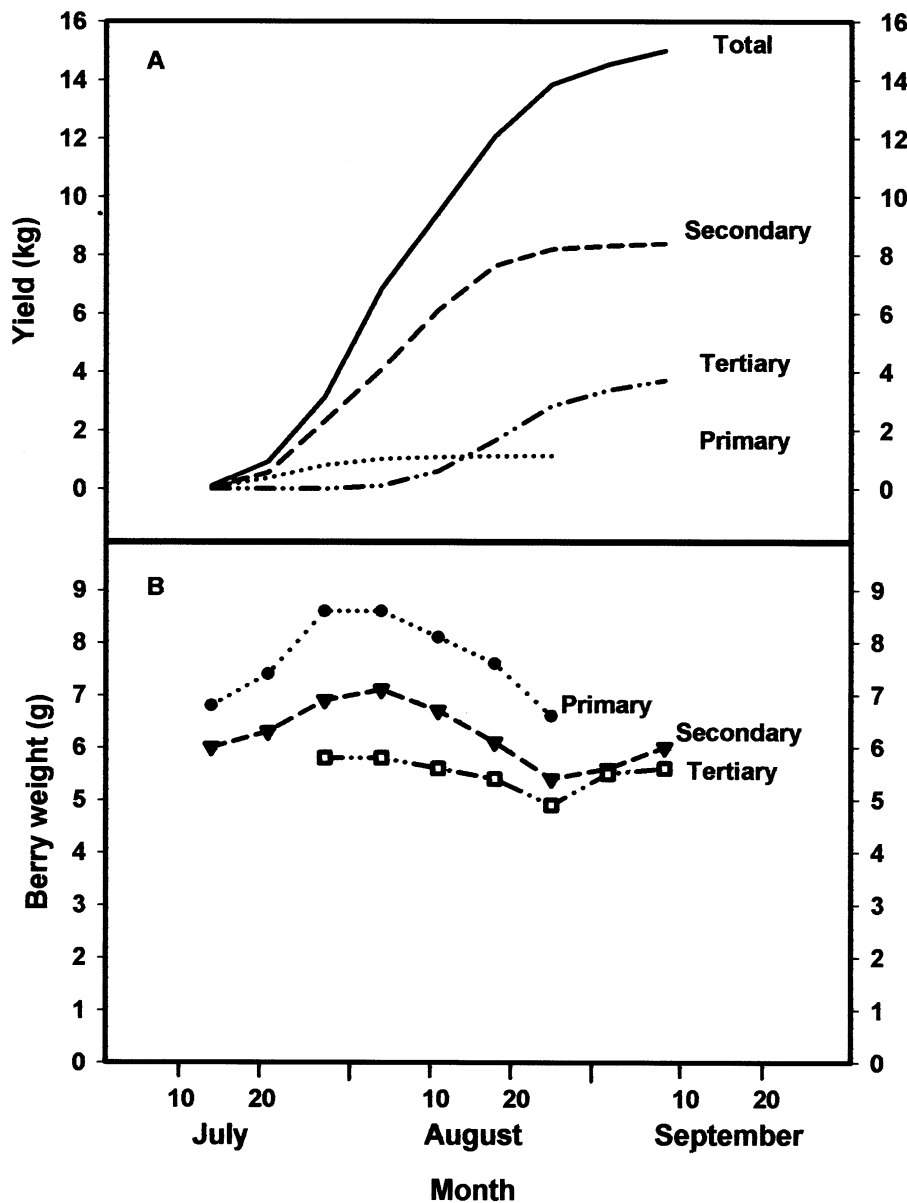
Fig. 1. (**A**) Cumulative hand-harvest yields and (**B**) weekly average weights of primary, secondary, and tertiary fruits of 'Chester Thornless' blackberry plants in the 2000 season.

the entire 8-week harvest period, with the peak harvests occurring about 4 Aug. (Fig. 1A). Over the season, the yield of the secondary fruit was about 10 kg per plant or comprised about 67% of the total yield for all three treatments. Tertiary fruit did not mature until early August. Peak harvests of tertiary fruit occurred in late August and they comprised ≈25% of total harvests (Fig. 1A). The contribution of quaternary fruit towards plant yield was negligible (data not presented). For the season, mean fruit weight of primary, secondary, and tertiary fruit was 8, 6, and 5 g, respectively (Fig. 1B). Fruit harvested from plants limited to two floricanes tended to be larger (≈0.5 g/fruit). These differences were significant for primary fruit harvested during the first two weeks of the harvest (data not presented). The size of both primary and secondary fruit increased slightly over the first 4 weeks and gradually declined, while the size of

tertiary fruit remained relatively constant over the second half of harvest (Fig. 1B).

In this study, growth parameters that would contribute to the productivity of blackberry plants trained to the RCA trellis were determined. Our results from both 1998–99 and 1999–2000 season suggest that in 'Chester Thornless' blackberry trained on the RCA trellis system, number of lateral branches per plant appears to be an important determinant of plant performance. Previously, Takeda (2002) reported that sufficient growth and development of lateral branches from the main primocanes were necessary to attain high plant productivity in 'Black Satin'.

Different cane management techniques are used to develop divided canopies (Crandall and Daubeny, 1990; Goulart and Demchak, 1993; Stiles, 1999; Swartz et al., 1984; Takeda, 2002; Takeda and Peterson, 1999), in order

to increase fruit production and facilitate fruit harvest. The results of these studies indicate that improved light conditions for primocanes achieved by divided canopies or an alternate-year production system promotes axillary branching. It is also apparent that the bending of primocanes to force their growth in a horizontal direction negated the apical control by the shoot tip over the axillary buds in more proximal positions (Takeda et al., 2003). Such cane manipulation significantly improved the development of lateral branches in eastern thornless blackberries. The average number of flowers or fruit per cluster (raceme) decreased when more floricanes were retained. Also, there was a trend for smaller fruit size when more racemes developed on the plant, a condition associated with a larger number of floricanes per plant.

The results of this study indicated that plants with two floricanes had fewer nodes and produced fewer racemes compared to plants with five to six floricanes (Table 3). However, all plants with a few primocanes produced larger racemes and slightly larger fruit. As a result, plants with only two primocanes yielded as much as 82% of yield obtained from plants in which as many as six floricanes were retained. Despite the slight reduction in productivity, retention of only two or three primocanes on each plant can potentially reduce labor costs for summer cane training and tying by 50%, from the estimated 240 h·ha^{-1} for training a full compliment of six primocanes (Harper et al., 1999) to 120 h·ha^{-1}. Retention of only two or three primocanes means that only those primocanes emerging from the crown by early May require tying and cane training can be completed by late June, prior to fruit harvesting. Primocanes that subsequently emerge from the crown may be suckered when they are still short and succulent. Alternatively, they may remain but would not be trained and tied to the trellis.

One of the difficulties in managing the eastern thornless blackberries is the need for high labor inputs during their long harvest duration and the necessity to harvest mature fruit at 2- or 3-d intervals. If up to six primocanes are retained, then the need for labor to train these additional primocanes will continue into July and August at the time when fruit is being harvested (Takeda et al., 2003). Blackberry cane management strategies that will not conflict with labor-intensive harvest operations and mitigate the scarcity of labor will improve crop economic viability. However, if labor were not scarce then it would be possible to continue cane training into the harvest season in order to retain more primocanes. Finally, it would be necessary to make a determination whether economical production is attainable for eastern thornless blackberries on the RCA trellis system and cane training technique. The evaluation will be based on cost estimates for commercial berry production (Harper, 2002; Harper et al., 1999), a sensitivity analysis for combinations of prices and the yields observed in this study, and modified budgets reflecting revised trellis design and labor requirements.

Literature Cited

Bernier, G., J. Kinet, and R.M. Sachs. 1981. The physiology of flowering. II. Transition to reproductive growth. CRC Press, Boca Raton, Fla.

Carew, J.G., T. Gillespie, J. White, H. Wainwright, R. Brennan, and N.H. Battey. 2000. The control of the annual growth cycle in raspberry. J. Hort. Sci. Biotechnol. 75:495–503.

Crandall, P.C. and H.A. Daubeny. 1990. Raspberry management, p. 157–213. In: G.J. Galletta and D.G. Himelrick (eds.). Small fruit crop management. Prentice Hall, Englewood Cliffs, N.J.

Demchak, K. 2000. Commercial berry production and pest management guide, 2000–2001. Pa. State Univ., Coll. Agr. Sci. AGRS 53.

Goulart, B.L. and K. Demchak. 1993. Physiological responses of "T", "V" and hedgerow trained red and black raspberries (*Rubus idaeus* L. and *R. occidentalis* L.). Acta Hort. 352:159–167.

Harper, J.K. 2002. Berry production budgets, p. 104–136. In: K. Demchak (ed.). Commercial berry production and pest management guide, 2002–04. Pa. State Univ., Coll. Agr. Sci. AGRS 53.

Harper, J.K., F. Takeda, and D.L. Peterson. 1999. Economic evaluation of improved mechanical harvesting system for eastern thornless blackberries. Appl. Eng. Agr. 15:597–603.

Moore, J.N. and R.M. Skirvin. 1990. Blackberry management. p. 214–244. In: G.J. Galletta and D.C. Himelrick (eds.). Small fruit crop management. Prentice-Hall Press, Englewood Cliffs, N.J.

Peterson, D.L. and F. Takeda. 2003. Feasibility of mechanically harvesting fresh market quality eastern thornless blackberry. Appl. Eng. Agr. 19:25–30.

Peterson, D.L., F. Takeda, and T. Kornecki. 1992. Harvester for "T", "V", and "Y" trellised eastern thornless blackberries. Appl. Eng. Agr. 8:9–12.

Stiles, H.D. 1999. Limited arm-rotation shift-trellis (LARS) and primocane management apparatus (PMA) for raspberries and blackberries (*Rubus* cvs. or crops). Virginia Agr. Expt. Sta. Bul. 99-1. Blacksburg.

Strik, B. 1992. Blackberry cultivars and production trends in the Pacific Northwest. Fruit Var. J. 46:202–206.

Swartz, H.J., S.E. Gray, L.W. Douglas, E. Durner, C.S. Walsh, and G.J. Galletta. 1984. The effect of divided canopy trellis design on thornless blackberry. HortScience 19:533–535.

Takeda, F. 1987. Some factors associated with fruit maturity range in cultivars of the semi-erect, tetraploid thornless blackberry. HortScience 22:405–408.

Takeda, F. 2002. Winter pruning affects yield components in 'Black Satin' eastern thornless blackberry. HortScience 37:101–103.

Takeda, F. and D.L. Peterson. 1999. Considerations for machine harvesting fresh-market eastern thornless blackberries: Trellis design, cane training systems, and mechanical harvester developments. HortTechnology 9:16–21.

Takeda, F., A.K. Hummell, and D.L. Peterson. 2003. Primocane growth in 'Chester Thornless' blackberry trained to the rotatable cross-arm trellis. HortScience 38:373–376.

Takeda, F. and M.E. Wisniewski. 1989. Organogenesis and pattern of floral bud development in two eastern thornless blackberry cultivars. J. Amer. Soc. Hort. Sci. 114:528–531.