AN ABSTRACT OF THE THESIS OF

Ellen Thompson for the degree of Master of Science in Horticulture presented on May 11, 2007.
Title: Primocane-fruiting Blackberries: The Effect of Summer-Pruning, Tipping, and Chilling on Primocane Morphology, Fruiting Season, and Yield.

Abstract approved

Bernadine C. Strik

The effect of primocane management on flowering and fruiting patterns was studied in primocane-fruiting blackberry (Rubus subgenus Rubus, Watson) cultivars ‘Prime-Jan®’ and ‘Prime-Jim®’ over two years. Primocanes that were “soft-tipped” (upper 2-5 cm removed) at 1.0 m were compared to un-tipped canes. In both years, soft-tipped primocanes developed 2-3 fold more branches and almost twice the number of flowers as un-tipped canes. ‘Prime-Jan’ and ‘Prime-Jim’ began blooming on the apices of branches of soft-tipped canes in mid-July, while un-tipped primocanes began to bloom on the apex in late July in 2005 and 2006. Within an inflorescence, the terminal or distal flower was always the first to open, followed by terminal flowers from axes located on the basal portion of the inflorescence. The blooming pattern within an inflorescence was similar for soft-tipped and un-tipped primocanes.

Primocane management treatments studied in the field were: 1) primocanes soft-tipped at 0.5 m, 2) primocanes soft-tipped once reaching 1.5 m, 3) primocanes re-cut (to crown) once reaching 0.5 m and subsequent primocanes left un-tipped, 4) inflorescence removed after first open bloom, and 5) primocanes soft-tipped at 1.0 m [control]. Primocane growth, flowering and yield were affected by treatment, but not cultivar. Cultivars responded similarly to management treatments. Primocanes that
were soft-tipped (0.5, 1.0, or 1.5 m) branched heavily just below the site of tipping and developed more branches than primocanes in treatments that were re-cut or had the inflorescence removed. Floral buds became visible on the apices of branches (tipped treatments) and primocanes (un-tipped treatment, prior to inflorescence removal) in late June and late July, respectively, in both years. Primocanes that grew after re-cutting developed floral buds in late July and early August, depending on year. Primocanes that were tipped to 0.5 m and 1.0 m consistently yielded the most fruit (7.8 and 8.8 t/ha, on average, respectively). Primocanes that grew after re-cutting or had the tip removed just after bloom yielded significantly less in both years.

The effect of chilling was studied in mature, potted plants of ‘Prime-Jan’ re-cut back to the crown using the following treatments: A) 0 CU [Chilling Units; 0 days of cold storage at ~2 ºC], B) 240 CU [10 days], C) 480 CU [20 days], or D) 720 CU [30 days]. Chilling, regardless of duration, resulted in earlier primocane emergence and longer branches on soft-tipped canes compared to those on un-chilled plants. Plants that received a minimum of 480 CU responded by producing primocanes with more reproductive nodes and a higher percentage of reproductive nodes than plants that received less chilling.

The impact of tipping and pruning on yield, fruit quality, and season extension was compared in tunnel- and field-grown ‘Prime-Jan’. Primocanes were managed under four treatments to promote branching and/or delay harvest: 1) re-cut primocanes [to crown] at 0.25 m, then soft-tip at 0.5 m, 2) re-cut primocanes at 0.5 m, then soft-tip at 0.5 m, 3) double-tip [soft-tip main cane at 0.5 m, then soft-tip branches at 0.5 m], and 4) soft-tip at 0.5 m [control]. Plastic was placed over the tunnel on 5 Sept. 2006 to protect fruit from inclement weather. Harvest began on 14 Sept. and ended on 26 Oct. in the field, and 15 Nov. in the tunnel. Primocanes that were double-tipped had nearly twice the flowers and fruit than canes that were soft-tipped only once. Also, double-tipped primocanes produced larger fruit than any other treatment. Harvest was not delayed in canes that were re-cut at 0.25 m, compared with the control and the double-tipped treatment. In contrast, harvest was delayed by about four weeks when primocanes were re-cut at 0.5 m. Our studies have shown that primocane-fruiting blackberry produces a much higher yield when soft-tipped.
Fruiting season could be manipulated through re-cutting; however, in a mild climate such as western Oregon, a tunnel is required to harvest much of the crop. This type of blackberry shows great promise for extended season production for the fresh market in mild climates.
Primocane-fruiting Blackberries: The Effect of Summer-Pruning, Tipping, and Chilling on Primocane Morphology, Fruiting Season, and Yield

by
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CONTRIBUTION OF AUTHORS

Dr. Bernadine Strik assisted with the experimental design, data analysis, data collection, and writing of each chapter. Dr. Chad Finn was involved with writing Chapter 2. Dr. John Clark was involved with writing Chapter 2 and reviewing this thesis in entirety. Gil Buller and Nicole Hampton assisted in field planting/set-up, maintenance, and data collection in Chapters 2, 3, 4, and 5.
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Chapter 1

General Introduction

Blackberries (*Rubus* subgenus *Rubus* Watson) grow on a perennial root system and produce biennial canes. The first-year canes (primocanes) emerge each spring; these canes typically do not fruit. After a dormant period, the second-year canes (floricanes) flower, fruit, and senesce; this type of blackberry is called “floricane-fruiting.” Fruiting on the primocane in *Rubus* does occur, but mainly in red raspberry (*Rubus ideaus* L. subgenus *Ideaobatus* Watson; Daubeney, 1996; Keep, 1961; Moore et al., 1999; Ourecky, 1976). Recently, the primocane-fruiting trait was intensified in blackberry in the University of Arkansas’ breeding program; this type of blackberry is called “primocane-fruiting.” The world’s first two erect, primocane-fruiting blackberry cultivars, ‘Prime-Jan’ and ‘Prime-Jim’, were released in 2004 (Clark et al., 2005).

Erect blackberries are grown almost exclusively for the fresh market. In the northern hemisphere, floricane- (summer) fruiting blackberries develop fruit from June through August, whereas primocane- (fall) fruiting types develop fruit later in the season, from late August through October, depending on geographical location (Drake and Clark, 2003; Strik et al., 2007a). The target date for off-season fresh market blackberry production is late September and early October, before imports from Mexico begin and prices for fruit are highest (Mark Hurst, personal communication, Hurst’s Berry Farm, Sheridan, Ore.).

In order to successfully produce fresh blackberries for the off-season, primocane management is critical. It is clear that primocane-fruiting blackberries must be managed differently than floricane-fruiting types and primocane-fruiting raspberry (B.C. Strik, personal communication). “Soft-tipping” (removal of 2-5 cm
from primocane tip) in ‘Prime-Jan’ and ‘Prime-Jim’ resulted in the development of many branches just below the site of tipping, aiding in primocane manageability, and increasing yield (Drake and Clark, 2003; Strik et al., 2007a; Thompson et al., 2007). In Oregon, harvest of ‘Prime-Jan’ and ‘Prime-Jim’ lasted until mid-October, but ceased when autumn rains began (Strik et al., 2007a). Primocane-fruiting blackberry is thus a good candidate for tunnel production. Primocane-fruiting raspberry is commonly grown under tunnels and production techniques often include summer pruning of primocanes to further delay the fruiting season (Oliveira et al., 1994, 1996, 1998, 2002). ‘Prime-Jan’ and ‘Prime-Jim’ may respond similarly to alternative primocane management techniques to extend the fruiting season, such as summer pruning, and in combination with protected culture.

In recent years, blackberry production has increased domestically and internationally (Strik et al., 2007b). In particular, fresh market blackberry production has been expanding in warmer climates, such as California and Mexico, where the fruiting season is extended, often into the winter months. However, it is unclear how primocane-fruiting blackberry would respond in a low-chill environment. Carter et al. (2006) showed that floricane cuttings of ‘Prime-Jan’ and ‘Prime-Jim’ required little chilling (100-300 h) to break dormancy. The chilling requirement for primocane production, however, remains unknown.

Understanding the growth, management needs, and chilling requirement of primocane-fruiting blackberry are necessary to optimize production for all climate types. Season extension for the fresh market holds important economical implications for small-acreage growers and the greater industry alike. The objectives of this project were to: 1) determine the effect of pruning, tipping, and chilling on growth, fruiting season, fruit quality, and yield in primocane-fruiting blackberry, 2) investigate the effect of tunnel production on season extension in western Oregon, and 3) develop primocane management guidelines for primocane-fruiting blackberry production in a mild climate.
Literature Cited


Strik, B.C., J.R. Clark, C.E. Finn, and G. Buller. 2007a. Management of primocane-fruiting blackberry to maximize yield and extend the fruiting season. Acta Hort

CHAPTER 2

Flowering and Fruiting Patterns of Primocane-fruiting Blackberries

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Abstract

The flowering morphology of the erect, thorny, primocane-fruiting blackberry (*Rubus* L. subgenus *Rubus*, Watson) cultivars Prime-Jan® and Prime-Jim® were studied in 2005 and 2006 in Aurora, Ore. Primocanes that were “soft-tipped” in early summer to 1.0 m were compared to un-tipped primocanes. In both years, soft-tipped primocanes developed 2-3 fold more branches and almost twice the number of flowers as un-tipped canes. ‘Prime-Jan’ and ‘Prime-Jim’ began blooming on the branches of soft-tipped canes in mid-July, while un-tipped primocanes began to bloom in late July in 2005 and 2006. Within a primocane inflorescence, the terminal or distal flower was always the first to open, followed by terminal flowers from axes located on the basal portion of the inflorescence. Flowers then opened acropetally within the inflorescence, with the exception of the most basal flower, which was typically the last to open. The blooming pattern within an inflorescence was similar for soft-tipped and un-tipped primocanes. Days from anthesis to black fruit for soft-tipped and un-tipped primocanes averaged 45 to 51 d in both years, depending on cultivar.

Introduction

The first primocane-fruiting blackberries, Prime-Jan® and Prime-Jim®, were released in 2004 (Clark et al., 2005). This type of erect blackberry produces flowers and fruit on the first-year cane, the primocane, in addition to the second-year cane, the floricane. Primocane-fruiting blackberries may offer opportunities for season extension and off-season fruit production in both northern and southern hemispheres, particularly in mild climates. However, field observations have revealed that erect-caned primocane-fruiting morphology is different from that of erect floricane-fruiting blackberry and primocane-fruiting raspberry (B. Strik, personal observation). Bloom pattern within an inflorescence and range in fruit maturity for semi-erect blackberries has been reported (Takeda, 1987). Fruiting lateral characteristics, such as fruitfulness and node position, have been described in red raspberry (Dale, 1979; Dale and
Topham, 1980). Production guidelines for floricane-fruiting blackberries and primocane-fruiting raspberries are well established; however, to date there are few reports on management guidelines for primocane-fruiting blackberries. Traditional cane management for erect, floricane-fruiting blackberries includes summer tipping of primocanes and winter pruning of floricanes. Tipping the upper portion of the primocane in early summer removes apical dominance and encourages branching. Similarly, soft-tipping (removing the upper 2-5 cm) primocane–fruiting types in early summer may be a feasible way to manage primocanes, to encourage branching and increase yield (Drake and Clark, 2003; Strik et al., 2007).

Studies are underway to determine optimal cane management practices in primocane-fruiting blackberry under mild climate conditions (Strik et al., 2007). Identifying the location of productivity within a primocane, bloom pattern among branches, and order of bloom within an inflorescence throughout the harvest season has not been done in this crop and is necessary to optimize primocane management to precisely target harvest for off-season markets.

The objectives of this study were to: 1) characterize flowering location, inflorescence morphology, bloom pattern, and range of fruit maturation in primocanes of ‘Prime-Jan’ and ‘Prime-Jim’ grown in western Oregon; and 2) determine the impact of soft-tipping on flowering and fruit ripening patterns of primocanes.

**Materials and Methods**

In June 2003, tissue-cultured plugs of ‘Prime-Jan’ and ‘Prime-Jim’ were established at the North Willamette Research and Extension Center (NWREC), Aurora, Ore., USA; U.S. Dept. of Agriculture (USDA) hardiness zone 8; elev. 46 m above sea level; average last freeze date 17 April; average first freeze date 25 Oct.; the weather records for this site can be viewed at Anonymous (2005-2006). The soil type was Quatama loam (fine-loamy, mixed, mesic Aqualtic Haploxeralfs). Plants were spaced 0.6 m in the row with 3 m between rows. Five-plant plots were 3 m long with 3 m separating plots. The field was drip irrigated (3.8 L/hr emitters at 0.6 m spacing) as required, typically twice daily for 30 min (3.8 L/d) from June through Sept. Plots
were fertilized with 55 kg of N, 15 kg of P, and 55 kg of K each spring and an additional 28 kg of N at primocane bloom. Weeds were controlled by use of pre-emergent herbicides and mechanical methods.

In early Aug. 2005 and 2006, three and six primocanes, respectively, of ‘Prime-Jan’ and ‘Prime-Jim’ under two cane management treatments were randomly chosen and flagged for observation: 1) primocanes “soft-tipped” (upper 2-5 cm removed) at 1 m and 2) un-tipped primocanes (control). In treatment 1, primocanes were soft-tipped to 1.0 m once during the growing season, on several occasions, from 15-29 June 2005 and from 7-26 June 2006, to appropriately tip the various flushes of cane growth. In both treatments, only a primocane crop was harvested. For each cultivar, order of bloom within an inflorescence, as described by Takeda (1987), number of flowers and berries per inflorescence, and days from terminal bloom anthesis to shiny black fruit (Perkins-Veazie et al., 1996) for fruiting structures were recorded. Branches on flagged canes for both treatments and cultivars were labeled and photographed daily to observe bloom pattern. Number of branches, node position of branches, branch length, total node number of branches and main cane, number of fruiting nodes, number of flowers, subsequent ripening among branches within a cane, and days from terminal bloom anthesis to shiny black fruit for each branch were recorded for each treatment and cultivar. The data were analyzed, where appropriate, using PROC GLM (version 9.1, SAS Institute Inc., Cary, N.C.).

Results and Discussion

In both years, primocane emergence for ‘Prime-Jan’ and ‘Prime-Jim’ began in early February. Primocanes emerged from adventitious buds on roots and the crown. On average, un-tipped primocanes of ‘Prime-Jan’ and ‘Prime-Jim’ developed two lateral branches in 2005 and less than one per cane in 2006. When present, branches were always located on nodes near the base of the cane. Un-tipped canes maintained apical dominance and were determinate in growth. Thus, fruiting sites were always found at the tips of the main cane and branches. Un-tipped primocanes of ‘Prime-Jan’ and ‘Prime-Jim’ averaged 1.8 and 2.0 m in length in 2005 and 2.1 and 2.2 m in 2006,
respectively. Average branch length for un-tipped canes was 1.3 m for ‘Prime-Jan’ and 1.0 m for ‘Prime-Jim’ in 2005. In 2006, average branch length for un-tipped ‘Prime-Jan’ and ‘Prime-Jim’ was 0.45 m and 0.68 m, respectively. Un-tipped primocanes (main cane + any branches) for ‘Prime-Jan’ averaged 95 total nodes in 2005; however, only 27% of the nodes were fruitful (Table 1). In ‘Prime-Jim’, total nodes averaged 98, with 19% of those being fruitful. In contrast, un-tipped ‘Prime-Jan’ and ‘Prime-Jim’ had fewer total nodes in 2006, 67 and 59, yet a higher percentage were fruitful than in 2005, 36% and 25%, respectively (Table 1).

Soft-tipped canes developed multiple lateral branches just below the site of tipping, resulting in an average of five branches per cane for both cultivars in 2005 and four branches in 2006. In both years, the first three nodes below the site of tipping always developed a lateral branch. Additional branches developed sporadically down the 1.0 m-long cane. The main cane on soft-tipped primocanes did not develop fruiting sites, as only lateral branches terminated in inflorescences. In 2005, average branch length for soft-tipped canes was 0.63 m and 0.52 m for ‘Prime-Jan’ and ‘Prime-Jim’, respectively. Similar to un-tipped canes, branches were also shorter on soft-tipped canes in 2006, averaging 0.46 m and 0.49 m for ‘Prime-Jan’ and ‘Prime-Jim’, respectively. In both cultivars and years, soft-tipping produced significantly more fruitful nodes. In 2005, ‘Prime-Jan’ and ‘Prime-Jim’ had 89 and 67 nodes on branches, with 55% and 54% being fruitful, respectively (Table 1). As with un-tipped canes, there were fewer total nodes on soft-tipped canes in 2006 than in 2005. ‘Prime-Jan’ and ‘Prime-Jim’ produced 70 and 64 total nodes, of which 60% and 63% were fruitful, respectively (Table 1). The greatest effect of primocane management technique was on the location of inflorescences and number of flowers per cane. Un-tipped canes and lateral branches on un-tipped and soft-tipped canes developed flowers on a panicle-like cyme (Judd et al., 1999), which terminated in an inflorescence and developed lower, secondary axial fruiting laterals. Bloom pattern for terminal inflorescences and lower fruiting laterals on un-tipped and soft-tipped primocanes was similar for cultivars and years. Below the terminal inflorescence on un-tipped and soft-tipped primocanes, four to seven secondary fruiting laterals generally developed.
In un-tipped canes, A₁ refers to the main cane or branch (Fig. 1). In soft-tipped canes, A₁ refers only to branches (Fig. 1). The terminal flower on the main cane or branch, located on A₁, was always the first to open in both cultivars (Fig. 1, “1”). This was followed by a terminal flower on a lower-fruited lateral located on an A₂ axis near the basal portion of the inflorescence, similar to semi-erect blackberry (Takeda 1987). However, the most basal A₂ axis in this study was often the last to bloom (Fig. 1, “8”). On soft-tipped and un-tipped primocane inflorescences, it was common to have A₃ axes, and occasionally A₄ axes. Blooming of A₃ axes would begin simultaneously with the last opening of the flower on the upper-most A₂ axis, which was generally the flower located directly below the terminal flower on the A₁ axis. The flower on the most basal A₂ axis also opened at the same time, or just after, the opening of the most apical A₂ axis flower. Most apical and basal A₂ axes consisted of a single flower. The time between the opening of the A₁ terminal flower and the first A₂ flower was typically 1-3 d for both cultivars and did not vary with year. Once the first A₂ axis began to bloom, other A₂ axes followed acropetally, opening at a constant rate of 2-3 flowers per day. For A₂ axes with multiple A₃ flowers, a 3-4 d period between A₃ flower openings was typical. When present, A₄ flowers opened last.

The time from first to last open flower (A₁ to A₄, respectively) within an inflorescence averaged 17 d for both cultivars and treatments in 2005 and 2006. In 2005, un-tipped canes averaged 49 flowers per cane and was unaffected by cultivar (Table 1). In 2006, un-tipped canes of ‘Prime-Jan’ averaged 68 flowers per cane, while ‘Prime-Jim’ averaged 59 (Table 1). Although ‘Prime-Jan’ and ‘Prime-Jim’ had a similar number of total flowers per cane, un-tipped primocanes of ‘Prime-Jim’ had fewer fruiting nodes than those of ‘Prime-Jan’ in 2005 and 2006 (Table 1). This may imply that ‘Prime-Jim’ developed more A₃ and A₄ axes within an inflorescence.

On soft-tipped canes, the most apical lateral branches bloomed within one day of each other in both years. Usually, the most basal of the three branches was the first to have the terminal flower on A₁ fully open, followed by the branches above it, located at nodes 1 and 2. The number of days between branch three A₁ and branch four A₁ bloom ranged from 2 to 6 d for ‘Prime-Jim’ and ‘Prime-Jan’, respectively. Most of the canes studied in 2005 had five branches and the number of days to bloom
from branch one A1 to branch five A1 ranged from 18 to 21 d for ‘Prime-Jan’ and ‘Prime-Jim’, respectively. In 2006, primocanes with five branches had a similar bloom pattern as observed in 2005. Canes with fewer than five branches had a shorter period between the bloom of A1 (Fig. 1) on branch one to A1 bloom on the most basipetal branch. In general, branch bloom pattern among soft-tipped canes was similar for both cultivars in 2005 and 2006. Soft-tipped canes had 31% to 70% more flowers than un-tipped primocanes, depending on cultivar and year (Table 1).

Once the terminal flowers on upper branches opened, bloom rate and pattern were as described above for both cultivars. Although A1 flowers on the third branch tended to open earlier than the upper two branches, A1 bloom pattern for the remaining lower branches was basipetal. In both cultivars and years, a few basal branches remained vegetative, while others were still blooming or fruiting when observations were stopped on 10 Oct. 2005, and 29 Oct. 2006 due to adverse weather.

In un-tipped primocanes, more variation occurred for branch A1 bloom pattern in both cultivars. In general, the A1 flower on the main cane opened before A1 flowers on basal lateral branches, when present. However, one primocane of ‘Prime-Jan’ in 2005 had black fruit on all branches before the A1 flower on the main cane opened. More typically on both cultivars, however, un-tipped primocanes with branches had open basal branch A1 flowers 18-21 d after the A1 flower on the main cane had opened, similar to basal branches on tipped canes. However, one basal branch on an un-tipped ‘Prime-Jim’ cane in 2006 developed late in the season, and subsequently bloomed 57 d after the A1 flower on the main cane had opened. As with soft-tipped primocanes, a few basal branches on un-tipped primocanes remained vegetative at the end of the growing season in both years.

Days from anthesis to shiny black fruit for soft-tipped and un-tipped primocanes were similar in both years, averaging 51 and 45 d for ‘Prime-Jan’ and ‘Prime-Jim’, respectively. Percent fruit set was similar in un-tipped canes in 2005 for both cultivars, but was nearly 10% higher in ‘Prime-Jim’ in 2006. ‘Prime-Jan’ had a significantly lower percent fruit set on soft-tipped canes than ‘Prime-Jim’ in both years.
In conclusion, soft-tipping primocanes to 1.0 m encouraged branching, and thereby significantly increased the number of fruiting nodes per cane compared to un-tipped primocanes. Furthermore, branching was more predictable in soft-tipped primocanes, particularly below the site of tipping, resulting in more uniformity of fruit ripening. Un-tipped primocanes consistently reached 2.0 m in length, making fruit difficult for pickers to reach and increased the risk of cane breakage. In both years, soft-tipped and un-tipped primocanes produced basal lateral branches that remained vegetative. This may imply that tipping branches, and thereby removing apical dominance, may encourage termination in an inflorescence and perhaps further increase the number of flowers per branch.
Table 1. The effect of soft-tipping primocanes on the flowering and fruiting pattern of primocanes of ‘Prime-Jan’ and ‘Prime-Jim’ in 2005 (n=3) and 2006 (n=6) (mean ± SE).

<table>
<thead>
<tr>
<th>Cane management</th>
<th>‘Prime-Jan’</th>
<th></th>
<th></th>
<th></th>
<th>‘Prime-Jim’</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total nodes/cane</td>
<td>Fruiting nodes/cane</td>
<td>Flowers/cane</td>
<td>Fruit Set (%)</td>
<td>Total nodes/cane</td>
<td>Fruiting nodes/cane</td>
<td>Flowers/cane</td>
<td>Fruit Set (%)</td>
</tr>
<tr>
<td>2005</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Un-tipped</td>
<td>95 ± 48</td>
<td>26 ± 15</td>
<td>50 ± 24</td>
<td>90 ± 2</td>
<td>98 ± 51</td>
<td>19 ± 6</td>
<td>48 ± 17</td>
<td>88 ± 4</td>
</tr>
<tr>
<td>Soft-tipped</td>
<td>89 ± 40</td>
<td>49 ± 17</td>
<td>74 ± 31</td>
<td>83 ± 1</td>
<td>67 ± 6</td>
<td>36 ± 4</td>
<td>82 ± 6</td>
<td>87 ± 0</td>
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<tr>
<td>2006</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Un-tipped</td>
<td>67 ± 13</td>
<td>24 ± 6</td>
<td>68 ± 17</td>
<td>85 ± 3</td>
<td>59 ± 5</td>
<td>15 ± 1</td>
<td>59 ± 12</td>
<td>94 ± 1</td>
</tr>
<tr>
<td>Soft-tipped</td>
<td>70 ± 13</td>
<td>42 ± 6</td>
<td>101 ± 12</td>
<td>84 ± 3</td>
<td>64 ± 14</td>
<td>40 ± 6</td>
<td>77 ± 19</td>
<td>94 ± 2</td>
</tr>
</tbody>
</table>

**Significance**

- Cultivar: NS, *, ** non-significant, or significant at P<0.05 or 0.01, respectively.
- Year: NS
- Tipping: NS
- Cult × year: NS

---

\[z\] Average total number of nodes/cane (including any branches).
\[y\] Average total number of nodes/cane (including any branches) that produced an inflorescence or flowering lateral.
\[x\] Average total flowers/cane (including any branches).
\[w\] Totals for soft-tipped canes include only branches, not the main cane.

Significance: NS, *, ** non-significant, or significant at P<0.05 or 0.01, respectively. Tipping treatment × year, tipping treatment × cultivar, and tipping treatment × year × cultivar were not significant for any variables and are thus not shown.
Fig. 1. Structure of bloom pattern of an inflorescence on soft-tipped (1.0 m) and un-tipped primocanes. Order of bloom is designated as “1” through “8”. Numbered flowers preceded lettered flowers.

Literature Cited


CHAPTER 3

Alternative Primocane Management Strategies for Primocane-fruiting Blackberry

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Abstract

‘Prime-Jan’ and ‘Prime-Jim’ were studied in a field planting established in June 2003 in Aurora, Ore. Beginning in 2005, primocane treatments were: 1) primocanes soft-tipped at 0.5 m, 2) primocanes soft-tipped once reaching 1.5 m, 3) primocanes re-cut (to crown) once reaching 0.5 m and subsequent primocanes left untipped, 4) inflorescence removed after first open bloom (by tipping main cane below determinate, apical floral structure), and 5) primocanes soft-tipped at 1.0 m (control). Primocane growth, flowering, and yield were affected by treatment, but not cultivar. On average, tipping or re-cutting primocanes at 0.5 m began on 21 May. Tipping primocanes at 1.0 and 1.5 m began 7 and 26 June, respectively, while removal of inflorescences (treatment 4) began on 26 July. Primocanes that were tipped at 0.5, 1.0, and 1.5 m developed significantly more branches than primocanes in treatments that were re-cut or had the inflorescence removed. Floral buds became visible on the apices of branches (tipped treatments) and primocanes (un-tipped treatments) in late June and late July, respectively, in both years. Primocanes in the re-cut treatment developed floral buds in late July and early August, depending on year. On average, bloom and harvest in tipped treatments began on 12-17 July and 29 Aug.-4 Sept., respectively, depending on year. Primocanes that grew after re-cutting had a significantly delayed bloom and harvest (21 d) in both years, on average. Primocanes that were tipped to 0.5 and 1.0 m consistently yielded the most fruit (7.8 and 8.8 t/ha, respectively). Primocanes that grew after re-cutting or had the inflorescence removed yielded significantly less in both years. However, all treatments yielded 56% more fruit in 2006 than in 2005 (e.g. 11.4 vs. 6.2 t/ha for control, respectively). Harvest stopped due to rain on 11 and 26 Oct. in 2005 and 2006, respectively.
Introduction

Traditional cane management for erect, floricane-fruiting blackberries includes summer tipping of primocanes and winter pruning of floricanes. Tipping the upper portion of the primocane in early summer removes apical dominance and encourages branching. Soft-tipping (removing the upper 5 cm) primocane-fruiting types in early summer has been shown to be a feasible way to manage primocanes, to encourage branching, increase flower number per cane, and increase yield (Drake and Clark, 2003; Strik et al., 2007). Strik et al. (2007) studying ‘Prime-Jan’ and ‘Prime-Jim’ in Oregon reported that tipping primocanes at 1 m advanced harvest and increased yield and berry weight in both cultivars, compared with un-tipped canes; yield for ‘Prime-Jan’ and ‘Prime-Jim’ was reported as 4.2 and 5.2 t/ha, respectively. Tipped primocanes (1.0 m) averaged five branches per cane and developed twice the amount of flowers than un-tipped canes, which averaged two branches per cane (Thompson et al., 2007; Chapter 2).

Strik et al. (2007) noted that when harvest in fields was curtailed in October due to rain, there were still flower buds, flowers, and unripe fruit present on most treatments. A tunnel would have allowed for much later harvest. Tunnel production in primocane-fruiting raspberry is well documented (Jordan and Ince, 1986; Oliveira et al. 1994, 1996, 1998, 1999, 2004). These studies have shown that primocane-fruiting raspberry harvest can easily be extended in production systems that include summer pruning of primocanes, tipping and tunnel protection.

Alternative primocane management strategies may offer flexibility in harvest advancement, or delayed fruit ripening. The objectives of this study were to: 1) determine the effect of alternative tipping treatments on growth and yield of ‘Prime-Jan’ and ‘Prime-Jim’, and 2) determine the effect of re-cutting primocanes (to crown) on growth, yield, and season extension.

Materials and Methods
Tissue-cultured plugs of ‘Prime-Jan’ and ‘Prime-Jim’ were planted on 3 June 2003 at Oregon State University’s North Willamette Research and Extension Center (NWREC), Aurora, Ore. The soil type was a Quatama loam (fine-loamy, mixed, mesic Aqualtic Haploxeralfs). Plants were spaced 0.6 m in the row with 3 m between rows. Five-plant plots were 3 m long with 3 m separating plots. There were two and four replicates in 2005 and 2006, respectively, of the following treatments arranged as a randomized complete block design: 1) primocanes soft-tipped at 0.5 m (by removing 2-5 cm of the tip), 2) primocanes soft-tipped upon reaching 1.5 m, 3) primocanes re-cut once reaching 0.5 m and the subsequent primocanes left un-tipped, 4) inflorescence removed after first open bloom (by tipping main cane below determinate, apical floral structure), and 5) primocanes soft-tipped at 1.0 m (control). In 2004, plants were managed as per Strik et al. (2007).

In the planting year, plants grew, un-trained and un-manipulated. The field was drip irrigated (3.8 L/hr emitters at 0.6 m spacing) as required, typically 30 min twice daily (3.8 L/d) from June through Sept. Plots were fertilized with 55, 15, and 55 kg of N-P-K, respectively, each spring. Weeds were controlled through use of pre-emergent herbicides and mechanical methods. Blackberry row width was maintained at 0.45 m using cultivation. Canes were trained between double sets of trellis wires located at 0.3 m and 1.7 m high, but were not tied to the wires. In Nov. 2005 and Feb. 2007, all canes were removed from plots for data collection.

In treatments 1, 2, and 5, primocanes were soft-tipped once during the growing season, on several occasions, to appropriately tip the various flushes of cane growth at the designated height. Primocanes in treatment 3 were left un-tipped after having been re-cut to the crown. In treatment 4, the entire inflorescence was removed by tipping the cane just below the basipetal flowering node, after the terminal flower opened.

Data collection for both cultivars and years included: date of primocane emergence, soft-tipping, flowering and terminal black fruit; primocane height at bloom, apical branch length (biweekly of four primocanes per plot); total number of fruiting and non-fruiting canes per plot and percent fruiting canes calculated, and plot fresh weight. Data collection for primocane subsamples (n=3) included: branch number, total branch length, total node number (main cane + branches), number of
fruiting nodes per cane (nodes which bore a flower bud or fruiting lateral), and total number of fruiting sites. The sub-sampled data collected for each plot were averaged before data analysis using the GLM procedure in SAS (SAS Institute Inc., 1999).

Results and Discussion

Growth: Primocanes of both cultivars emerged from adventitious buds on the roots and crown in early Feb. 2005 and 2006. Observations revealed that ‘Prime-Jan’ produced more adventitious shoots per plot than ‘Prime-Jim’ in both years (Fig. 1). Due to vigor, treatments in ‘Prime-Jan’ began 2-5 d earlier than ‘Prime-Jim’ on average. Treatment dates were similar for 2005 and 2006. On average, tipping or re-cutting primocanes at 0.5 m began on 21 May. Tipping primocanes at 1.0 m (control) and 1.5 m began 7 and 26 June, respectively, while removal of inflorescences began on 26 July, for both years.

In 2005 and 2006, branch development was affected by primocane management treatment, but not cultivar. Branches developed just below the site of tipping. Primocanes that were tipped at 0.5, 1.0, and 1.5 m developed significantly more branches (3.5) than primocanes that were re-cut and left un-tipped (0) or had the inflorescence removed after terminal bloom (1.2). This agrees with Thompson et al. (2007; Chapter 2), where ‘Prime-Jan’ and ‘Prime-Jim’ responded similarly to tipping treatments; primocanes that were soft-tipped to 1.0 m produced 4-5 branches just below the site of tipping, while un-tipped canes produced <1-2 branches on average, depending on year. The growth habit of these primocane-fruiting blackberry cultivars is such that un-tipped primocanes terminate in an inflorescence, thereby maintaining apical dominance and inhibiting branch development. When primocanes are tipped, apical dominance is removed and branch development is promoted. For primocanes that were tipped just below the inflorescence after the first bloom (treatment 4), it was hypothesized that branches and/or subsequent floral structures would develop from nodes just below the site of tipping. However, very few branches or subsequent floral structures developed when tipping after bloom, and below the fruiting structure. It is possible that when an actively growing meristem transitioned from the vegetative to
the reproductive state, a shift in hormones or source/sink relationship occurred, thus lower buds remained inhibited because apical dominance could no longer be removed. Apical dominance is such that the upper-most bud inhibits lower buds from developing. Thompson et al. (2007; Chapter 2) showed that un-tipped primocanes of ‘Prime-Jan’ and ‘Prime-Jim’ are determinate in growth; an inflorescence developed on the primocane apex that spanned 15-17 nodes, with no floral structures, and few branches, if any, developing below.

Primocane growth (average branch length and total nodes per cane) was affected by treatment in both years and by cultivar only in 2005. ‘Prime-Jim’ produced longer branches, with more nodes, than ‘Prime-Jan’ in 2005. Branches on primocanes tipped at 0.5 m were longer (0.8 m; \( P \leq 0.001 \)) than on primocanes tipped at 1.0 m (0.5 m) and 1.5 m (0.2 m), on average. When present, branches on primocanes that had the inflorescence removed averaged 0.09 m. Primocanes that grew after re-cutting were left un-tipped, thus branches were not produced. Primocanes tipped at 0.5 and 1.5 m produced more nodes than other treatments (Fig 2). Similarly, branches on primocanes that were tipped at 0.5 m were 24% shorter in 2006 (Fig 3). Primocanes that were tipped at 1.0 m consistently developed 71 nodes, while those that were re-cut at 0.5 m averaged 32 nodes, the least of any treatment. ‘Prime-Jan’ tended to have less growth (average branch length, total node number) than ‘Prime-Jim’ for all treatments in both years, agreeing with Strik et al. (2007).

In general, branches on tipped canes (0.5, 1.0, and 1.5 m) were shorter near the site of tipping and longer from more basipetal nodes. Some branches produced from basipetal nodes never terminated in an inflorescence by the end of the harvest season in 2005 and 2006. This growth habit was described in Thompson et al. (2007; Chapter 2) for primocanes tipped at 1.0 m.

**Flowering:** Floral buds became visible on the apices of branches (tipped treatments) and primocanes (un-tipped treatments) in late June and late July, respectively, in both years. Primocanes that grew after re-cutting at 0.5 m developed floral buds in late July and early August, depending on year. Bloom date and primocane height at bloom were not affected by cultivar or treatment in 2005, but there was a significant interaction between cultivar and treatment in 2006.
of ‘Prime-Jim’ were longer at bloom, and tended to flower earlier than ‘Prime-Jan’. Primocanes that were tipped at 0.5 or 1.0 m bloomed on 16 July in both years, at 1.1 m and 1.3 m, respectively. When tipped at 1.5 m, primocanes bloomed 5 d later (21 July), on average. Primocanes tipped at 1.5 m were significantly longer than those from other treatments at bloom (2006 only), but developed lateral inflorescences rather than branches (average length .03 m). Primocane bloom was delayed in the re-cut treatment (28 d; 13 Aug.), compared to the control, and primocane height was less at flowering (1.0 m) in both years. In 2005, removal of the apical inflorescence did not delay flowering compared to the control, yet bloom was drastically delayed in 2006, by over 1 month (35 d). This may be due to incomplete removal of the inflorescence in 2005, such that remaining basal floral structures (bud or lateral inflorescence at the lower portion of the entire apical inflorescence) would have bloomed earlier than if the apex had been left intact.

**Fruit:** Date of first fully black terminal fruit was affected by treatment in both years, but only for cultivar in 2006. Days from anthesis to black fruit were similar for all treatments (42 d), except in primocanes that grew after re-cutting (50 d) for both years. This agrees with other studies on ‘Prime-Jan’ and ‘Prime-Jim’ (Strik et al., 2007; Thompson et al., 2007; Chapter 2), in which primocanes of both cultivars averaged 36 to 43 d from bloom to black fruit, depending on year. As with bloom, ‘Prime-Jim’ ripened significantly earlier than ‘Prime-Jan’ in 2006 (Table 2). Primocanes of both cultivars tipped at 0.5, 1.0, or 1.5 m ripened fruit earliest on average (28 Aug.) in both years. The date of first black fruit was significantly delayed by approx. 1 month (24 Sept.) in the re-cut, un-tipped treatment in both years compared with the control. Fruit development may have taken longer on the re-cut, un-tipped treatment because of shortening day length (autumn equinox 2006: 24 Sept.) and decreasing autumnal night temperatures. Again, removal of the inflorescence did not delay ripening in 2005 (1 Sept.), but did in 2006 (23 Sept.).

Development of reproductive nodes and subsequent fruiting sites was affected by treatment, but not cultivar, in both years (Fig. 4). Tipped treatments developed significantly more reproductive nodes and fruiting sites than the un-tipped primocanes in the re-cut treatment and primocanes with the inflorescence removed after first
bloom. Primocanes tipped at 0.5 and 1.0 m produced more fruiting sites than all other treatments; branches on tipped treatments regularly produced 6-10 reproductive nodes, agreeing with Thompson et al. (2007; Chapter 2).

The total number of canes per plot (fruiting + non-fruiting) was affected only by cultivar in 2005. The percentage of fruitful canes per plot was affected by cultivar and treatment in 2005, and only by treatment in 2006 (Table 1). In both years, ‘Prime-Jan’ produced more canes per plot than ‘Prime-Jim’; however, ‘Prime-Jim’ had a higher proportion of primocanes that fruited. Plots of ‘Prime-Jan’ that were left untipped after re-cutting developed more canes than all other treatments (Table 1). This may be due to emergence of two or more primocanes from basal nodes on the re-cut canes. Re-cutting may also have stimulated adventitious shoots from buds on the roots. Again, ‘Prime-Jan’ was more vigorous in both years during primocane emergence.

The percentage of canes per plot that were fruitful was similar for tipped and un-tipped, re-cut treatments in both years, particularly for ‘Prime-Jan’. More variation in cane development occurred in ‘Prime-Jim’ (Table 1). Primocanes that had the inflorescence removed at bloom had significantly fewer fruitful canes than the control in ‘Prime-Jan’ (78% fewer) and ‘Prime-Jim’ (52% fewer), on average. The fresh weight of primocanes per plot was affected by treatment and cultivar in 2006, but not in 2005. In 2005, fresh weight for all treatments was similar, ranging from 10-12 kg/plot. Fresh weight was slightly less in 2006 for all treatments except for re-cut primocanes, which produced significantly less biomass than all other treatments, averaging 6 kg/plot (P ≤ 0.001). This may be because plots were destructively harvested much later in 2006 than in 2005. Plants may have lost more leaves or have been slightly desiccated from winter winds.

Harvest began on 29 Aug. 2005 and 4 Sept. 2006 for tipped treatments, but was delayed until 12 and 21 Sept. 2005 and 2006, respectively, for un-tipped, re-cut treatments. Primocanes that grew un-tipped after re-cutting or had the inflorescence removed after first bloom yielded significantly less in both years (Table 1). Primocanes that were tipped to 0.5 and 1.0 m consistently yielded the most fruit (7.8 and 8.8 t/ha, on average, respectively; Table 1). Yield was 57% higher in 2006 than in
2005 for all treatments, on average (11.4 vs. 6.2 t/ha for primocanes tipped at 1.0 m, respectively). The large increase in yield is perhaps due to planting maturity, however, the total number of primocanes per plot, and the percentage of those that were fruitful, were similar in 2005 and 2006 (Table 1). Harvest stopped due to rain on 11 and 26 Oct. in 2005 and 2006, respectively.

Average berry weight was affected only by treatment in 2005, with a significant interaction between cultivar and treatment in 2006. In both years, average berry weight was similar in tipped primocane treatments (0.5, 1.0, and 1.5 m; Table 1). Primocanes that grew after re-cutting or had the inflorescence removed after first bloom produced significantly smaller fruit (Table 1). Drake and Clark (2003) found that tipping primocanes two weeks after inflorescence development reduced berry weight in ‘Prime-Jan’ and ‘Prime-Jim’. Percent fruit rot was negligible in both years, with no difference among treatments or cultivars (data not shown).

In conclusion, primocane growth, flowering and fruiting were affected by primocane management and year, but not cultivar. Strik et al. (2007) and Drake and Clark (2003) also showed that primocanes of ‘Prime-Jan’ and ‘Prime-Jim’ tipped at 1.0 m responded similarly in growth and floral development. Re-cutting primocanes at 0.5 m significantly delayed flower and fruit development of the subsequent, untipped primocanes. Soft-tipping primocanes after re-cutting may promote branching, which could increase yield and delay harvest. Primocanes tipped at 0.5 and 1.0 m developed a similar number of branches, however, average branch length was 37% longer on those tipped at 0.5 m. Branches on primocanes tipped at 1.0 m also grew longer from the base of the cane, and often remained vegetative (Thompson et al., 2007; Chapter 2). Tipping (before floral development) on longer branches may remove apical dominance and promote inflorescence development. Tipping primocanes after floral development (i.e. removal of full or partial inflorescence) does not promote lateral branch or inflorescence development, and clearly reduces primocane yield in ‘Prime-Jan’ and ‘Prime-Jim’ (Drake and Clark, 2003). Use of a tunnel to protect fruit from rain would extend the season for all treatments, particularly in primocanes that were delayed from being re-cut.
Table 1. Yield and growth components of ‘Prime-Jan’ and ‘Prime-Jim’ as affected by primocane management in 2005 (n=2) and 2006 (n=4; ± SE). Primocanes were tipped at 0.5, 1.0, and 1.5 m, un-tipped primocanes were retained after cutting at 0.5 m (“re-cut 0.5 m”), or primocanes were tipped below the determinate apical inflorescence after bloom (“Flowers removed”).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>‘Prime-Jan’</th>
<th></th>
<th>‘Prime-Jim’</th>
<th></th>
</tr>
</thead>
<tbody>
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<td></td>
<td>Yield (kg/plot)</td>
<td>Berry wt. (g)</td>
<td>Canes/plot (%)</td>
<td>Fruitful canes (%)</td>
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<td>2005</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tip 0.5 m</td>
<td>4.5 a</td>
<td>4.3 a</td>
<td>71</td>
<td>75 a</td>
</tr>
<tr>
<td>Tip 1.0 m (control)</td>
<td>6.3 a</td>
<td>3.8 a</td>
<td>88</td>
<td>75 a</td>
</tr>
<tr>
<td>Tip 1.5 m</td>
<td>5.7 b</td>
<td>5.8 a</td>
<td>90</td>
<td>81 a</td>
</tr>
<tr>
<td>Re-cut 0.5 m</td>
<td>0.2 c</td>
<td>2.4 b</td>
<td>92</td>
<td>68 a</td>
</tr>
<tr>
<td>Flowers removed</td>
<td>0.1 c</td>
<td>1.6 b</td>
<td>72</td>
<td>23 b</td>
</tr>
</tbody>
</table>

**Significance**

- ** Treatment: *** NS ** NS *** -- -- -- --
- Cultivar: NS NS ** * -- -- -- --
- Treatment*Cultivar: NS NS NS NS -- -- -- --

2006

<table>
<thead>
<tr>
<th>Treatment</th>
<th>‘Prime-Jan’</th>
<th></th>
<th>‘Prime-Jim’</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield (kg/plot)</td>
<td>Berry wt. (g)</td>
<td>Canes/plot (%)</td>
<td>Fruitful canes (%)</td>
</tr>
<tr>
<td>2006</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tip 0.5 m</td>
<td>9.3 ± 1.3 a</td>
<td>5.1 ± 0.2 a</td>
<td>88 ± 14.5</td>
<td>86 a</td>
</tr>
<tr>
<td>Tip 1.0 m (control)</td>
<td>10.3 ± 1.4 a</td>
<td>5.0 ± 0.2 a</td>
<td>91 ± 11.6</td>
<td>80 a</td>
</tr>
<tr>
<td>Tip 1.5 m</td>
<td>7.1 ± 1.0 b</td>
<td>5.2 ± 0.1 a</td>
<td>85 ± 6.5</td>
<td>72 a</td>
</tr>
<tr>
<td>Re-cut 0.5 m</td>
<td>1.9 ± 0.6 c</td>
<td>3.6 ± 0.4 a</td>
<td>97 ± 15.7</td>
<td>71 a</td>
</tr>
<tr>
<td>Flowers removed</td>
<td>0.5 ± 0.4 d</td>
<td>0.9 ± 0.5 a</td>
<td>77 ± 9.8</td>
<td>9 b</td>
</tr>
</tbody>
</table>

**Significance**

- ** Treatment: *** NS NS *** -- -- -- --
- Cultivar: NS NS NS NS -- -- -- --
- Treatment*Cultivar: NS NS * NS -- -- -- --

\(^2\) Total number of primocanes (fruiting + non-fruiting) per plot.

\(^y\) NS, *, **, *** = Non-significant or significant at P \(\leq\) 0.05, 0.01, or 0.001, respectively.

\(^x\) Means followed by the same letter within year are not significantly different.
Table 2. Average days from date of bloom to first black fruit for ‘Prime-Jan’ and ‘Prime-Jim’ as affected by primocane management treatment in 2005 and 2006. Primocanes were tipped at 0.5, 1.0, and 1.5 m, un-tipped primocanes were retained after cutting at 0.5 m (“re-cut 0.5 m”), or primocanes were tipped below the determinate apical inflorescence after bloom (“Flowers removed”).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>2005 Bloom date</th>
<th>2005 Black fruit date</th>
<th>Days $^z$</th>
<th>2005 Bloom date</th>
<th>2005 Black fruit date</th>
<th>Days $^z$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tip 0.5 m</td>
<td>11 July</td>
<td>20 Aug.</td>
<td>40</td>
<td>18 July</td>
<td>27 Aug.</td>
<td>40</td>
</tr>
<tr>
<td>Tip 1.0 m (control)</td>
<td>13 July</td>
<td>30 Aug.</td>
<td>48</td>
<td>16 July</td>
<td>24 Aug.</td>
<td>39</td>
</tr>
<tr>
<td>Tip 1.5 m</td>
<td>12 July</td>
<td>12 Aug.</td>
<td>31</td>
<td>22 July</td>
<td>24 Aug.</td>
<td>33</td>
</tr>
<tr>
<td>Re-cut 0.5 m</td>
<td>7 Aug.</td>
<td>27 Sept.</td>
<td>51</td>
<td>5 Aug.</td>
<td>17 Sept.</td>
<td>43</td>
</tr>
<tr>
<td>Flowers removed</td>
<td>7 July</td>
<td>30 Aug.</td>
<td>52</td>
<td>17 July</td>
<td>3 Sept.</td>
<td>48</td>
</tr>
<tr>
<td>2006 Ti p 0.5 m</td>
<td>15 July</td>
<td>3 Sept.</td>
<td>50</td>
<td>15 July</td>
<td>28 Aug.</td>
<td>46</td>
</tr>
<tr>
<td>Tip 1.0 m (control)</td>
<td>17 July</td>
<td>1 Sept.</td>
<td>46</td>
<td>19 July</td>
<td>27 Aug.</td>
<td>39</td>
</tr>
<tr>
<td>Tip 1.5 m</td>
<td>15 July</td>
<td>8 Sept.</td>
<td>57</td>
<td>27 July</td>
<td>6 Sept.</td>
<td>41</td>
</tr>
<tr>
<td>Re-cut 0.5 m</td>
<td>3 Aug.</td>
<td>29 Sept.</td>
<td>57</td>
<td>3 Aug.</td>
<td>22 Sept.</td>
<td>50</td>
</tr>
<tr>
<td>Flowers removed</td>
<td>13 Aug.</td>
<td>23 Sept.</td>
<td>41</td>
<td>11 Sept.</td>
<td>-- $^y$</td>
<td>--</td>
</tr>
</tbody>
</table>

$^z$The days from bloom to first black fruit.

$^y$There were no black fruit present when harvest ended on Oct. 2006.
Figure 1. Primocane vigor in ‘Prime-Jim’ (left) and ‘Prime-Jan’ (right). (Photo taken 24 April, 2006.)

Figure 2. Average total nodes per cane for ‘Prime-Jim’ and ‘Prime-Jan’ as affected by primocane management treatment in 2005 (n=2) and 2006 (n=4; ± SE). Primocanes were tipped at 0.5, 1.0, or 1.5 m, un-tipped primocanes were retained after cutting at 0.5 m (“re-cut 0.5 m”), or primocanes were tipped below the inflorescence after the first flower opened (“Flowers removed”).
Figure 3. Average branch length for ‘Prime-Jim’ and ‘Prime-Jan’ as affected by primocane management treatment in 2005 (n=2) and 2006 (n=4; ± SE). Primocanes were tipped at 0.5, 1.0, or 1.5 m, un-tipped primocanes were retained after cutting at 0.5 m (“re-cut 0.5 m”), or primocanes were tipped below the inflorescence after the first flower opened (“Flowers removed”).

Figure 4. Effect of primocane management treatment on the average number of reproductive nodes and subsequent fruiting sites in both cultivars (‘Prime-Jan’ and ‘Prime-Jim’ combined), 2005 (n=2) and 2006 (n=4; ± SE). Primocanes were tipped at 0.5, 1.0, or 1.5 m, un-tipped primocanes were retained after cutting at 0.5 m (“re-cut 0.5 m”), or primocanes were tipped below the inflorescence after the first flower opened (“Flowers removed”).


CHAPTER 4

Chilling Affects Primocane Growth and Flowering of ‘Prime-Jan®’ Primocane-fruited Blackberry

Ellen Thompson¹ and Bernadine C. Strik¹

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Abstract

The effect of chilling on ‘Prime-Jan®’ primocane-fruiting blackberry (Rubus subgenus Rubus, Watson) was investigated using mature, potted plants re-cut back to the crown. Chilling (~2 °C), regardless of duration, resulted in earlier primocane emergence and longer branches on soft-tipped canes compared to those on un-chilled plants. Although chilling elongated branches, it did not significantly increase the total node number per plant. Plants (crowns + roots) that received a minimum of 480 chilling units (CU) responded by producing primocanes with significantly more reproductive nodes than plants that received less chilling. This same pattern was observed for percent reproductive nodes: the proportion of nodes on each branch that produced a flower bud, inflorescence, or fruiting lateral. Plants that received at least 480 CU produced the first open bloom after 110 d, on average. Most un-chilled plants (88%) remained vegetative through the end of the study (140 d; 17 Nov. 2006), which may be attributed to re-cutting plants later than other treatments. Primocane growth and flowering in ‘Prime-Jan’ does not require, yet benefits, from chilling.

Introduction

For many temperate fruit crops, including floricane-fruiting blackberry, chilling has long been recognized as a dormancy requirement to promote uniform bud break and optimize flower bud development. The number of hours to satisfy chilling has been shown to vary greatly among floricane-fruiting blackberry (Carter et al., 2006; Warmund and Byers, 2002; Warmund and Krumme, 2005) and primocane-fruiting red raspberry (Dale et al., 2001) cultivars. In primocane-fruiting red raspberry, exposure to low temperatures resulted in a shortened vegetative growth phase, advanced harvest, and increased yield in many cultivars (Carew et al., 2001, 1999; Dale et al., 2005; Takeda, 1993; Vasilakakis et al., 1980). In primocane-fruiting
blackberry, exposure of floricanes to 300 h of chilling resulted in 30 and
50% budbreak of ‘Prime-Jim’ and ‘Prime-Jan’, respectively. Longer exposure to
c Chilling, however, promoted more uniform budbreak of floricanes (Carter et al., 2006).
The plant chilling requirement for primocane growth and flowering has not yet been studied in this crop.

Determining the chilling requirement of primocane-fruiting blackberry holds important horticultural implications and would potentially allow scheduling of fruit
harvest in the field or greenhouse, particularly in the off-season when prices are
generally higher. Further, it is important to know if ‘Prime-Jan’ is suitable for low-
chill environments, where there has been increased blackberry production in recent
years. The objectives of this study were to: 1) determine the range of hours needed to satisfy the chilling requirement of roots and crown for primocane growth and 2)
determine if chilling promotes flowering of primocanes in ‘Prime-Jan’.

Materials and Methods

Study I: Tissue cultured plugs (300 count; approx. 6 wk old) of ‘Prime-Jan’
(Sakuma Bros. Nursery, Burlington, Wash.) were received 19 Nov. 2004 and potted
into 10 cm Gage Dura Pot containers (Gage Industries, Lake Oswego, Ore.) using a soil-less, peat-based bedding plant mix #2 (OBC Northwest, Canby, Ore.). Plants
were fertigated weekly using a Hozon brass siphon mixer (1:16 ratio) at 100 ppm with Scotts General Purpose 20N-8.8P-16.6K complete water-soluble fertilizer (The Scotts Co., Marysville, Ohio). Plants were repotted on 19 Jan. and 15 March 2005 into 15
cm Gage Dura Pot and 7.5 L Classic 600 containers (Nursery Supplies Inc.,
McMinnville, Ore.), respectively, and maintained as aforementioned. Plants were kept
in a greenhouse under long day lighting conditions (18 h day, 6 h night) with min. and max. daily temperatures of approx. 11 ºC and 29 ºC, respectively, from 19 Nov. 2004
to 18 April 2005. Plants were then transported to the North Willamette Research and Extension Center (NWREC), Aurora, Ore., and hardened off in a protective,
retractable roof Cravo greenhouse (Cravo Equipment Ltd., Brantford, Ont., Can.). Plants were fertilized with approx. 8 g Osmocote 14N-6.2P-11.6K slow release
fertilizer (The Scotts Co., Marysville, Ohio) and watered regularly. Once hardened off, plants were moved out of the Cravo greenhouse and maintained in a full sun location at the NWREC.

On 19 Oct. 2005, 40 plants were randomly chosen, repotted into 23 L Classic 2800 containers, pruned to the crown (soil level), and received one of five chilling treatments: A) 0 chill units (CU), B) 240 CU, C) 480 CU, D) 720 CU, or E) 960 CU. All plants were placed in cold storage (~2 °C) to satisfy chilling, with the exception of treatment A, in which plants were placed directly into the greenhouse. Plants in treatments B, C, D, and E were placed in cold storage for 10, 20, 30, or 40 d, respectively. After each subsequent chilling treatment, plants were transported from cold storage to the greenhouse. Potted plants were arranged in a randomized complete block design with eight replications, with one plant per experimental unit. Plants were fertilized with 22 g Osmocote 14N-6.2P-11.6K and watered regularly. Air temperature was recorded hourly using a data logger (average monthly temperature 17 °C; 12/28 °C average monthly min./max. temperature). After primocane emergence, three canes per pot were flagged for subsequent data collection, which included: primocane height (biweekly), number of primocanes per plant, and date of bloom. The study was aborted on 11 Mar. 2006 (143 d after the 0 chill treatment was placed in the greenhouse) due to excessive cane growth in the greenhouse, which led to subsequent cane breakage and space limitations. Data were analyzed using PROC REG (version 9.1, SAS Institute Inc., Cary, N.C.).

**Study II:** Plants were grown and maintained under the same conditions as those described in Study I, but were allowed to over-winter in an unheated, protective structure, exposed to winter temperatures. Sixty-four, 1.5 year-old potted ‘Prime-Jan’ plants were randomly chosen for the following chilling treatments: A) 0 CU (0 days of cold storage at ~2 °C), B) 240 CU (10 days), C) 480 CU (20 days), or D) 720 CU (30 days). Beginning on 31 May 2006, 16 plants were repotted into 50 L Classic 6900 containers, pruned to crown height, and placed in cold storage. Every 10 d this was repeated, with the exception of treatment A, which received no artificial chilling. Chilling treatments were thus staggered such that all treatments (B-D) were removed from cold storage on 30 June 2006; plants of treatment A (0 CU) were thus repotted
and primocanes re-cut on this date. Plants from all treatments were placed inside an uncovered Haygrove tunnel (Haygrove Tunnels, Herefordshire, UK) and arranged in a completely randomized design with 16 replications per chilling treatment. Plants were drip irrigated using four, 3.8 L emitters and fertilized with 70 g Apex 14N-6.2P-11.6K slow release pellets (J.R. Simplot Co., Boise, Ida.) on 30 June and 30 Sept. 2006. Once reaching 0.5 m, primocanes were thinned to two per pot, and soft-tipped (upper 2-5 cm removed). Plants were weeded (including any latent adventitious shoots) regularly. Luminance THB (Visqueen Building Products BPI, London, UK) plastic film (6 mm) was placed over the Haygrove tunnel on 5 Sept. 2006. Observations stopped on 17 Nov. and plants were destructively harvested in early Dec. 2006. Data collection per cane for each plant included: date of primocane emergence, soft-tipping and bloom, apical branch length (biweekly), branch number, branch location (node), total branch length, total node number (main cane + branches), number of reproductive nodes per branch (nodes which bore flower buds or fruiting laterals), and percent reproductive nodes was calculated. Growing-degree days (GDD) for 2006 were calculated online with a USDA Integrated Plant Protection Center model, using a base and max. temperature of 10 and 31 ºC, respectively (Anonymous, 2007). GDD modeling used temperature data from the U.S. Bureau of Reclamation agricultural meteorology station (AgriMet-ARAO) located at the NWREC, Aurora, Ore (Anonymous, 2006). Growth of the apical branch for each treatment was analyzed using repeated measures (PROC GLM). The data collected for the two canes/plant were averaged before data analysis using PROC GLM and PROC REG (version 9.1, SAS Institute Inc., Cary, N.C.).

Results and Discussion

Study I: Primocanes began to emerge after approx. 10 d in the greenhouse for all chilling treatments. After 6 weeks, all treatments were similar in vigor, averaging six primocanes per plant. Plants that received chilling (240-960 CU) displayed an erect growth habit, while a proportion of plants that did not receive any chilling failed to elongate and remained stunted with very short internodes. This agrees with Lopez-
Medina and Moore (1999), where un-chilled plants of A-1836, a floricane-fruiting parent of ‘Prime-Jan’, remained stunted and were characterized by the formation of rosettes with very short internodes.

There was no significant relationship between CU and time to bloom. However, there was a trend for plants receiving more CU to bloom earlier. Primocanes from plants receiving 720 or 960 CU were the first to bloom, 57 d and 61 d after the plants were placed in the greenhouse, respectively. This was followed by bloom on plants receiving 480, 240, and 0 CU at 67, 77, and 101 d, respectively. However, on 11 Mar. 2006 (143 d) when observations were stopped, only two of the eight (25%) canes measured on un-chilled plants had bloomed, while 88% of canes from plants receiving 480 CU had bloomed, the highest percentage for any treatment. In most treatments, canes were approx. 1.3 m long by the time bloom started. The canes had to be supported by bamboo stakes, and began to be damaged from the grow lights above the bench. Soft-tipping and thinning the primocanes would have likely reduced the problems we experienced in the greenhouse.

**Study II:** Primocanes began to emerge approx. 11 d after plants were placed in the un-covered tunnel. There was a significant linear relationship between amount of CU and date of primocane emergence with emergence being 3 d earlier on plants receiving 720 CU compared to 0 CU ($r^2=0.12; y = -0.0051x + 13.9; P \leq 0.031$). Lopez-Medina and Moore (1999) similarly found that primocanes on chilled root pieces of the primocane-fruiting selection APF-13 emerged earlier than on un-chilled ones.

There was a significant linear relationship between amount of CU and number of days to soft-tipping at 0.5 m, with tipping occurring 9 d earlier on plants receiving 720 CU (17 Aug.) compared to 0 CU (26 Aug.; Fig. 1). The most apical branch on soft-tipped primocanes was significantly ($P \leq 0.001$) longer in plants that received 720 CU for each date measured (Fig. 2).

Primocanes branched heavily after soft-tipping. Previous studies have shown that primocane-fruiting blackberries benefit from tipping (Drake and Clark, 2003; Strik et al., 2007; Thompson et al., 2007; Chapters 2 and 3). There was no significant effect of CU on the number of nodes on the main cane (number of nodes at time of
tipping) or the number of branches per cane, which averaged 14.4 and 10.2, respectively. Thus, a lateral branch developed at nearly every node of the main cane, after soft tipping. This differs from our previous research, where ‘Prime-Jan’ primocanes soft-tipped at 1.0 m rarely developed more than five branches, on average (Thompson et al., 2007; Chapter 2). A shorter tipping height and better light exposure resulting from thinning canes in the pots may have promoted greater branching in this study than in our previous work.

Plants receiving chilling (240-720 CU) produced primocanes with a significantly greater total branch length (Fig. 3), average branch length (0.6 and 0.4 m for chilled and un-chilled, respectively; \( P \leq 0.0001 \)), and average branch node number (17.2 and 14.2 for chilled and un-chilled, respectively; \( P \leq 0.01 \)) than un-chilled plants. There was no effect of CU on total branch node number, agreeing with previous work on A-1836, a floricane-fruiting parent of ‘Prime-Jan’ (Lopez-Medina and Moore, 1999). Primocanes on chilled plants thus produced branches with longer internodes.

The amount of CU plants received had the greatest effect on primocane fruitfulness. There was a positive relationship between amount of CU and average reproductive nodes (Fig. 4) and percent reproductive nodes per branch (Fig. 5).

Branches differed in the number of reproductive nodes (Table 1). In general, basipetal branches developed later and were more elongated and less floriferous than apical branches. Thompson et al. (2007; Chapter 2) observed a similar growth pattern in basipetal branches on soft-tipped (1 m) primocanes of ‘Prime-Jan’ and ‘Prime-Jim’; lower branches often remained vegetative at the end of the growing season (November). Un-chilled plants developed few reproductive nodes per branch, however, those that did were located in apical node positions.

All plants received 1811 cumulative growing-degree days (GDD) from 30 June to 17 Nov. (Fig. 6). Most primocanes on un-chilled plants remained vegetative; this may be because plants were re-cut at a later date (30 June) than other treatments. Primocanes and floricanes were present in pots when re-cut. Complete removal of the aerial portion of the plants in containers at this stage of the growing season may have stressed plants. It is possible that the floricanes were a stronger nutrient sink than the
crown and roots, and once removed, roots had insufficient reserves to support floral development. Primocanes that received 240 CU were re-cut only 10 d (20 June) prior to un-chilled plants, but developed significantly more reproductive nodes and flowers, yet significantly fewer than treatments that received 480 and 720 CU (re-cut on 30 May and 10 June, respectively). In the field, primocanes that were re-cut at 0.5 m (25 May) re-grew and flowered (Chapter 3); however, field-grown plants may have been less stressed than container-grown plants.

There was no significant relationship between CU and date of bloom. Plants began to bloom 117 d (24 Oct.) after the study began, on average. In general, plants that received more CU had a greater percentage of primocanes that flowered; 88% of plants that received 720 CU flowered, the highest percentage for any treatment, while only 13% of canes from un-chilled plants flowered. Sixty-nine percent of plants that received 240 and 480 CU produced flowering primocanes.

Drake and Clark (2000) determined that the floricanes of ‘Arapaho’, a parent of ‘Prime-Jan’, had a chilling requirement between 400-500 h. ‘Arapaho’ is also the parent of ‘Prime-Jim’, the only other primocane-fruiting blackberry currently commercially available. Carter et al. (2006) found that floricane stem cuttings of two-year-old, field grown ‘Prime-Jim’ had a chilling requirement of 100-200 h (<7 °C), yet a significant increase in budbreak (43%) was observed at 400 h. Maximum budbreak (67%) was observed at 800 h. Floricane cuttings of ‘Prime-Jan’ had 50% budbreak after 300 h of chilling. Field observations revealed 100% budbreak for ‘Arapaho’, ‘Prime-Jim’, and ‘Prime-Jan’ after 1448 h chilling. Although the floricanes of primocane-fruiting blackberries will break dormancy between 200-500 h of chilling, uniformity of budbreak seems to improve after floricanes receive more chilling hours.

From previous work on ‘Prime-Jan’ (Strik et al., 2007; Chapter 3), production of a primocane-only crop in a mild climate is suitable for late-season production (Sept.-Oct.), particularly if soft-tipped. Chilling in floricanes can thus be disregarded, as primocanes may be pruned to the ground after fruiting. In a low chill environment, it is possible that multiple primocane crops could be harvested via intensive tipping and pruning treatments.
In conclusion exposure of ‘Prime-Jan’ plants (crown and roots) to 480 CU seemed to provide the greatest benefit for primocane production in terms of hastened primocane emergence, branch elongation, and increased development of reproductive nodes. Re-cutting potted plants in late June (0 to 240 CU) may have been detrimental to floral development if plants were stressed. In study I, where plants received 0 to 960 CU during the normal winter growth cycle, we observed a positive response to chilling on flowering even though the study could not be carried out long enough to have definitive data. It is thus necessary to repeat this study.

Table 1. Mean number of reproductive nodes for branches 1-8 in ‘Prime-Jan’ exposed to four chilling treatments.

<table>
<thead>
<tr>
<th>Chilling (h)</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
<th>B5</th>
<th>B6</th>
<th>B7</th>
<th>B8</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.0 b</td>
<td>2.2 c</td>
<td>2.0 b</td>
<td>0.8 b</td>
<td>0.4 c</td>
<td>0.0 c</td>
<td>0.0 c</td>
<td>0.0 b</td>
</tr>
<tr>
<td>240</td>
<td>7.1 a</td>
<td>5.5 b</td>
<td>3.9 b</td>
<td>2.2 b</td>
<td>2.8 b</td>
<td>2.4 b</td>
<td>2.5 b</td>
<td>2.3 a</td>
</tr>
<tr>
<td>480</td>
<td>8.8 a</td>
<td>7.9 a</td>
<td>7.1 a</td>
<td>5.1 a</td>
<td>5.1 a</td>
<td>4.5 a</td>
<td>2.9 ab</td>
<td>2.8 a</td>
</tr>
<tr>
<td>720</td>
<td>9.0 a</td>
<td>8.4 a</td>
<td>7.2 a</td>
<td>5.3 a</td>
<td>4.1 ab</td>
<td>4.5 a</td>
<td>4.8 a</td>
<td>3.3 a</td>
</tr>
</tbody>
</table>

²Branches 1-8 (B1-B8) from the most apical node to basal node on the main cane; average of two canes/plant (n=16).

³Means separated within columns followed by the same letter are not significantly different. Means separated by Fisher’s Protected LSD (P<0.05).
Fig. 1. The number of days to tipping primocanes at 0.5 m in ‘Prime-Jan’, as affected by the number of chilling hours (~2°C); mean ± SE (P ≤ 0.01; r² = 0.17; y = -0.014x + 57.1; n=16).

Fig. 2. Apical branch length for all chilling treatments in the 2006 growing season.
Fig. 3. Total branch length in ‘Prime-Jan’ as affected by the number of hours of chilling (~2 ºC); mean ± SE ($r^2=0.18; y = 0.25x + 4.9; P \leq 0.0006; n=16$).

Fig. 4. Average number of reproductive nodes/branch in ‘Prime-Jan’ as affected by the number of hours of chilling (~2 ºC); mean ± SE ($r^2=0.42; y = 0.006x + 1.25; P \leq 0.0001; n=16$).
Fig. 5. Percent reproductive nodes/branch in ‘Prime-Jan’ as affected by the number of hours of chilling (~2 °C); mean ± SE ($r^2$=0.37; $y = 0.034 x + 8.07$; $P \leq 0.0001$; n=16).

Fig. 6. Cumulative growing degree days (GDD; base and max. temperature of 10 and 31 °C) from 30 June to 17 Nov. 2006 at the North Willamette Research and Extension Center, Aurora, Ore.


CHAPTER 5

Season Extension of Primocane-fruiting Blackberry using Pruning, Tipping and High Tunnels

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Abstract

Primocane-fruiting blackberries (*Rubus* subgenus *Rubus* Watson) may offer opportunities for season extension and off-season fruit production, particularly in mild climates with protected cultivation. In May 2005, ‘Prime-Jan®’ was established at the North Willamette Research and Extension Center, Aurora, Ore., under a mild winter climate (45ºN). Half of the planting was established under a Haygrove tunnel, and the remainder planted in an adjacent field with no tunnel protection. Throughout the growing season, primocanes were managed under four treatments to promote branching and/or delay harvest: 1) re-cut primocanes [to crown] at 0.25 m, then “soft-tip” [2 to 5 cm of tip removed] at 0.5 m, 2) re-cut primocanes at 0.5 m, then soft-tip at 0.5 m, 3) double-tip (soft-tip at 0.5 m, then soft-tip branches at 0.5 m), and 4) soft-tip at 0.5 m (control). Plastic was placed over the tunnel on 5 Sept. 2006 to protect fruit from inclement weather. Harvest began on 14 Sept. and lasted until 26 Oct. in the field, and 15 Nov. in the tunnel. Primocanes that were double-tipped had nearly twice the flowers and fruit than canes that were soft-tipped only once. Also, double-tipped primocanes developed larger fruit than any other treatment, on average. Harvest was not delayed in canes that were re-cut at 0.25 m, compared with the control and the double-tipped treatment. In contrast, harvest was delayed by about 4 weeks when primocanes were re-cut at 0.5 m. Although fruit under the tunnel was protected from rain, quality began to decline in late October, likely due to cool night temperatures.

Introduction

The ability to produce fruit in the off-season clearly offers an economic advantage in the fresh market. The target for off-season fresh market blackberry harvest in North America is from mid-Sept. through Oct., before imports from Mexico and Guatemala begin (Mark Hurst, Hurst’s Berry Farm, Sheridan, Ore., personal communication). Blackberry prices are highest during this annual lag period in fruit production.
As with primocane-fruiting raspberry, blackberries of this type may offer the advantage of extending the harvest into the autumn and winter months, particularly in milder climates (average annual minimum temperature $\geq -12 ^\circ C$). Oliveira et al. (1994, 1996, 1998, 1999, 2004) and Jordan and Ince (1986) have shown that harvest of primocane-fruiting raspberry can easily be delayed in production systems that include summer pruning of primocanes, tipping and tunnel protection. With the use of greenhouses, scheduling primocane-fruiting raspberry for year-round production is possible (Dale et al., 2001; 2005), and often includes the combination of floricane- and primocane-fruiting cultivars (Bal and Meesters, 1992; Djikstra and Scholtens, 1993; Faby, 1993; Hamminga, 1995; Oliveira et al., 2002). Scheduling floricane-fruiting blackberries for year-round production has been reported using artificial chilling and forcing in greenhouses (Bal and Meesters, 1995).

Few studies on primocane-fruiting blackberry production have been done, as this crop is too new. Strik et al. (2007) studying ‘Prime-Jan’ and ‘Prime-Jim’ in Oregon noted that when harvest in unprotected fields was curtailed in Oct. due to rain, there were still flower buds, flowers, and unripe fruit present on most treatments, particularly those tipped at 1 m (compared to an un-tipped control). A tunnel would have allowed for much later harvest.

Currently, no information is available on extended-season production systems for primocane-fruiting blackberry. The objectives of this study were to: 1) determine the impact of summer pruning [re-cutting to crown] and soft-tipping in ‘Prime-Jan’ on yield and fruiting season extension and 2) target blackberry harvest for mid-Sept. through Oct. with the aid of a tunnel in western Oregon.

Materials and Methods

Tissue cultured plugs (300 count; approx. 6 wk. old) of ‘Prime-Jan’ (Sakuma Bros. Nursery, Burlington, Wash.) were received 19 Nov. 2004 and potted into 10 cm Gage Dura Pot containers (Gage Industries, Lake Oswego, Ore.) using a soil-less, peat-based bedding plant mix #2 (OBC Northwest, Canby, Ore.). Plants were fertigated weekly using a Hozon brass siphon mixer (1:16 ratio) at 100 ppm with
Scotts General Purpose 20N-4P-14K complete water-soluble fertilizer (The Scotts Co., Marysville, Ohio). Plants were repotted on 19 Jan. and 15 Mar. 2005 into 15 cm Gage Dura Pot and 7.5 L Classic containers (Nursery Supplies Inc., McMinnville, Ore.), respectively, and maintained as aforementioned. Plants were kept in a greenhouse under long day lighting conditions (18 h day, 6 h night) with min. and max. daily temperatures of approx. 11 °C and 29 ºC, respectively, from 19 Nov. 2004 to 18 April 2005. Plants were then transported to the Oregon State University’s North Willamette Research and Extension Center (NWREC), Aurora, Ore. [lat. 45°17 ’N, long. 122°45 ’W; U.S. Dept. of Agriculture (USDA) hardiness zone 8; elev. 46 m above sea level; average last freeze date 17 April; average first freeze date 25 Oct.; the weather records for this site can be viewed at Anonymous (2005)], and hardened off in a protective, retractable roof Cravo greenhouse (Cravo Equipment Ltd., Brantford, Ont., Can.).

On 6 May 2005, 160 ‘Prime-Jan’ plants were planted at the NWREC in a Willamette soil type (fine-silty, mixed Mesic Pachic Ultic Argixerolls) [pH 5.6; 5 t/ha dolomite (CaMg(CO3)2), 48 kg K, and 2.7 kg B added to soil in the fall prior to planting]. Half of the plants (80 count) were placed in an uncovered Haygrove tunnel [61 x 8.5 m] (Haygrove Tunnels, Herefordshire, UK). Plants were spaced 0.6 m in the row with 3 m between rows. Five-plant plots were 3 m long with 1.5 m separating plots.

The tunnel and field plantings were drip irrigated (3.8 L/hr emitters at 0.6 m spacing) as required, typically 30 min. twice daily (3.8 L/d), from June through Sept., and 15 min. every other day (0.95 L/d) in Oct. and Nov. Luminance THB (Visqueen Building Products BPI, London, UK) plastic film (6 mm) was placed over the Haygrove tunnel on 5 Sept. 2006 and removed on 13 Nov, just before the final harvest. When present, plastic only covered the roof of the tunnel; the sides (1.5 m) and ends (8.5 m) were left open. No supplemental heat was provided in the tunnel.

Plots were fertilized with 55 kg of N, 15.4 kg of P, and 54.8 kg of K each spring, respectively. Weeds were controlled by use of pre-emergent herbicides and mechanical methods. Row width was maintained at 0.45 m using cultivation. In the
planting year, plants grew un-trained and un-manipulated. No trellis wires were used in 2005 or 2006.

There were four replicates of the following treatments arranged as a randomized complete block design in the tunnel and field: 1) primocanes re-cut at 0.25 m, then “soft-tipped” [2 to 5 cm of the tip removed] at 0.5 m, 2) primocanes re-cut at 0.5 m, then soft-tipped at 0.5 m, 3) primocanes double-tipped [main cane + any branches soft-tipped at 0.5 m], 4) primocanes soft-tipped at 0.5 m (control).

In the planting year (2005), plants grew un-manipulated and no data were collected. Data collection per plot in 2006 included: dates of primocane emergence, soft-tipping, flowering and terminal black fruit, primocane height at bloom, apical branch length (biweekly), number of fruiting and non-fruiting canes, average fruiting and non-fruiting cane length, and plot fresh weight. A sub-sample of three primocanes per plot was collected for: branch number, total branch length, total node number (main cane + branches), number of reproductive nodes per branch (nodes which bore a flower bud or fruiting lateral), percent reproductive nodes calculated (proportion of nodes that developed a flower bud or fruiting lateral). During fruit harvest, average berry weight (n=25) was recorded and sub-samples (n=5) frozen for later counts of drupelets and unset ovules; total ovules per flower was calculated by adding set drupelets and un-set ovules.

Photosynthetically active radiation (PAR; μmol·m⁻²·s⁻¹; averaged over 15 s) was measured on full sun days using a LI-250 photometer (LI-COR Biosciences, Lincoln, Neb.) in the tunnel and field during early, mid-, and late season fruit harvests. Photometer readings were collected one hour before, during, and one hour after solar noon at upper canopy height (1.0 m). Percent soluble solids (ºBrix) was determined with an Atago Palette PR-100 digital refractometer (Atago, Tokyo, Jap.) using pooled samples of berries from all treatments in the tunnel and field during early (21 Sept.) and mid-season harvests (12 Oct.). Mid-canopy (0.5 m) and soil temperatures (5 and 10 cm depth) were collected using Hobo H8 data loggers with external sensors; ambient air temperature and relative humidity (RH) data were collected using HOBO Pro Series data loggers (Onset Computer Corp., Bourne, Mass.).
Growth of apical branch length over time for each treatment was analyzed using repeated measures (PROC GLM). The sub-sample data collected for each plot were averaged before data analysis using PROC GLM. Data collected on PAR, °Brix, drupelet number, and temperature were averaged before data analysis using PROC GLM (version 9.1, SAS Institute Inc., Cary, N.C.). The tunnel and field-grown treatments could not be compared statistically, as the plots were adjacent and not replicated. Thus, trends in the data are described.

**Results and Discussion**

“Soft-tipped” primocanes will be referred to as “tipped.” Primocanes that received pruning + tipping treatments will be referred to as “re-cut”, as all treatments were tipped at 0.5 m. The term “culture” will be used to collectively refer to production types: tunnel and field.

**Growth:** Primocanes emerged beginning in early Feb. 2006. Growth of ‘Prime-Jan’ was affected by primocane management treatment. Culture did not affect primocane growth, as there was no plastic on the tunnel until 5 Sept. 2006, when growth had slowed and fruit ripening began. Primocanes that grew after re-cutting at 0.5 m (re-cut on 15 May; tipped on 3 July; Fig. 1) were significantly delayed in growth at the end of the growing season; apical branch length averaged 0.45 m (Fig. 2). In contrast, the apical branch length of primocanes that were tipped at 0.5 m (control) (tipped on 15 May; Fig. 1) averaged 1.1 m; this treatment consistently had the longest apical branch length throughout, and at the end of the growing season (Fig. 2). Primocanes that grew after re-cutting at 0.25 m (re-cut on 26 Apr.; tipped on 7 June; Fig. 1) or double-tipped (main cane tipped on 15 May; branches tipped beginning 3 July; Fig. 1) produced apical branches of similar length, averaging 0.8 m at the end of the season. Average branch length (apical + lower branches) and node number were not significantly affected by treatment, averaging 0.4 m and 96 nodes, respectively.

**Flowering:** Flower bud development largely occurred when plastic was absent on the tunnel. On average, primocanes that were double-tipped developed
twice the number of reproductive nodes and fruiting sites, and tended to have a higher average percentage of reproductive nodes than any other treatment (Table 1). Soft-tipped branches typically developed 2-3 inflorescences (0.1 to 0.15 m in length), whereas an un-tipped branch (as on the control) terminated in a single inflorescence. Other studies on ‘Prime-Jan’ showed that soft-tipping removed apical dominance and promoted branching (Strik et al., 2007; Thompson and Strik, 2007; Chapters 2 and 3). Soft-tipping branches likely has a similar effect on promoting inflorescence development. Primocanes that were tipped at 0.5 m (control) tended to have the fewest number and percentage of reproductive nodes and number of fruiting sites (Table 1).

Bloom was significantly delayed in primocanes after re-cutting at 0.5 m (13 Aug.) compared to other treatments (26 Jul.; Fig. 1). Primocanes were significantly longer (1.4 m; \( P \leq 0.001 \)) at bloom in plants that were tipped at 0.5 m than primocanes that were double tipped or re-cut at 0.25 m (1.2 m), on average. Primocanes that grew after re-cutting at 0.5 m were significantly shorter at bloom than any other treatment, averaging 0.98 m.

**Fruit:** The date of first fruit harvest was similar in the tunnel and field; the plastic was not placed on the tunnel until 5 Sept. The average date of the terminal fruit turning fully black was significantly delayed in primocanes that grew after re-cutting at 0.5 m (15 Oct.; \( P \leq 0.001 \)), compared to all other treatments (12 Sept.). Harvest began on 14 Sept. in all treatments except those that were delayed because primocanes were re-cut at 0.5 m (harvest began 12 Oct.; Fig. 1). Tunnel protection extended fruit harvest by three weeks, thus cumulative yield for all treatments, except the control (tipped at 0.5 m), was higher in the tunnel (Table 2; Fig.3). In the tunnel, cumulative yield was significantly higher in double-tipped primocanes than all other treatments, averaging 9.9 kg/plot (10.7 t/ha; Table 2). Cumulative yield for double-tipped primocanes was 41% less (5.8 kg/plot; 6.2 t/ha) in the field than in the tunnel (Table 2). Plots that were re-cut at 0.25 m consistently produced the highest number of canes per plot that fruited (Table 1). The number of non-fruiting canes was similar for all treatments, averaging three per plot (data not shown).
In the tunnel, average berry weight was significantly greater in double-tipped primocanes than all other treatments (Table 2; Fig. 4). In the field, primocanes that grew after re-cutting at 0.5 m produced significantly smaller fruit, however, there were no significant differences in berry weight among the other treatments (Table 2).

Counts of drupelets and unset ovules indicated that flowers on primocanes that were double-tipped did not have more ovules, but had significantly more drupelets set compared to primocanes tipped at 0.5 m (Fig. 5). Primocanes from both tipping treatments tended to have more ovules in the early harvest season, but a lower percentage of drupelets set; the opposite occurred in the late harvest season (Fig 6). This is perhaps because the first, and often largest, fruit develop on the apices of the primary and secondary floral axes, as described in Thompson and Strik (2007; Chapter 2). Thus berry weights are generally greater in the early harvest season, and decline over time as fruits on tertiary and quaternary axes ripen. Berry weights in all treatments declined in the late harvest season. Further, ovule viability and receptivity to pollen grains has been shown to decline with exposure to high temperatures (29-35 °C; Stanton et al., 2007). Higher temperatures in the early harvest season may have thus reduced ovule viability and receptivity, leading to a decrease in the percentage of drupelets set.

Presence of plastic on the tunnel did not affect percent soluble solids of ripe fruit, which averaged 12 °Brix in the tunnel and field, during early (21 Sept.) and mid-season (12 Oct.) harvests. Photosynthetically active radiation (PAR) was consistently reduced under the tunnel for all sampling dates, by 31% on average. Harvest in the field stopped on 26 Oct. due to rain; harvest in the tunnel continued until 16 Nov. In the tunnel, fruit ripening began to slow (drupelets remained red) and overall quality began to decline (winter winds desiccated fruit) with cool Oct. and Nov. temperatures. The tunnel had no effect on canopy and soil temperature, or relative humidity (RH). Average monthly temperature and RH data for 2006 are presented in Fig. 7.

Using a tunnel to extend the fruiting season for ‘Prime-Jan’ is feasible in western Oregon. Primocanes that were more intensely managed (i.e. double-tipped) responded most favorably in terms of growth, time of harvest, and yield. Thompson et al. (2007; Chapter 2) studying ‘Prime-Jan’ and ‘Prime-Jim’ found that tipped
primocanes (1.0 m) developed twice the amount of flowers as un-tipped canes. Strik et al. (2007) reported that tipping primocanes at 1.0 m advanced harvest, increased yield and berry weight in ‘Prime-Jan’ and ‘Prime-Jim’, compared with un-tipped canes. In our study, double-tipping ‘Prime-Jan’, in combination with protected culture, increased yield by 73 and 61% (10.7 t/ha) compared to soft-tipping at 0.5 m in the tunnel (2.9 t/ha), and soft-tipping at 1.0 m in the field (4.2 t/ha; Strik et al., 2007), respectively. The yield and quality we obtained in our study likely make tunnel production an economically viable option for growers.

Berry weight and drupelet set in double-tipped plots was consistently higher than other treatments. This was likely due to better pollination. Double-tipped plots had a greater concentration of flowers per plot, with good uniformity among primocanes; pollinators (A. mellifera, Bombus spp.) were attracted to this (Ellen Thompson, personal observation). The plastic covering the tunnel did not seem to inhibit pollinator flight or movement.

Double-tipped primocanes had the highest yields during early Oct., well within our objectives for target harvest dates, before imports from Mexico begin and prices for fresh market blackberry are highest. Plots that were re-cut at 0.5 m produced primocanes that were significantly delayed in growth, flowering and fruiting. Yields were also greatly reduced due to the shortened growing season, low light and cool autumn temperatures. Similar results have been reported in primocane-fruiting raspberry. In Portugal, Oliveira et al. (1994, 1996, 1998, 1999, 2004) found that re-cutting primocane-fruiting raspberries in July and Aug. extended the harvest season to Dec. and Jan., but low light and temperature limited yields. Biomass removal (re-cutting) of actively growing primocanes during the summer removes a large amount of soluble protein and carbohydrate photoassimilates in the whole plant system. Oliveira et al. (2007) found that primocanes of ‘Autumn Bliss’ that had been re-cut in late July had low yields, yet high levels of reserves in the roots at the end of harvest in Dec. It is unclear whether these plants accumulated root reserves at the expense of fruiting. However, under growth-limiting conditions (low light, cool temperature), it is possible that the root system sink was stronger than the fruiting sink. Since re-cutting primocanes in the summer did not deplete carbohydrate reserves in ‘Autumn Bliss’, it
remains a viable option for season extension. The same may be true for primocane-fruited blackberry.

From a management perspective, tunnel plastic placement, removal, and venting during wind events are labor intensive. However, because double-tipped primocanes were manually “hedged”, no trellis was necessary. All other treatments would have benefited from trellising.

Table 1. The effect of re-cutting, tipping, and culture on flowering and fruiting of primocanes in ‘Prime-Jan’ (n=4; mean ± SE), NWREC, 2006.

<table>
<thead>
<tr>
<th>Culture</th>
<th>Treatment</th>
<th>Total nodes/cane</th>
<th>Fruiting sites/cane</th>
<th>Reproductive nodes (%)</th>
<th>Fruiting canes/plot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunnel</td>
<td>Re-cut 0.25 m</td>
<td>64 ± 9.6</td>
<td>41 ± 2.6 b</td>
<td>52</td>
<td>54 ± 7.5 a</td>
</tr>
<tr>
<td>Tunnel</td>
<td>Re-cut 0.5 m</td>
<td>61 ± 6.2</td>
<td>48 ± 5.3 bc</td>
<td>68</td>
<td>34 ± 15.4 b</td>
</tr>
<tr>
<td>Tunnel</td>
<td>Double-tip</td>
<td>106 ± 8.7</td>
<td>111 ± 12.1 a</td>
<td>74</td>
<td>29 ± 3.9 b</td>
</tr>
<tr>
<td>Tunnel</td>
<td>Tip 0.5 m (control)</td>
<td>155 ± 28.1</td>
<td>27 ± 2.3 c</td>
<td>18</td>
<td>29 ± 2.7 b</td>
</tr>
<tr>
<td>Field</td>
<td>Re-cut 0.25 m</td>
<td>58 ± 3.9</td>
<td>44 ± 4.5 ab</td>
<td>58</td>
<td>56 ± 5.4 a</td>
</tr>
<tr>
<td>Field</td>
<td>Re-cut 0.5 m</td>
<td>58 ± 9.2</td>
<td>26 ± 7.0 b</td>
<td>40</td>
<td>46 ± 4.0 b</td>
</tr>
<tr>
<td>Field</td>
<td>Double-tip</td>
<td>73 ± 8.2</td>
<td>56 ± 5.3 a</td>
<td>67</td>
<td>48 ± 6.5 ab</td>
</tr>
<tr>
<td>Field</td>
<td>Tip 0.5 m (control)</td>
<td>81 ± 3.4</td>
<td>23 ± 7.5 b</td>
<td>36</td>
<td>41 ± 7.8 b</td>
</tr>
</tbody>
</table>

Significance: NS, *, **, ***= Non-significant or significant at P ≤ 0.05, 0.01, or 0.001, respectively, within culture.

z Average total number of nodes/cane (main cane + branches).
y Average total flowers/cane.
x Average number of canes per plot that fruited (n=4).

NS, *, **, ***= Non-significant or significant at P ≤ 0.05, 0.01, or 0.001, respectively, within culture.
Table 2. The effect of primocane management on yield and berry weight of ‘Prime-Jan’ grown in field and tunnel at the NWREC, 2006 (n=4; mean ± SE).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Tunnel Yield (kg/plot)$^z$</th>
<th>Tunnel Berry wt. (g)$^y$</th>
<th>Field Yield (kg/plot)</th>
<th>Field Berry wt. (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Re-cut 0.25 m</td>
<td>5.4 ± 0.6 b</td>
<td>5.0 ± 0.1 b</td>
<td>4.3 ± 0.6 ab</td>
<td>3.4 ± 0.4 a</td>
</tr>
<tr>
<td>Re-cut 0.5 m</td>
<td>1.5 ± 0.3 c</td>
<td>4.0 ± 0.5 c</td>
<td>0.3 ± 0.09 c</td>
<td>1.9 ± 0.5 b</td>
</tr>
<tr>
<td>Double-tip</td>
<td>9.9 ± 1.2 a</td>
<td>6.8 ± 0.1 a</td>
<td>5.8 ± 1.0 a</td>
<td>4.1 ± 0.4 a</td>
</tr>
<tr>
<td>Tip 0.5 m (control)</td>
<td>2.7 ± 0.4 c</td>
<td>4.4 ± 0.2 bc</td>
<td>2.8 ± 0.5 b</td>
<td>3.1 ± 0.4 a</td>
</tr>
</tbody>
</table>

Significance$^w$: *** *** *** *

$^z$ Average cumulative yield/plot (n=4).
$^y$ Average berry weight for harvest 2006.
$^w$ NS, *, **, *** = Non-significant or significant at P ≤ 0.05, 0.01, or 0.001, respectively, within tunnel or field.
Fig. 1. Dates of primocane emergence (E), re-cutting (C), tipping primocanes at 0.5 m (T), tipping branches at 0.5 m (Tb), average bloom (B), beginning of harvest (H0), 50% harvest (H1), and final harvest (Hf) in field and tunnel production at the NWREC, 2006.

Fig. 2. Apical branch length in ‘Prime-Jan’ for various primocane management treatments (averaged over tunnel and field; n=8; mean ± SE).
Fig 3. Cumulative yield (kg/plot) of ‘Prime-Jan’ as affected by primocane management system in the tunnel and field, NWREC, 2006 (n=4).

Fig. 4. Average berry weight (mean ± SE) for ‘Prime-Jan’ that were double-tipped (main cane and branches at 0.5 m) or re-cut at 0.5 m in the tunnel and field, NWREC, 2006.
Fig. 5. The number of drupelets and total ovules of fruit from double-tipped and soft-tipped (control) primocanes from an early (9/21/06) and late harvest (10/19/06) in the tunnel and field combined (n=5).

Fig. 6. The average percentage of drupelets set from flowers on primocanes that were double-tipped and tipped at 0.5 m (“Tip 0.5 m (control)”) from the early (21 Sept.) and late (19 Oct.) harvest season, 2006 in the tunnel and field combined (n=5).
Fig. 7. Average monthly canopy (0.5 m) and soil temperature (0.05 and 0.1 m) and percent relative humidity in tunnel and field combined, 2006.

**Literature Cited**


Chapter 6

General Conclusion

Growth, flowering, and fruiting of ‘Prime-Jan’ and ‘Prime-Jim’ responded favorably to soft-tipping of primocanes. Soft-tipping primocanes at 1.0 m increased the number of flowers, and subsequent yield, compared to un-tipped primocanes. In both cultivars, soft-tipping primocanes at 0.5 or 1.0 m resulted in similar yields. Yield, and plant manageability, was further increased in ‘Prime-Jan’ by double-tipping primocanes. Plants that were double-tipped grew as a hedge, and did not require a trellis for support. Double-tipping appears to be the optimum management technique for ‘Prime-Jan’. ‘Prime-Jim’ responded similarly to tipping at 0.5 and 1.0 m as ‘Prime-Jan’, and likely would respond similarly to double-tipping.

The chilling requirement for primocane production and fruitfulness in ‘Prime-Jan’ has yet to be determined. Thus far, it appears that roots and crown do not require any exposure to chilling for primocane growth and bloom to occur, but primocane fruitfulness may increase with chilling. Exposure of plants to 480 CU seemed to provide the greatest benefit in terms of reproductive node and subsequent flower development. It is critical to understand the number of hours to satisfy dormancy, if any, particularly for low-chill production areas, such as California and Mexico. Year-round production of primocane-fruiting blackberry may be easier to achieve once the chilling requirement of primocanes is better understood. In combination with floricane-fruiting types, primocane-fruiting blackberry may one day share a year-round production schedule, or a variation thereof, with red raspberry.

With the use of a tunnel, season extension is possible in western Oregon. Although harvest was successfully delayed by re-cutting primocanes at 0.5 m, yield, fruit size, and overall quality were low. Again, the double-tipped treatment provided the highest yield at the optimum off-season target dates, in late September and early October. Re-cutting primocanes, in combination with double-tipping, may improve yield and delay harvest.
In conclusion, double-tipping primocanes may currently be the most ideal management technique for primocane-fruiting blackberry. Future management techniques may need to be adapted as subsequent primocane-fruiting cultivars are released for commercial fresh market production.


Hurst, Mark. Hurst’s Berry Farm, Sheridan, Ore. Personal communication.


