Weed control increases growth, cumulative yield, and economic returns of machine-harvested organic trailing blackberry

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Abstract

A trailing blackberry planting was established at Oregon State University's North Willamette Research and Extension Center (Aurora, OR, USA) in 2010 to evaluate cultivar and weed management practices for a machine-harvested, processed fruit market. The planting was 0.4 ha in size and was certified organic (Oregon Tilth) in 2012, prior to the first harvest. Treatments studied were cultivar ('Marion' and 'Black Diamond') and in-row weed management [non-weeded, hand-weeded, and a porous, polyethylene ground cover (weed mat)] during establishment and three fruiting seasons (2012-2014). On average, plants growing in hand-weeded and weed mat plots produced 50% more primocanes than those in non-weeded plots, but the resulting floricane biomass was 50% higher in weed mat plots than either hand-weeded or non-weeded plots. This difference in plant growth response to the weed management treatments led to weed mat plots producing 36.1 t ha^{-1} of cumulative yield, 25 and 100% greater than the hand-weeded and non-weeded plots, respectively. Weed control (either with hand-weeding or weed mat) increased average berry weight compared to the non-weeded plots. Weed mat required a high initial investment to install, but only 16 h ha^{-1} to maintain over the study period (labor was valued at US$ 15 h^{-1}). The non-weeded and hand-weeded treatments required 25 and 215 h ha^{-1} of labor to mow tall weeds prior to harvest or hand hoe, respectively. Total cumulative costs, including materials and installation (weed mat) over the 5 years were US$ 3,302 ha^{-1} for weed mat, US$ 3,231 ha^{-1} for hand-weeded, and US$ 370 ha^{-1} for non-weeded. Despite the relatively low cost of the non-weeded management strategy, low yield significantly reduced net returns (gross fruit sales – weed management costs). The hand-weeded and weed mat management strategies increased net returns by 40 and 71% compared to non-weeded, respectively. Weed mat had a 22% greater cumulative net return than the hand-weeded treatment. Weed mat increased growth, yield, and net returns and appears to be an excellent option for weed management in machine-harvested organic trailing blackberry.

Keywords: landscape fabric, weed mat, *Rubus*, economics, certified organic, weed management, cost

INTRODUCTION

Interest in organic production has been growing due to increased consumer demand for organic products. Worldwide production of organic blackberries was 2500 ha in 2008 (Strik et al., 2008). Oregon is the leading producer of blackberry in the United States with most of the production coming from trailing types for processing (Strik and Finn, 2012). Although interest has been increasing, and there is a growing body of research devoted to blackberry production, there are relatively few publications dedicated to organic production methods. Kuepper et al. (2003) detailed small-scale fresh market production, Harkins et al. (2013, 2014) studied trailing blackberry establishment and the effects of weed management and cultivar, Dixon et al. (2015) continued the work of Harkins et al. (2013) adding the impacts of training and irrigation for mature trailing blackberry, and Fernandez-Salvador et al. (2015a, b) explored a broader selection of trailing cultivars as well as fertilizer options in organic production systems.

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When compared with conventional production, weed management is one of the more expensive management practices in organic production. Chemical control options are limited so hand-weeding and weed barriers are often used (Dixon et al., 2015; Harkins et al., 2013; Makus, 2011; Meyers et al., 2014). Some blackberry growers use no weed control at all, although weeds compete with blackberry and can reduce yield (Dixon et al., 2015; Harkins et al., 2013; Meyers et al., 2014).

'Black Diamond' and 'Marion' are two commonly planted trailing blackberry cultivars in Oregon. Together they accounted for over 75% of the blackberry produced in 2012 (US Department of Agriculture, 2013). 'Marion' is an older cultivar that has been popular, whereas 'Black Diamond' is a newer cultivar from the USDA program, with thornless canes that are preferred because there is no risk of thorny petioles in machine-harvested fruit (Strik and Buller, 2002).

Here we use the findings of Harkins et al. (2013) and Dixon et al. (2015) to determine the effect of weed management systems on the cumulative yield and production costs in 'Black Diamond' and 'Marion' trailing blackberry from establishment through maturity in a certified organic field.

MATERIALS AND METHODS

This study was carried out over the first three fruiting seasons of a trailing blackberry planting at the North Willamette Research and Extension Center in Aurora, OR (lat. 45°16'47"N; long. 122°45'23"W) that was certified organic by a USDA accredited agency (Oregon Tilth, Certified Organic, Corvallis, OR). The soil is a Willamette silt loam, classified as a fine-silty, mixed, superactive mesic Pachic Ultic Argixeroll.

The field was planted in May 2010 with tissue-cultured plants and managed so that 2012 was the first fruiting year. Harkins et al. (2013) and Dixon et al. (2015) described the development of the planting during establishment and maturation, respectively. The study site was arranged as a split-split-split plot design with five replicates. Main plots were comprised of two rows, one of 'Marion' and one of 'Black Diamond' blackberry. Subplots included two irrigation strategies (postharvest and non-postharvest irrigation) and sub-subplots included a combination of three weed management strategies (weed mat, hand-weeded, and non-weeded) and two primocane training dates (August and February) Primocanes were lifted from the ground and wrapped onto two trellis wires (approximately 1.2 and 1.6 m from the ground) either immediately after pruning out the senescent floricanes in August or near the end of the winter in February. Sub-subplots included four plants spaced 1.5-m apart in-row and were separated from plants in adjacent plots by 3.0 m, so that the machine harvester could be cleared. Between row spacing was 3.0 m (2222 plants ha^{-1}). The planting consisted of 120 treatment plots and was surrounded by border plots.

The training time and irrigation treatments were not implemented until after fruit harvest in 2012, so only the two cultivars and three weed management strategies are considered here. In addition, we only report on the treatment combinations that were not irrigated postharvest and had primocanes trained in August. Dixon et al. (2015) found that withholding irrigation postharvest allowed for considerable water savings, reduced weed pressure in the hand-weeded plots, and had no effect on yield, so we chose that treatment for this study.

The planting was fertilized using OMRI-approved (listed by the Organic Materials Review Institute, Eugene, OR) products using standard industry procedures (see Harkins et al., 2013; Dixon et al., 2015 for details of fertilizer applications). During the first fruiting season, 56 kg ha^{-1} N was applied, and 90 kg ha^{-1} N was applied per year once the planting reached maturity.

Weeds in the non-weeded plots were allowed to grow after the planting year. During the fruiting years, weeds were cut to the soil surface and left in the rows prior to machine harvest (in early July) to avoid interference with the catcher plates. Weeds in the hand-weeded plots were removed by hand hoeing as needed throughout the growing season. The weed mat plots were covered in a 1.4-m-wide strip of black woven polyethylene ground cover (TenCate Protective Fabrics; OBC Northwest Inc., Canby, OR) centered on the row and secured using 0.1-m long nails. According to the manufacturer, the weed mat had a density of 0.11 kg m^{-2} and a water flow rate 6.8 L h m^{-2}. Weeds were removed from the planting hole area and the seams of the weed mat, as required. The labor required to weed each treatment was recorded. Labor was valued at $ 15 h^{-1}.

Plants were irrigated based on plant and soil water status using a single lateral of drip tubing (UNIRAM; Netafim USA, Fresno, CA) located under the weed mat or on a 0.3-m-high trellis wire in the other weed management treatments (Harkins et al., 2013; Dixon et al., 2015). The no-postharvest irrigation plots used in this study received irrigation from May 9 to July 30, 2012, May 17 to July 19, 2013, and May 28 to July 15, 2014.

Primocanes were trained to the trellis in mid- to late-August of each year (Harkins et al., 2013; Dixon et al., 2015). Primocanes (at 0.3 m height) were counted on two separate plants in each four-plant plot in January 2012 and 2013, and February 2014 and average primocanes $plant^{-1}$ was calculated. Ripe fruit were harvested twice weekly in July 2012 and June-July 2013 and 2014 using an over-the-row rotary harvester (Littau harvesters Inc., Stayton, OR) and weighed for total yield in each plot. A subsample of 25 berries was randomly selected from the machine-harvested, marketable yield of each plot and weighed; a weighted average for individual fruit weight was calculated for the fruiting season.

Senescing floricanes were removed by pruning at the base of the plant (approximately 0.1-m high) after fruit harvest each year from late-July to early-August, per standard commercial practice in Oregon (Strik and Finn, 2012). Two floricanes were randomly selected per plot and measured for length. Percent budbreak was calculated from the number of nodes and the number of laterals, and fruit/lateral (subsample of 10 laterals) was counted. The total fresh biomass of the pruned floricanes was determined per plot. A subsample of the pruned canes in each plot was shipped overnight to Brookside Laboratories (New Bremen, OH) for analysis of percent moisture content. Dry weight was then calculated. After pruning and data collection, the floricanes were left between the rows and flail-mowed (chopped), per standard commercial practice.

Average primocane number, individual fruit weight, floricane dry weight, floricane length, budbreak, and fruit/lateral were calculated for each treatment combination over the three fruiting years. Total cumulative yield was also calculated.

Data were analyzed as a split plot design with cultivar as the main plot factor and weed management as the subplot factor, using PROC MIXED in SAS (version 9.3; SAS Institute Inc., Cary, NC). Residuals were plotted to assess homogeneity of variance (residual by fitted value plot). When strong fanning was observed in the residual plots, the data were log-transformed prior to analysis to improve homogeneity of variance and to assess proportional effects. Data were back-transformed for presentation. Normality was assessed using a histogram of the residuals. Means from significant main effects were compared using a Tukey's honestly significant difference test with α=0.05.

RESULTS AND DISCUSSION

Cultivar and weed management affected most of the variables measured, however, there were no significant interactions between them (Table 1). 'Black Diamond' produced shorter canes and 23% less floricane biomass per plant on average over the 3 years, but it had higher budbreak and 27% greater cumulative yield than 'Marion'. Previous studies have found that resource limitation likely restricts budbreak in longer canes (Bell et al., 1995; Cortell and Strik, 1997). 'Black Diamond' had greater individual fruit weight than 'Marion', similar to results from previous studies (Dixon et al., 2015; Harkins et al., 2013). There have been varying results on whether 'Black Diamond' produces more yield than 'Marion' (Dixon et al., 2015; Fernandez-Salvador et al., 2015a; Harkins et al., 2013).

Weed management effects were also clear. Weed control, either hand-weeded or weed mat, increased individual fruit weight and there was a trend for increased primocane number per plant (P=0.07), over the non-weeded treatment. Hand-weeded plots produced plants with the most fruit per lateral, although only significantly more than the weed mat plots. Floricane biomass increased 50% under the weed mat treatment, but hand-weeded and non-weeded plots produced the same amount. Makus (2011) also observed that weed mat increased erect blackberry vigor as compared with bare soil.

Table 1. Growth, yield, and fruit weight in organic machine-harvested trailing blackberry grown at the North Willamette Research and Extension Center, Aurora, OR, (2012-2014) for plots that received no irrigation postharvest and were trained in August of each year (2222 plants ha^{-1}).

Treatment[1]	Primocane number $plant^{-1}$	Floricane dry wt (kg $plant^{-1}$)	Floricane length (m)	Budbreak (%)	Fruit per lateral	Total cumulative yield (kg $plant^{-1}$)	Fruit wt (g)
Cultivar (C)							
Black Diamond	5	1.0 b	4 b	59 a	8.0	14 a	5.5 a
Marion	6	1.3 a	6 a	46 b	6.7	11 b	5.1 b
Weed management (W)							
Non-weeded	4	0.9 b	5	54	7.4 ab	8 c	5.0 b
Hand-weeded	6	1.1 b	5	53	7.6 a	13 b	5.5 a
Weed mat	6	1.5 a	6	50	6.9 b	16 a	5.4 a
Significance[2]							
C	NS	<0.0001	0.0038	0.005	NS	0.0113	0.044
W	NS	<0.0001	NS	NS	0.0443	<0.0001	<0.0001
C×W	NS	NS	NS	NS	NS	NS	NS

[1]Treatment effects were averaged over 2012–2014, except for total cumulative yield, which was summed over the three years.
[2]NS=non-significant; P-values provided for significant factors.

Weed management had a marked effect on cumulative yield. Not only did weed mat increase yield 100% over the non-weeded treatment, it increased yield 23% over the hand-weeded treatment. These results are similar to previous results in trailing blackberry as well as those in erect blackberry and blueberry (*Vaccinium corymbosum* L.) (Dixon et al., 2015; Harkins et al., 2013; Krewer et al., 2009; Makus, 2011; Meyers et al., 2014). Since the hand-weeded and weed mat treatments both resulted in the blackberry plants growing weed free, it is uncertain why they differed in vegetative production and yield. It is possible that young weeds present before each hoeing date were in competition with the plants (Dixon et al., 2015).

The three weed management treatments also differed in material and labor costs. The weed mat treatment cost US$ 1600 ha^{-1} $year^{-1}$ amortized over 5 years (2010, the planting year, through 2014, the third fruit harvest) to purchase, install, and cut holes in for the plants (Harkins et al., 2013). The non-weeded and hand-weeded treatments did not have upfront material costs, but they required more labor to maintain throughout the study. The weed mat treatment required a cumulative 16 h ha^{-1} to maintain over 5 years while the non-weeded and hand-weeded treatments required 25 and 215 h ha^{-1} of labor, respectively, to mow tall weeds prior to harvest or hand hoe. The cumulative labor and materials costs for the weed mat, hand-weeded, and non-weeded management treatments were US$ 3302, 3231, and 370 ha^{-1}, respectively. Net returns for the three weed management treatments over the 5 years of the study (assuming all other management costs were the same and a price of $ 2.11 kg^{-1} of fruit for processing) were 40% greater in the hand-weeded than the non-weeded treatment, 71% greater for weed mat than the non-weeded, and weed mat increased cumulative net returns by 22% over hand-weeding. Management costs were low for the non-weeded treatment, but yield was also low. Despite similar management costs for the hand-weeded and weed mat treatments, the high yield of the weed mat treatment resulted in much greater returns.

CONCLUSIONS

Cultivar and weed management were important factors for growth and cumulative yield of organic machine-harvested trailing blackberry. 'Black Diamond' produced short canes with less biomass than 'Marion', but that resulted in higher budbreak, heavier fruit, and ultimately a higher cumulative yield. Weed control, either hand-weeded or weed mat, increased fruit production over the non-weeded treatment. Weed mat plots outperformed hand-weeded plots in both biomass production and cumulative yield, although the reason for this difference still needs to be determined. The weed mat treatment was also the most economical. Despite similar management costs to the hand-weeded treatment, weed mat still resulted in considerably higher net returns than hand-weeded. Also, weed mat may last longer than the 5 years assumed in this study, decreasing annual costs.

Weed mat was the most effective management strategy in this organic production system, reducing labor costs and increasing machine-harvested yield. Even though the yield of 'Marion' was less than 'Black Diamond', both cultivars still yielded higher than what would be expected from a commercial conventional field during the first 5 years of production (Julian et al., 2009) with weed control.

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